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INTRODUCTION

The structure of NetworkX can be seen by the organization of its source code. The package provides classes for graph objects, generators to create standard graphs, IO routines for reading in existing datasets, algorithms to analyze the resulting networks and some basic drawing tools.

Most of the NetworkX API is provided by functions which take a graph object as an argument. Methods of the graph object are limited to basic manipulation and reporting. This provides modularity of code and documentation. It also makes it easier for newcomers to learn about the package in stages. The source code for each module is meant to be easy to read and reading this Python code is actually a good way to learn more about network algorithms, but we have put a lot of effort into making the documentation sufficient and friendly. If you have suggestions or questions please contact us by joining the NetworkX Google group.

Classes are named using CamelCase (capital letters at the start of each word). functions, methods and variable names are lower_case_underscore (lowercase with an underscore representing a space between words).

1.1 NetworkX Basics

After starting Python, import the networkx module with (the recommended way)

```python
>>> import networkx as nx
```

To save repetition, in the documentation we assume that NetworkX has been imported this way.

If importing networkx fails, it means that Python cannot find the installed module. Check your installation and your PYTHONPATH.

The following basic graph types are provided as Python classes:

**Graph** This class implements an undirected graph. It ignores multiple edges between two nodes. It does allow self-loop edges between a node and itself.

**DiGraph** Directed graphs, that is, graphs with directed edges. Provides operations common to directed graphs, (a subclass of Graph).

**MultiGraph** A flexible graph class that allows multiple undirected edges between pairs of nodes. The additional flexibility leads to some degradation in performance, though usually not significant.

**MultiDiGraph** A directed version of a MultiGraph.

Empty graph-like objects are created with

```python
>>> G = nx.Graph()
>>> G = nx.DiGraph()
>>> G = nx.MultiGraph()
>>> G = nx.MultiDiGraph()
```
All graph classes allow any hashable object as a node. Hashable objects include strings, tuples, integers, and more. Arbitrary edge attributes such as weights and labels can be associated with an edge.

The graph internal data structures are based on an adjacency list representation and implemented using Python dictionary data structures. The graph adjacency structure is implemented as a Python dictionary of dictionaries; the outer dictionary is keyed by nodes to values that are themselves dictionaries keyed by neighboring node to the edge attributes associated with that edge. This “dict-of-dicts” structure allows fast addition, deletion, and lookup of nodes and neighbors in large graphs. The underlying datastructure is accessed directly by methods (the programming interface “API”) in the class definitions. All functions, on the other hand, manipulate graph-like objects solely via those API methods and not by acting directly on the datastructure. This design allows for possible replacement of the ‘dicts-of-dicts’-based datastructure with an alternative datastructure that implements the same methods.

### 1.2 Graphs

The first choice to be made when using NetworkX is what type of graph object to use. A graph (network) is a collection of nodes together with a collection of edges that are pairs of nodes. Attributes are often associated with nodes and/or edges. NetworkX graph objects come in different flavors depending on two main properties of the network:

- **Directed**: Are the edges directed? Does the order of the edge pairs \((u, v)\) matter? A directed graph is specified by the “Di” prefix in the class name, e.g., `DiGraph()`. We make this distinction because many classical graph properties are defined differently for directed graphs.

- **Multi-edges**: Are multiple edges allowed between each pair of nodes? As you might imagine, multiple edges requires a different data structure, though clever users could design edge data attributes to support this functionality. We provide a standard data structure and interface for this type of graph using the prefix “Multi”, e.g., `MultiGraph()`.

The basic graph classes are named: `Graph`, `DiGraph`, `MultiGraph`, and `MultiDiGraph`.

#### 1.2.1 Nodes and Edges

The next choice you have to make when specifying a graph is what kinds of nodes and edges to use.

If the topology of the network is all you care about then using integers or strings as the nodes makes sense and you need not worry about edge data. If you have a data structure already in place to describe nodes you can simply use that structure as your nodes provided it is hashable. If it is not hashable you can use a unique identifier to represent the node and assign the data as a node attribute.

Edges often have data associated with them. Arbitrary data can be associated with edges as an edge attribute. If the data is numeric and the intent is to represent a weighted graph then use the ‘weight’ keyword for the attribute. Some of the graph algorithms, such as Dijkstra’s shortest path algorithm, use this attribute name by default to get the weight for each edge.

Attributes can be assigned to an edge by using keyword/value pairs when adding edges. You can use any keyword to name your attribute and can then query the edge data using that attribute keyword.

Once you’ve decided how to encode the nodes and edges, and whether you have an undirected/directed graph with or without multiedges you are ready to build your network.

### 1.3 Graph Creation

NetworkX graph objects can be created in one of three ways:

- **Graph generators**—standard algorithms to create network topologies.
• Importing data from pre-existing (usually file) sources.
• Adding edges and nodes explicitly.

Explicit addition and removal of nodes/edges is the easiest to describe. Each graph object supplies methods to manipulate the graph. For example,

```python
>>> import networkx as nx
>>> G = nx.Graph()
>>> G.add_edge(1, 2)  # default edge data=1
>>> G.add_edge(2, 3, weight=0.9)  # specify edge data
```

Edge attributes can be anything:

```python
>>> import math
>>> G.add_edge('y', 'x', function=math.cos)
>>> G.add_node(math.cos)  # any hashable can be a node
```

You can add many edges at one time:

```python
>>> elist = [(1, 2), (2, 3), (1, 4), (4, 2)]
>>> G.add_edges_from(elist)
>>> elist = [('a', 'b', 5.0), ('b', 'c', 3.0), ('a', 'c', 1.0), ('c', 'd', 7.3)]
>>> G.add_weighted_edges_from(elist)
```

See the Tutorial for more examples.

Some basic graph operations such as union and intersection are described in the operators module documentation.

Graph generators such as `binomial_graph()` and `erdos_renyi_graph()` are provided in the graph generators subpackage.

For importing network data from formats such as GML, GraphML, edge list text files see the reading and writing graphs subpackage.

### 1.4 Graph Reporting

Class views provide basic reporting of nodes, neighbors, edges and degree. These views provide iteration over the properties as well as membership queries and data attribute lookup. The views refer to the graph data structure so changes to the graph are reflected in the views. This is analogous to dictionary views in Python 3. If you want to change the graph while iterating you will need to use e.g. `for e in list(G.edges)`: The views provide set-like operations, e.g. union and intersection, as well as dict-like lookup and iteration of the data attributes using `G.edges[u, v]['color']` and for `e`, `datadict in G.edges.items()`: Methods `G.edges.items()` and `G.edges.values()` are familiar from python dicts. In addition `G.edges.data()` provides specific attribute iteration e.g. `for e, e_color in G.edges.data('color'):`.

The basic graph relationship of an edge can be obtained in two ways. One can look for neighbors of a node or one can look for edges. We jokingly refer to people who focus on nodes/neighbors as node-centric and people who focus on edges as edge-centric. The designers of NetworkX tend to be node-centric and view edges as a relationship between nodes. You can see this by our choice of lookup notation like `G[u]` providing neighbors (adjacency) while edge lookup is `G.edges[u, v]`. Most data structures for sparse graphs are essentially adjacency lists and so fit this perspective. In the end, of course, it doesn’t really matter which way you examine the graph. `G.edges` removes duplicate representations of undirected edges while neighbor reporting across all nodes will naturally report both directions.

Any properties that are more complicated than edges, neighbors and degree are provided by functions. For example `nx.triangles(G, n)` gives the number of triangles which include node n as a vertex. These functions are
grouped in the code and documentation under the term *algorithms*.

### 1.5 Algorithms

A number of graph algorithms are provided with NetworkX. These include shortest path, and breadth first search (see *traversal*), clustering and isomorphism algorithms and others. There are many that we have not developed yet too. If you implement a graph algorithm that might be useful for others please let us know through the NetworkX Google group or the Github Developer Zone.

As an example here is code to use Dijkstra’s algorithm to find the shortest weighted path:

```python
>>> G = nx.Graph() >>> e = [('a', 'b', 0.3), ('b', 'c', 0.9), ('a', 'c', 0.5), ('c', 'd', 1.2)] >>> G.add_weighted_edges_from(e) >>> print(nx.dijkstra_path(G, 'a', 'd')) ['a', 'c', 'd']
```

### 1.6 Drawing

While NetworkX is not designed as a network drawing tool, we provide a simple interface to drawing packages and some simple layout algorithms. We interface to the excellent Graphviz layout tools like dot and neato with the (suggested) pygraphviz package or the pydot interface. Drawing can be done using external programs or the Matplotlib Python package. Interactive GUI interfaces are possible, though not provided. The drawing tools are provided in the module `drawing`.

The basic drawing functions essentially place the nodes on a scatterplot using the positions you provide via a dictionary or the positions are computed with a layout function. The edges are lines between those dots.

```python
>>> import matplotlib.pyplot as plt >>> G = nx.cubical_graph() >>> plt.subplot(121) <matplotlib.axes._subplots.AxesSubplot object at ...> >>> nx.draw(G) # default spring_layout >>> plt.subplot(122) <matplotlib.axes._subplots.AxesSubplot object at ...> >>> nx.draw(G, pos=nx.circular_layout(G), nodecolor='r', edge_color='b')
```
1.7 Data Structure

NetworkX uses a “dictionary of dictionaries of dictionaries” as the basic network data structure. This allows fast lookup with reasonable storage for large sparse networks. The keys are nodes so $G[u]$ returns an adjacency dictionary keyed by neighbor to the edge attribute dictionary. A view of the adjacency data structure is provided by the dict-like object $G$.\texttt{adj} as e.g. for node, \texttt{nbrsdict in G.adj.items()}. The expression $G[u][v]$ returns the edge attribute dictionary itself. A dictionary of lists would have also been possible, but not allow fast edge detection nor convenient storage of edge data.

Advantages of dict-of-dicts-of-dicts data structure:

- Find edges and remove edges with two dictionary look-ups.
- Prefer to “lists” because of fast lookup with sparse storage.
- Prefer to “sets” since data can be attached to edge.
- $G[u][v]$ returns the edge attribute dictionary.
- \texttt{n in G} tests if node \texttt{n} is in graph \texttt{G}.
- \texttt{for n in G: iterates through the graph.}
- \texttt{for nbr in G[n]: iterates through neighbors.}

See the examples for more ideas.
As an example, here is a representation of an undirected graph with the edges \((A, B)\) and \((B, C)\).

```python
>>> G = nx.Graph()
>>> G.add_edge('A', 'B')
>>> G.add_edge('B', 'C')
>>> print(G.adj)
{'A': {'B': {}}, 'C': {'B': {}}, 'B': {'A': {}, 'C': {}}}
```

The data structure gets morphed slightly for each base graph class. For DiGraph two dict-of-dicts-of-dicts structures are provided, one for successors \((G.succ)\) and one for predecessors \((G.pred)\). For MultiGraph/MultiDiGraph we use a dict-of-dicts-of-dicts-of-dicts\(^1\) where the third dictionary is keyed by an edge key identifier to the fourth dictionary which contains the edge attributes for that edge between the two nodes.

Graphs provide two interfaces to the edge data attributes: adjacency and edges. So \(G[u][v][\text{'width'}]\) is the same as \(G.edges[u, v][\text{'width'}]\).

```python
>>> G = nx.Graph()
>>> G.add_edge(1, 2, color='red', weight=0.84, size=300)
>>> print(G[1][2][\text{'size'}])
300
>>> print(G.edges[1, 2][\text{'color'}])
red
```

\(^1\) “It’s dictionaries all the way down.”
NetworkX provides data structures and methods for storing graphs. All NetworkX graph classes allow (hashable) Python objects as nodes and any Python object can be assigned as an edge attribute. The choice of graph class depends on the structure of the graph you want to represent.

### 2.1 Which graph class should I use?

<table>
<thead>
<tr>
<th>Graph Type</th>
<th>NetworkX Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undirected Simple</td>
<td>Graph</td>
</tr>
<tr>
<td>Directed Simple</td>
<td>DiGraph</td>
</tr>
<tr>
<td>With Self-loops</td>
<td>Graph, DiGraph</td>
</tr>
<tr>
<td>With Parallel edges</td>
<td>MultiGraph, MultiDiGraph</td>
</tr>
</tbody>
</table>

### 2.2 Basic graph types

#### 2.2.1 Graph—Undirected graphs with self loops

**Overview**

```python
class Graph
(incoming_graph_data=None, **attr)
```

Base class for undirected graphs.

A Graph stores nodes and edges with optional data, or attributes.

Graphs hold undirected edges. Self loops are allowed but multiple (parallel) edges are not.

Nodes can be arbitrary (hashable) Python objects with optional key/value attributes. By convention `None` is not used as a node.

Edges are represented as links between nodes with optional key/value attributes.

**Parameters**

- `incoming_graph_data` *(input graph (optional, default: None)) – Data to initialize graph. If None (default) an empty graph is created. The data can be any format that is supported by the to_networkx_graph() function, currently including edge list, dict of dicts, dict of lists, NetworkX graph, NumPy matrix or 2d ndarray, SciPy sparse matrix, or PyGraphviz graph.*
• **attr** *(keyword arguments, optional (default= no attributes)) – Attributes to add to graph as key=value pairs.*

**See also:**

*DiGraph, MultiGraph, MultiDiGraph, OrderedGraph*

### Examples

Create an empty graph structure (a “null graph”) with no nodes and no edges.

```python
>>> G = nx.Graph()
```

G can be grown in several ways.

**Nodes:**

Add one node at a time:

```python
>>> G.add_node(1)
```

Add the nodes from any container (a list, dict, set or even the lines from a file or the nodes from another graph).

```python
>>> G.add_nodes_from([2, 3])
>>> G.add_nodes_from(range(100, 110))
>>> H = nx.path_graph(10)
>>> G.add_nodes_from(H)
```

In addition to strings and integers any hashable Python object (except None) can represent a node, e.g. a customized node object, or even another Graph.

```python
>>> G.add_node(H)
```

**Edges:**

G can also be grown by adding edges.

Add one edge,

```python
>>> G.add_edge(1, 2)
```

a list of edges,

```python
>>> G.add_edges_from([(1, 2), (1, 3)])
```

or a collection of edges,

```python
>>> G.add_edges_from(H.edges)
```

If some edges connect nodes not yet in the graph, the nodes are added automatically. There are no errors when adding nodes or edges that already exist.

**Attributes:**

Each graph, node, and edge can hold key/value attribute pairs in an associated attribute dictionary (the keys must be hashable). By default these are empty, but can be added or changed using add_edge, add_node or direct manipulation of the attribute dictionaries named graph, node and edge respectively.
Add node attributes using `add_node()`, `add_nodes_from()` or `G.nodes`.

```python
>>> G.add_node(1, time='5pm')
>>> G.add_nodes_from([3], time='2pm')
>>> G.nodes[1]  
{'time': '5pm'}
>>> G.nodes[1]['room'] = 714  # node must exist already to use G.nodes
>>> del G.nodes[1]['room']  # remove attribute
>>> list(G.nodes(data=True))
[(1, {'time': '5pm'}), (3, {'time': '2pm'})]
```

Add edge attributes using `add_edge()`, `add_edges_from()`, subscript notation, or `G.edges`.

```python
>>> G.add_edge(1, 2, weight=4.7)
>>> G.add_edges_from(((3, 4), (4, 5)), color='red')
>>> G.add_edges_from([(1, 2, {'color': 'blue'}), (2, 3, {'weight': 8})])
>>> G[1][2]['weight'] = 4.7
>>> G.edges[1, 2]['weight'] = 4
```

Warning: we protect the graph data structure by making `G.edges` a read-only dict-like structure. However, you can assign to attributes in e.g. `G.edges[1, 2]`. Thus, use 2 sets of brackets to add/change data attributes: `G.edges[1, 2]['weight'] = 4` (For multigraphs: `MG.edges[u, v, key][name] = value`).

**Shortcuts:**

Many common graph features allow python syntax to speed reporting.

```python
>>> 1 in G  # check if node in graph
True
>>> [n for n in G if n < 3]  # iterate through nodes
[1, 2]
>>> len(G)  # number of nodes in graph
5
```

Often the best way to traverse all edges of a graph is via the neighbors. The neighbors are reported as an adjacency-dict `G.adj` or as `G.adjacency()`.

```python
>>> for n, nbrsdict in G.adjacency():
...     for nbr, eattr in nbrsdict.items():
...         if 'weight' in eattr:
...             # Do something useful with the edges
...             pass
```

But the `edges()` method is often more convenient:

```python
>>> for u, v, weight in G.edges.data('weight'):
...     if weight is not None:
...         # Do something useful with the edges
...         pass
```

**Reporting:**

Simple graph information is obtained using object-attributes and methods. Reporting typically provides views instead of containers to reduce memory usage. The views update as the graph is updated similarly to dict-views. The objects `nodes`, `edges` and `adj` provide access to data attributes via lookup.
(e.g. nodes[n], `edges[u, v], adj[u][v]) and iteration (e.g. nodes.items(), nodes.data('color'), nodes.data('color', default='blue') and similarly for edges) Views exist for nodes, edges, neighbors(adj) and degree.

For details on these and other miscellaneous methods, see below.

Subclasses (Advanced):

The Graph class uses a dict-of-dict-of-dict data structure. The outer dict (node_dict) holds adjacency information keyed by node. The next dict (adjlist_dict) represents the adjacency information and holds edge data keyed by neighbor. The inner dict (edge_attr_dict) represents the edge data and holds edge attribute values keyed by attribute names.

Each of these three dicts can be replaced in a subclass by a user defined dict-like object. In general, the dict-like features should be maintained but extra features can be added. To replace one of the dicts create a new graph class by changing the class() variable holding the factory for that dict-like structure. The variable names are node_dict_factory, adjlist_inner_dict_factory, adjlist_outer_dict_factory, and edge_attr_dict_factory.

**node_dict_factory** [function, (default: dict)] Factory function to be used to create the dict containing node attributes, keyed by node id. It should require no arguments and return a dict-like object

**adjlist_outer_dict_factory** [function, (default: dict)] Factory function to be used to create the outer-most dict in the data structure that holds adjacency info keyed by node. It should require no arguments and return a dict-like object.

**adjlist_inner_dict_factory** [function, (default: dict)] Factory function to be used to create the adjacency list dict which holds edge data keyed by neighbor. It should require no arguments and return a dict-like object.

**edge_attr_dict_factory** [function, (default: dict)] Factory function to be used to create the edge attribute dict which holds attribute values keyed by attribute name. It should require no arguments and return a dict-like object.

**Examples**

Create a low memory graph class that effectively disallows edge attributes by using a single attribute dict for all edges. This reduces the memory used, but you lose edge attributes.

```python
>>> class ThinGraph(nx.Graph):
...     all_edge_dict = {'weight': 1}
...     def single_edge_dict(self):
...         return self.all_edge_dict
...     edge_attr_dict_factory = single_edge_dict

>>> G = ThinGraph()
>>> G.add_edge(2, 1)
>>> G[2][1]
{'weight': 1}
>>> G.add_edge(2, 2)
>>> G[2][1] is G[2][2]
True
```

Please see [ordered](#) for more examples of creating graph subclasses by overwriting the base class `dict` with a dictionary-like object.
Methods

Adding and removing nodes and edges

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>Graph.__init__</code></td>
<td>Initialize a graph with edges, name, or graph attributes.</td>
</tr>
<tr>
<td><code>Graph.add_node</code></td>
<td>Add a single node <code>node_for_adding</code> and update node attributes.</td>
</tr>
<tr>
<td><code>Graph.add_nodes_from</code></td>
<td>Add multiple nodes.</td>
</tr>
<tr>
<td><code>Graph.remove_node</code></td>
<td>Remove node <code>n</code>.</td>
</tr>
<tr>
<td><code>Graph.remove_nodes_from</code></td>
<td>Remove multiple nodes.</td>
</tr>
<tr>
<td><code>Graph.add_edge</code></td>
<td>Add an edge between <code>u</code> and <code>v</code>.</td>
</tr>
<tr>
<td><code>Graph.add_edges_from</code></td>
<td>Add all the edges in <code>ebunch_to_add</code>.</td>
</tr>
<tr>
<td><code>Graph.add_weighted_edges_from</code></td>
<td>Add weighted edges in <code>ebunch_to_add</code> with specified weight <code>attr</code>.</td>
</tr>
<tr>
<td><code>Graph.remove_edge</code></td>
<td>Remove the edge between <code>u</code> and <code>v</code>.</td>
</tr>
<tr>
<td><code>Graph.remove_edges_from</code></td>
<td>Remove all edges specified in <code>ebunch</code>.</td>
</tr>
<tr>
<td><code>Graph.clear</code></td>
<td>Remove all nodes and edges from the graph.</td>
</tr>
</tbody>
</table>

**networkx.Graph.__init__**

`Graph.__init__(incoming_graph_data=None, **attr)`

Initialize a graph with edges, name, or graph attributes.

**Parameters**

- **incoming_graph_data** *(input graph (optional, default: None)) – Data to initialize graph. If None (default) an empty graph is created. The data can be an edge list, or any NetworkX graph object. If the corresponding optional Python packages are installed the data can also be a NumPy matrix or 2d ndarray, a SciPy sparse matrix, or a PyGraphviz graph.*

- **attr** *(keyword arguments, optional (default= no attributes)) – Attributes to add to graph as key=value pairs.*

**Examples**

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G = nx.Graph(name='my graph')
>>> e = [(1, 2), (2, 3), (3, 4)]  # list of edges
>>> G = nx.Graph(e)
```

Arbitrary graph attribute pairs (key=value) may be assigned

```python
>>> G = nx.Graph(e, day='Friday')
>>> G.graph
{'day': 'Friday'}
```
**networkx.Graph.add_node**

Graph.add_node(node_for_adding, **attr)
Add a single node node_for_adding and update node attributes.

**Parameters**

- node_for_adding (node) – A node can be any hashable Python object except None.
- attr (keyword arguments, optional) – Set or change node attributes using key=value.

**See also:**

add_nodes_from()

**Examples**

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_node(1)
>>> G.add_node('Hello')
>>> K3 = nx.Graph([[(0, 1), (1, 2), (2, 0)]]
>>> G.add_node(K3)
>>> G.number_of_nodes()
3
```

Use keywords set/change node attributes:

```python
>>> G.add_node(1, size=10)
>>> G.add_node(3, weight=0.4, UTM=('13S', 382871, 3972649))
```

**Notes**

A hashable object is one that can be used as a key in a Python dictionary. This includes strings, numbers, tuples of strings and numbers, etc.

On many platforms hashable items also include mutables such as NetworkX Graphs, though one should be careful that the hash doesn’t change on mutables.

**networkx.Graph.add_nodes_from**

Graph.add_nodes_from(nodes_for_adding, **attr)
Add multiple nodes.

**Parameters**

- nodes_for_adding (iterable container) – A container of nodes (list, dict, set, etc.). OR A container of (node, attribute dict) tuples. Node attributes are updated using the attribute dict.
- attr (keyword arguments, optional (default= no attributes)) – Update attributes for all nodes in nodes. Node attributes specified in nodes as a tuple take precedence over attributes specified via keyword arguments.

**See also:**

add_node()
Examples

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_nodes_from('Hello')
>>> K3 = nx.Graph([(0, 1), (1, 2), (2, 0)])
>>> G.add_nodes_from(K3)
>>> sorted(G.nodes(), key=str)
[0, 1, 2, 'H', 'e', 'l', 'o']
```

Use keywords to update specific node attributes for every node.

```python
>>> G.add_nodes_from([1, 2], size=10)
>>> G.add_nodes_from([3, 4], weight=0.4)
```

Use (node, attrdict) tuples to update attributes for specific nodes.

```python
>>> G.add_nodes_from([(1, dict(size=11)), (2, {'color': 'blue'})])
```

```python
>>> G.nodes[1]['size']
11
>>> H = nx.Graph()
>>> H.add_nodes_from(G.nodes(data=True))
```

networkx.Graph.remove_node

Graph.remove_node(n)
Remove node n.
Removes the node n and all adjacent edges. Attempting to remove a non-existent node will raise an exception.

Parameters n (node) – A node in the graph

Raises NetworkXError – If n is not in the graph.

See also:
remove_nodes_from()

Examples

```python
>>> G = nx.path_graph(3)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> list(G.edges)
[(0, 1), (1, 2)]
>>> G.remove_node(1)
>>> list(G.edges)
[]
```

networkx.Graph.remove_nodes_from

Graph.remove_nodes_from(nodes)
Remove multiple nodes.
Parameters **nodes** (*iterable container*) — A container of nodes (list, dict, set, etc.). If a node in the container is not in the graph it is silently ignored.

See also:

*remove_node()*

---

**networkx.Graph.add_edge**

```python
>>> G = nx.path_graph(3)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> e = list(G.nodes)
>>> e
[0, 1, 2]
>>> G.remove_nodes_from(e)
>>> list(G.nodes)
[]
```

Add an edge between `u` and `v`.

The nodes `u` and `v` will be automatically added if they are not already in the graph.

Edge attributes can be specified with keywords or by directly accessing the edge’s attribute dictionary. See examples below.

**Parameters**

- `u, v (nodes)` — Nodes can be, for example, strings or numbers. Nodes must be hashable (and not None) Python objects.
- `attr (keyword arguments, optional)` — Edge data (or labels or objects) can be assigned using keyword arguments.

See also:

*add_edges_from() add a collection of edges*

---

**Notes**

Adding an edge that already exists updates the edge data.

Many NetworkX algorithms designed for weighted graphs use an edge attribute (by default `weight`) to hold a numerical value.

**Examples**

The following all add the edge `e=(1, 2)` to graph `G`:

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> e = (1, 2)
>>> G.add_edge(1, 2)  # explicit two-node form
>>> G.add_edge(*e)   # single edge as tuple of two nodes
>>> G.add_edges_from([(1, 2)])  # add edges from iterable container
```
Associate data to edges using keywords:

```python
>>> G.add_edge(1, 2, weight=3)
>>> G.add_edge(1, 3, weight=7, capacity=15, length=342.7)
```

For non-string attribute keys, use subscript notation.

```python
>>> G.add_edge(1, 2)
>>> G[1][2].update({0: 5})
>>> G.edges[1, 2].update({0: 5})
```

`networkx.Graph.add_edges_from`

`Graph.add_edges_from(ebunch_to_add, **attr)`

Add all the edges in `ebunch_to_add`.

**Parameters**

- **ebunch_to_add** (*container of edges*) – Each edge given in the container will be added to the graph. The edges must be given as as 2-tuples (u, v) or 3-tuples (u, v, d) where d is a dictionary containing edge data.
- **attr** (*keyword arguments, optional*) – Edge data (or labels or objects) can be assigned using keyword arguments.

**See also:**

- `add_edge()` add a single edge
- `add_weighted_edges_from()` convenient way to add weighted edges

**Notes**

Adding the same edge twice has no effect but any edge data will be updated when each duplicate edge is added.

Edge attributes specified in an ebunch take precedence over attributes specified via keyword arguments.

**Examples**

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_edges_from([(0, 1), (1, 2)])  # using a list of edge tuples
>>> e = zip(range(0, 3), range(1, 4))  # a list of edge tuples
>>> G.add_edges_from(e)  # Add the path graph 0-1-2-3
```

Associate data to edges

```python
>>> G.add_edges_from([(1, 2), (2, 3)], weight=3)
>>> G.add_edges_from([(3, 4), (1, 4)], label='WN2898')
```

`networkx.Graph.add_weighted_edges_from`

`Graph.add_weighted_edges_from(ebunch_to_add, weight='weight', **attr)`

Add weighted edges in `ebunch_to_add` with specified weight `attr`
Parameters

- **ebunch_to_add** (*container of edges*) – Each edge given in the list or container will be added to the graph. The edges must be given as 3-tuples (u, v, w) where w is a number.
- **weight** (*string, optional (default= ‘weight’)*) – The attribute name for the edge weights to be added.
- **attr** (*keyword arguments, optional (default= no attributes]*) – Edge attributes to add/update for all edges.

See also:

- `add_edge()`  add a single edge
- `add_edges_from()`  add multiple edges

Notes

Adding the same edge twice for Graph/DiGraph simply updates the edge data. For MultiGraph/MultiDiGraph, duplicate edges are stored.

Examples

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_weighted_edges_from([(0, 1, 3.0), (1, 2, 7.5)])
```

`networkx.Graph.remove_edge`

**Graph.remove_edge (u, v)**

Remove the edge between u and v.

Parameters  

- **u, v** (*nodes*) – Remove the edge between nodes u and v.

Raises  

- `NetworkXError` – If there is not an edge between u and v.

See also:

- `remove_edges_from()`  remove a collection of edges

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, etc
>>> G.remove_edge(0, 1)
>>> e = (1, 2)
>>> G.remove_edge(*e)  # unpacks e from an edge tuple
>>> e = (2, 3, {'weight': 7})  # an edge with attribute data
>>> G.remove_edge(*e[:2])  # select first part of edge tuple
```
NetworkX Reference, Release 2.2rc1.dev20180319181321

networkx.Graph.remove_edges_from

Graph.remove_edges_from(ebunch)
  Remove all edges specified in ebunch.

Parameters ebunch (list or container of edge tuples) – Each edge given in the list or container will be removed from the graph. The edges can be:
  • 2-tuples (u, v) edge between u and v.
  • 3-tuples (u, v, k) where k is ignored.

See also:
  remove_edge() remove a single edge

Notes
Will fail silently if an edge in ebunch is not in the graph.

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> ebunch=[(1, 2), (2, 3)]
>>> G.remove_edges_from(ebunch)
```

networkx.Graph.clear

Graph.clear()
  Remove all nodes and edges from the graph.
  This also removes the name, and all graph, node, and edge attributes.

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.clear()
>>> list(G.nodes)
[]
>>> list(G.edges)
[]
```

Reporting nodes edges and neighbors

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<td>Return the attribute dictionary associated with edge (u, v).</td>
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<td><code>Graph.neighbors(n)</code></td>
<td>Return an iterator over all neighbors of node n.</td>
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networkx.Graph.nodes

A NodeView of the Graph as G.nodes or G.nodes().

Can be used as G.nodes for data lookup and for set-like operations. Can also be used as G.nodes(data='color', default=None) to return a NodeDataView which reports specific node data but no set operations. It presents a dict-like interface as well with G.nodes.items() iterating over (node, nodedata) 2-tuples and G.nodes[3]['foo'] providing the value of the foo attribute for node 3. In addition, a view G.nodes.data('foo') provides a dict-like interface to the foo attribute of each node. G.nodes.data('foo', default=1) provides a default for nodes that do not have attribute foo.

Parameters

- **data** *(string or bool, optional (default=False))* – The node attribute returned in 2-tuple (n, ddict[data]). If True, return entire node attribute dict as (n, ddict). If False, return just the nodes n.

- **default** *(value, optional (default=None))* – Value used for nodes that don’t have the requested attribute. Only relevant if data is not True or False.

Returns

Allows set-like operations over the nodes as well as node attribute dict lookup and calling to get a NodeDataView. A NodeDataView iterates over (n, data) and has no set operations. A NodeView iterates over n and includes set operations.

When called, if data is False, an iterator over nodes. Otherwise an iterator of 2-tuples (node, attribute value) where the attribute is specified in data. If data is True then the attribute becomes the entire data dictionary.

Return type  NodeView

Notes

If your node data is not needed, it is simpler and equivalent to use the expression `for n in G, or list(G).`

Examples

There are two simple ways of getting a list of all nodes in the graph:
To get the node data along with the nodes:

```python
>>> G.add_node(1, time='5pm')
>>> G.nodes[0]['foo'] = 'bar'
>>> list(G.nodes(data=True))
[(0, {'foo': 'bar'}), (1, {'time': '5pm'}), (2, {})]
```

```python
>>> list(G.nodes.data('foo'))
[(0, 'bar'), (1, None), (2, None)]
```

```python
>>> list(G.nodes(data='time'))
[(0, None), (1, '5pm'), (2, None)]
```

```python
>>> list(G.nodes.data('time', default='Not Available'))
[(0, 'Not Available'), (1, '5pm'), (2, 'Not Available')]
```

If some of your nodes have an attribute and the rest are assumed to have a default attribute value you can create a dictionary from node/attribute pairs using the `default` keyword argument to guarantee the value is never `None`:

```python
>>> G = nx.Graph()
>>> G.add_node(0)
>>> G.add_node(1, weight=2)
>>> G.add_node(2, weight=3)
>>> dict(G.nodes(data='weight', default=1))
{0: 1, 1: 2, 2: 3}
```

### networkx.Graph.__iter__

**Graph.__iter__**

Iterate over the nodes. Use: ‘for n in G’.

**Returns**

* niter – An iterator over all nodes in the graph.

**Return type**

iter
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> [n for n in G]
[0, 1, 2, 3]
>>> list(G)
[0, 1, 2, 3]

networkx.Graph.has_node

Graph.has_node(n)
Return True if the graph contains the node n.

Identical to n in G

Parameters

Examples

>>> G = nx.path_graph(3)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.has_node(0)
True

It is more readable and simpler to use

>>> 0 in G
True

networkx.Graph.__contains__

Graph.__contains__(n)
Return True if n is a node, False otherwise. Use: ‘n in G’.

Examples

>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> 1 in G
True

networkx.Graph.edges

Graph.edges
An EdgeView of the Graph as G.edges or G.edges().

edges(self, nbunch=None, data=False, default=None)
The EdgeView provides set-like operations on the edge-tuples as well as edge attribute lookup. When called, it also provides an EdgeDataView object which allows control of access to edge attributes (but does not provide set-like operations). Hence, G.edges[u, v]["color"] provides the value of the color attribute for edge (u, v) while for (u, v, c) in G.edges.data("color", default='red'): iterates through all the edges yielding the color attribute with default 'red' if no color attribute exists.
Parameters

- **nbunch** *(single node, container, or all nodes (default=all nodes)) – The view will only report edges incident to these nodes.*
- **data** *(string or bool, optional (default=False)) – The edge attribute returned in 3-tuple (u, v, ddict[data]). If True, return edge attribute dict in 3-tuple (u, v, ddict). If False, return 2-tuple (u, v).*
- **default** *(value, optional (default=None)) – Value used for edges that don’t have the requested attribute. Only relevant if data is not True or False.*

**Returns edges** – A view of edge attributes, usually it iterates over (u, v) or (u, v, d) tuples of edges, but can also be used for attribute lookup as `edges[u, v]['foo']`.

**Return type** *EdgeView*

**Notes**

Nodes in nbunch that are not in the graph will be (quietly) ignored. For directed graphs this returns the out-edges.

**Examples**

```python
>>> G = nx.path_graph(3)  # or MultiGraph, etc
>>> G.add_edge(2, 3, weight=5)
>>> [e for e in G.edges]
[(0, 1), (1, 2), (2, 3)]
>>> G.edges.data()  # default data is {} (empty dict)
EdgeDataView([(0, 1, {}), (1, 2, {}), (2, 3, {'weight': 5})])
>>> G.edges.data('weight', default=1)
EdgeDataView([(0, 1, 1), (1, 2, 1), (2, 3, 5)])
>>> G.edges([0, 3])  # only edges incident to these nodes
EdgeDataView([(0, 1)])
>>> G.edges(0)  # only edges incident to a single node (use G.adj[0]?)
EdgeDataView([(0, 1)])
```

**networkx.Graph.has_edge**

Graph.**has_edge** *(u, v)*

Return True if the edge (u, v) is in the graph.

This is the same as `v in G[u]` without KeyError exceptions.

**Parameters** *u, v (nodes) – Nodes can be, for example, strings or numbers. Nodes must be hashable (and not None) Python objects.*

**Returns edge_ind** – True if edge is in the graph, False otherwise.

**Return type** *bool*

**Examples**
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.has_edge(0, 1)  # using two nodes
True
>>> e = (0, 1)
>>> G.has_edge(*e)  # e is a 2-tuple (u, v)
True
>>> e = {0, 1, {'weight':7}}
>>> G.has_edge(*e[:2])  # e is a 3-tuple (u, v, data_dictionary)
True

The following syntax are equivalent:

>>> G.has_edge(0, 1)
True
>>> 1 in G[0]  # though this gives KeyError if 0 not in G
True

networkx.Graph.get_edge_data

```
Graph.get_edge_data(u, v, default=None)
```

Return the attribute dictionary associated with edge (u, v).

This is identical to `G[u][v]` except the default is returned instead of an exception is the edge doesn’t exist.

**Parameters**

- `u, v (nodes)`
- `default (any Python object (default=None))` – Value to return if the edge (u, v) is not found.

**Returns**

- `edge_dict` – The edge attribute dictionary.

**Return type**

- `dictionary`

**Examples**

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G[0][1]
{}
```

Warning: Assigning to `G[u][v]` is not permitted. But it is safe to assign attributes `G[u][v]['foo']`

```python
>>> G[0][1]['weight'] = 7
>>> G[0][1]['weight']
7
>>> G[1][0]['weight']
7
```

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.get_edge_data(0, 1)  # default edge data is {}
{}
```

```python
>>> e = (0, 1)
>>> G.get_edge_data(*e)  # tuple form
{}
```

```python
>>> G.get_edge_data('a', 'b', default=0)  # edge not in graph, return 0
0
```
networkx.Graph.neighbors

Graph.neighbors(n)

Return an iterator over all neighbors of node n.
This is identical to iter(G[n])

Parameters
n (node) – A node in the graph

Returns
neighbors – An iterator over all neighbors of node n

Return type
iterator

 Raises NetworkXError – If the node n is not in the graph.

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> [n for n in G.neighbors(0)]
[1]
```

Notes

It is usually more convenient (and faster) to access the adjacency dictionary as G[n]:

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_edge('a', 'b', weight=7)
>>> G['a']
AtlasView({'b': {'weight': 7}})
>>> G = nx.path_graph(4)
>>> [n for n in G[0]]
[1]
```

networkx.Graph.adj

Graph.adj

Graph adjacency object holding the neighbors of each node.

This object is a read-only dict-like structure with node keys and neighbor-dict values. The neighbor-dict is keyed by neighbor to the edge-data-dict. So G.adj[3][2]['color'] = 'blue' sets the color of the edge (3, 2) to "blue".

Iterating over G.adj behaves like a dict. Useful idioms include for nbr, datadict in G.adj[n].items():

The neighbor information is also provided by subscripting the graph. So for nbr, foovalue in G[node].data('foo', default=1): works.

For directed graphs, G.adj holds outgoing (successor) info.

networkx.Graph.__getitem__

Graph.__getitem__ (n)

Return a dict of neighbors of node n. Use: ‘G[n]’. 

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Parameters  n (node) – A node in the graph.
Returns  adj_dict – The adjacency dictionary for nodes connected to n.
Return type  dictionary

Notes

G[n] is the same as G.adj[n] and similar to G.neighbors(n) (which is an iterator over G.adj[n])

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G[0]
AtlasView({1: {}})
```

networkx.Graph.adjacency

Graph.adjacency()
Return an iterator over (node, adjacency dict) tuples for all nodes.
For directed graphs, only outgoing neighbors/adjacencies are included.

Returns  adj_iter – An iterator over (node, adjacency dictionary) for all nodes in the graph.
Return type  iterator

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> [(n, nbrdict) for n, nbrdict in G.adjacency()]
[(0, {1: {}}), (1, {0: {}, 2: {}}), (2, {1: {}, 3: {}}), (3, {2: {}})]
```

networkx.Graph.nbunch_iter

Graph.nbunch_iter(nbunch=None)
Return an iterator over nodes contained in nbunch that are also in the graph.
The nodes in nbunch are checked for membership in the graph and if not are silently ignored.

Parameters  nbunch (single node, container, or all nodes (default= all nodes)) – The view will only report edges incident to these nodes.

Returns  niter – An iterator over nodes in nbunch that are also in the graph. If nbunch is None, iterate over all nodes in the graph.
Return type  iterator

Raises  NetworkXError – If nbunch is not a node or or sequence of nodes. If a node in nbunch is not hashable.

See also:

Graph.__iter__()
Notes

When nbunch is an iterator, the returned iterator yields values directly from nbunch, becoming exhausted when nbunch is exhausted.

To test whether nbunch is a single node, one can use “if nbunch in self,” even after processing with this routine. If nbunch is not a node or a (possibly empty) sequence/iterator or None, a NetworkXError is raised. Also, if any object in nbunch is not hashable, a NetworkXError is raised.

Counting nodes edges and neighbors

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<td>Return the number of nodes in the graph.</td>
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<td><code>networkx.Graph.number_of_nodes()</code></td>
<td>Return the number of nodes in the graph.</td>
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<td><code>networkx.Graph.__len__()</code></td>
<td>Return the number of nodes.</td>
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<td><code>networkx.Graph.degree</code></td>
<td>A DegreeView for the Graph as G.</td>
</tr>
<tr>
<td><code>networkx.Graph.size([weight])</code></td>
<td>Return the number of edges or total of all edge weights.</td>
</tr>
<tr>
<td><code>networkx.Graph.number_of_edges([u, v])</code></td>
<td>Return the number of edges between two nodes.</td>
</tr>
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</table>

Examples

```python
>>> G = nx.path_graph(3)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> len(G)
3
```
networkx.Graph.__len__

Graph.__len__()

Return the number of nodes. Use: ‘len(G)’.

Returns nnodes – The number of nodes in the graph.

Return type int

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> len(G)
4
```

networkx.Graph.degree

Graph.degree

A DegreeView for the Graph as G.degree or G.degree().

The node degree is the number of edges adjacent to the node. The weighted node degree is the sum of the edge weights for edges incident to that node.

This object provides an iterator for (node, degree) as well as lookup for the degree for a single node.

Parameters

• nbunch (single node, container, or all nodes (default= all nodes)) – The view will only report edges incident to these nodes.

• weight (string or None, optional (default=None)) – The name of an edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1. The degree is the sum of the edge weights adjacent to the node.

Returns

• If a single node is requested

• deg (int) – Degree of the node

• OR if multiple nodes are requested

• nd_view (A DegreeView object capable of iterating (node, degree) pairs)

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.degree[0]  # node 0 has degree 1
1
>>> list(G.degree([0, 1, 2]))
[(0, 1), (1, 2), (2, 2)]
```
networkx.Graph.size

Graph.size(weight=None)
Return the number of edges or total of all edge weights.

Parameters weight (string or None, optional (default=None)) – The edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1.

Returns
size – The number of edges or (if weight keyword is provided) the total weight sum.
If weight is None, returns an int. Otherwise a float (or more general numeric if the weights are more general).

Return type numeric

See also:
number_of_edges()

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.size()
3

>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_edge('a', 'b', weight=2)
>>> G.add_edge('b', 'c', weight=4)
>>> G.size()
2
>>> G.size(weight='weight')
6.0
```

networkx.Graph.number_of_edges

Graph.number_of_edges(u=None, v=None)
Return the number of edges between two nodes.

Parameters u, v (nodes, optional (default=all edges)) – If u and v are specified, return the number of edges between u and v. Otherwise return the total number of all edges.

Returns nedges – The number of edges in the graph. If nodes u and v are specified return the number of edges between those nodes. If the graph is directed, this only returns the number of edges from u to v.

Return type int

See also:
size()

Examples

For undirected graphs, this method counts the total number of edges in the graph:
If you specify two nodes, this counts the total number of edges joining the two nodes:

```python
>>> G.number_of_edges(0, 1)
1
```

For directed graphs, this method can count the total number of directed edges from \( u \) to \( v \):

```python
>>> G = nx.DiGraph()
>>> G.add_edge(0, 1)
>>> G.add_edge(1, 0)
>>> G.number_of_edges(0, 1)
1
```

### Making copies and subgraphs

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<td><code>Graph.to_undirected([as_view])</code></td>
<td>Return an undirected copy of the graph.</td>
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<td>Return a directed representation of the graph.</td>
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<td>Returns the subgraph induced by the specified edges.</td>
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<tr>
<td><code>Graph.fresh_copy()</code></td>
<td>Return a fresh copy graph with the same data structure.</td>
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**networkx.Graph.copy**

- **Graph.copy (as_view=False)**
  - Return a copy of the graph.

  The copy method by default returns a shallow copy of the graph and attributes. That is, if an attribute is a container, that container is shared by the original an the copy. Use Python’s `copy.deepcopy` for new containers.

  If `as_view` is True then a view is returned instead of a copy.

**Notes**

All copies reproduce the graph structure, but data attributes may be handled in different ways. There are four types of copies of a graph that people might want.

- **Deepcopy** – The default behavior is a “deepcopy” where the graph structure as well as all data attributes and any objects they might contain are copied. The entire graph object is new so that changes in the copy do not affect the original object. (see Python’s `copy.deepcopy`)

- **Data Reference (Shallow)** – For a shallow copy the graph structure is copied but the edge, node and graph attribute dicts are references to those in the original graph. This saves time and memory but could cause confusion if you change an attribute in one graph and it changes the attribute in the other. NetworkX does not provide this level of shallow copy.
Independent Shallow – This copy creates new independent attribute dicts and then does a shallow copy of the attributes. That is, any attributes that are containers are shared between the new graph and the original. This is exactly what `dict.copy()` provides. You can obtain this style copy using:

```
>>> G = nx.path_graph(5)
>>> H = G.copy()
>>> H = G.copy(as_view=False)
>>> H = nx.Graph(G)
>>> H = G.fresh_copy().__class__(G)
```

Fresh Data – For fresh data, the graph structure is copied while new empty data attribute dicts are created. The resulting graph is independent of the original and it has no edge, node or graph attributes. Fresh copies are not enabled. Instead use:

```
>>> H = G.fresh_copy()
>>> H.add_nodes_from(G)
>>> H.add_edges_from(G.edges)
```

View – Inspired by dict-views, graph-views act like read-only versions of the original graph, providing a copy of the original structure without requiring any memory for copying the information.

See the Python copy module for more information on shallow and deep copies, https://docs.python.org/2/library/copy.html.

Parameters **as_view** (*bool*, *optional (default=False)*) – If True, the returned graph-view provides a read-only view of the original graph without actually copying any data.

Returns **G** – A copy of the graph.

Return type **Graph**

See also:

to_directed() return a directed copy of the graph.

Examples

```
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> H = G.copy()
```

networkx.Graph.to_undirected

Graph.to_undirected(*as_view=False*)

Return an undirected copy of the graph.

Parameters **as_view** (*bool (optional, default=False)*) – If True return a view of the original undirected graph.

Returns **G** – A deepcopy of the graph.

Return type **Graph/MultiGraph**

See also:

* Graph(), copy(), add_edge(), add_edges_from()
Notes

This returns a “deepcopy” of the edge, node, and graph attributes which attempts to completely copy all of the data and references.

This is in contrast to the similar \( G = \text{nxDiGraph}(D) \) which returns a shallow copy of the data.

See the Python copy module for more information on shallow and deep copies, https://docs.python.org/2/library/copy.html.

Warning: If you have subclassed DiGraph to use dict-like objects in the data structure, those changes do not transfer to the Graph created by this method.

Examples

```python
>>> G = nx.path_graph(2)  # or MultiGraph, etc
>>> H = G.to_directed()
>>> list(H.edges)
[(0, 1), (1, 0)]
>>> G2 = H.to_undirected()
>>> list(G2.edges)
[(0, 1)]
```

networkx.Graph.to_directed

Graph.to_directed(\text{as\_view}=False)

Return a directed representation of the graph.

Returns \( G \) – A directed graph with the same name, same nodes, and with each edge \((u, v, \text{data})\) replaced by two directed edges \((u, v, \text{data})\) and \((v, u, \text{data})\).

Return type \text{DiGraph}

Notes

This returns a “deepcopy” of the edge, node, and graph attributes which attempts to completely copy all of the data and references.

This is in contrast to the similar \( D=\text{DiGraph}(G) \) which returns a shallow copy of the data.

See the Python copy module for more information on shallow and deep copies, https://docs.python.org/2/library/copy.html.

Warning: If you have subclassed Graph to use dict-like objects in the data structure, those changes do not transfer to the DiGraph created by this method.

Examples

```python
>>> G = nx.Graph()  # or MultiGraph, etc
>>> G.add_edge(0, 1)
>>> H = G.to_directed()
>>> list(H.edges)
[(0, 1), (1, 0)]
```
If already directed, return a (deep) copy

```python
>>> G = nx.DiGraph()  # or MultiDiGraph, etc
>>> G.add_edge(0, 1)
>>> H = G.to_directed()
>>> list(H.edges)
[(0, 1)]
```

**networkx.Graph.subgraph**

Graph.subgraph(nodes)

Return a SubGraph view of the subgraph induced on nodes.

The induced subgraph of the graph contains the nodes in nodes and the edges between those nodes.

- **Parameters**
  - nodes (list, iterable) – A container of nodes which will be iterated through once.

- **Returns**
  - G – A subgraph view of the graph. The graph structure cannot be changed but node/edge attributes can and are shared with the original graph.

- **Return type**
  - SubGraph View

**Notes**

The graph, edge and node attributes are shared with the original graph. Changes to the graph structure is ruled out by the view, but changes to attributes are reflected in the original graph.

To create a subgraph with its own copy of the edge/node attributes use: G.subgraph(nodes).copy()

For an inplace reduction of a graph to a subgraph you can remove nodes: G.remove_nodes_from([n for n in G if n not in set(nodes)])

**Examples**

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> H = G.subgraph([0, 1, 2])
>>> list(H.edges)
[(0, 1), (1, 2)]
```

**networkx.Graph.edge_subgraph**

Graph.edge_subgraph(edges)

Returns the subgraph induced by the specified edges.

The induced subgraph contains each edge in edges and each node incident to any one of those edges.

- **Parameters**
  - edges (iterable) – An iterable of edges in this graph.

- **Returns**
  - G – An edge-induced subgraph of this graph with the same edge attributes.

- **Return type**
  - Graph
Notes

The graph, edge, and node attributes in the returned subgraph view are references to the corresponding attributes in the original graph. The view is read-only.

To create a full graph version of the subgraph with its own copy of the edge or node attributes, use:

```python
>>> G.edge_subgraph(edges).copy()
```

Examples

```python
>>> G = nx.path_graph(5)
>>> H = G.edge_subgraph([(0, 1), (3, 4)])
>>> list(H.nodes)
[0, 1, 3, 4]
>>> list(H.edges)
[(0, 1), (3, 4)]
```

`networkx.Graph.fresh_copy`

`Graph.fresh_copy()`

Return a fresh copy graph with the same data structure.

A fresh copy has no nodes, edges or graph attributes. It is the same data structure as the current graph. This method is typically used to create an empty version of the graph.

Notes

If you subclass the base class you should overwrite this method to return your class of graph.

### 2.2.2 DiGraph—Directed graphs with self loops

Overview

`class DiGraph(incoming_graph_data=None, **attr)`

Base class for directed graphs.

A DiGraph stores nodes and edges with optional data, or attributes.

DiGraphs hold directed edges. Self loops are allowed but multiple (parallel) edges are not.

Nodes can be arbitrary (hashable) Python objects with optional key/value attributes. By convention `None` is not used as a node.

Edges are represented as links between nodes with optional key/value attributes.

Parameters

- `incoming_graph_data` *(input graph (optional, default: None)) – Data to initialize graph. If None (default) an empty graph is created. The data can be any format that is supported by the `to_networkx_graph()` function, currently including edge list, dict of dicts, dict of lists, NetworkX graph, NumPy matrix or 2d ndarray, SciPy sparse matrix, or PyGraphviz graph.*
• **attr** *(keyword arguments, optional (default= no attributes)) – Attributes to add to graph as key=value pairs.*

**See also:**

`Graph, MultiGraph, MultiDiGraph, OrderedDiGraph`

### Examples

Create an empty graph structure (a “null graph”) with no nodes and no edges.

```python
>>> G = nx.DiGraph()
```

G can be grown in several ways.

**Nodes:**

Add one node at a time:

```python
>>> G.add_node(1)
```

Add the nodes from any container (a list, dict, set or even the lines from a file or the nodes from another graph).

```python
>>> G.add_nodes_from([2, 3])
>>> G.add_nodes_from(range(100, 110))
>>> H = nx.path_graph(10)
>>> G.add_nodes_from(H)
```

In addition to strings and integers any hashable Python object (except None) can represent a node, e.g. a customized node object, or even another Graph.

```python
>>> G.add_node(H)
```

**Edges:**

G can also be grown by adding edges.

Add one edge,

```python
>>> G.add_edge(1, 2)
```

a list of edges,

```python
>>> G.add_edges_from([(1, 2), (1, 3)])
```

or a collection of edges,

```python
>>> G.add_edges_from(H.edges)
```

If some edges connect nodes not yet in the graph, the nodes are added automatically. There are no errors when adding nodes or edges that already exist.

**Attributes:**

Each graph, node, and edge can hold key/value attribute pairs in an associated attribute dictionary (the keys must be hashable). By default these are empty, but can be added or changed using add_edge, add_node or direct manipulation of the attribute dictionaries named graph, node and edge respectively.
>>> G = nx.DiGraph(day="Friday")
>>> G.graph
{'day': 'Friday'}

Add node attributes using add_node(), add_nodes_from() or G.nodes

>>> G.add_node(1, time='5pm')
>>> G.add_nodes_from([3], time='2pm')
>>> G.nodes[1]
{'time': '5pm'}
>>> G.nodes[1]['room'] = 714
>>> del G.nodes[1]['room'] # remove attribute
>>> list(G.nodes(data=True))
[(1, {'time': '5pm'}), (3, {'time': '2pm'})]

Add edge attributes using add_edge(), add_edges_from(), subscript notation, or G.edges.

>>> G.add_edge(1, 2, weight=4.7)
>>> G.add_edges_from([(3, 4), (4, 5)], color='red')
>>> G.add_edges_from([(1, 2, {'color':'blue'}), (2, 3, {'weight':8})])
>>> G[1][2]['weight'] = 4.7
>>> G.edges[1, 2]['weight'] = 4

Warning: we protect the graph data structure by making G.edges[1, 2] a read-only dict-like structure. However, you can assign to attributes in e.g. G.edges[1, 2]. Thus, use 2 sets of brackets to add/change data attributes: G.edges[1, 2]['weight'] = 4 (For multigraphs: MG.edges[u, v, key][name] = value).

Shortcuts:

Many common graph features allow python syntax to speed reporting.

>>> 1 in G # check if node in graph
True
>>> [n for n in G if n < 3] # iterate through nodes
[1, 2]
>>> len(G) # number of nodes in graph
5

Often the best way to traverse all edges of a graph is via the neighbors. The neighbors are reported as an adjacency-dict G.adj or as G.adjacency()

>>> for n, nbrsd in G.adjacency():
... for nbr, eattr in nbrsd.items():
... if 'weight' in eattr:
... # Do something useful with the edges
... pass

But the edges reporting object is often more convenient:

>>> for u, v, weight in G.edges(data='weight'):
... if weight is not None:
... # Do something useful with the edges
... pass

Reporting:

Simple graph information is obtained using object-attributes and methods. Reporting usually provides views instead of containers to reduce memory usage. The views update as the graph is updated simi-
larly to dict-views. The objects `nodes`, `edges` and `adj` provide access to data attributes via lookup (e.g. `nodes[n]`, `edges[u, v]`, `adj[u][v]`) and iteration (e.g. `nodes.items()`, `nodes.data('color')`, `nodes.data('color', default='blue')` and similarly for `edges`). Views exist for `nodes`, `edges`, `neighbors()`/`adj` and `degree`.

For details on these and other miscellaneous methods, see below.

**Subclasses (Advanced):**

The `Graph` class uses a dict-of-dict-of-dict data structure. The outer dict (`node_dict`) holds adjacency information keyed by node. The next dict (`adjlist_dict`) represents the adjacency information and holds edge data keyed by neighbor. The inner dict (`edge_attr_dict`) represents the edge data and holds edge attribute values keyed by attribute names.

Each of these three dicts can be replaced in a subclass by a user defined dict-like object. In general, the dict-like features should be maintained but extra features can be added. To replace one of the dicts create a new graph class by changing the class() variable holding the factory for that dict-like structure. The variable names are `node_dict_factory`, `adjlist_outer_dict_factory`, `adjlist_inner_dict_factory`, and `edge_attr_dict_factory`.

- **node_dict_factory** [function, (default: `dict`)]: Factory function to be used to create the dict containing node attributes, keyed by node id. It should require no arguments and return a dict-like object.

- **adjlist_outer_dict_factory** [function, (default: `dict`)]: Factory function to be used to create the outer-most dict in the data structure that holds adjacency info keyed by node. It should require no arguments and return a dict-like object.

- **adjlist_inner_dict_factory** [function, optional (default: `dict`)]: Factory function to be used to create the adjacency list dict which holds edge data keyed by neighbor. It should require no arguments and return a dict-like object.

- **edge_attr_dict_factory** [function, optional (default: `dict`)]: Factory function to be used to create the edge attribute dict which holds attribute values keyed by attribute name. It should require no arguments and return a dict-like object.

**Examples**

Create a low memory graph class that effectively disallows edge attributes by using a single attribute dict for all edges. This reduces the memory used, but you lose edge attributes.

```python
>>> class ThinGraph(nx.Graph):
...     all_edge_dict = {'weight': 1}
...     def single_edge_dict(self):
...         return self.all_edge_dict
...     edge_attr_dict_factory = single_edge_dict
>>> G = ThinGraph()
>>> G.add_edge(2, 1)
>>> G[2][1]
{'weight': 1}
>>> G.add_edge(2, 2)
>>> G[2][1] is G[2][2]
True
```

Please see `ordered` for more examples of creating graph subclasses by overwriting the base class `dict` with a dictionary-like object.
Methods

Adding and removing nodes and edges

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**networkx.DiGraph.__init__**

DiGraph.__init__(incoming_graph_data=None, **attr)

Initialize a graph with edges, name, or graph attributes.

**Parameters**

- **incoming_graph_data** (input graph (optional, default: None)) – Data to initialize graph. If None (default) an empty graph is created. The data can be an edge list, or any NetworkX graph object. If the corresponding optional Python packages are installed the data can also be a NumPy matrix or 2d ndarray, a SciPy sparse matrix, or a PyGraphviz graph.

- **attr** (keyword arguments, optional (default= no attributes)) – Attributes to add to graph as key=value pairs.

**See also:**

`convert()`

**Examples**

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G = nx.Graph(name='my graph')
>>> e = [(1, 2), (2, 3), (3, 4)]  # list of edges
>>> G = nx.Graph(e)

Arbitrary graph attribute pairs (key=value) may be assigned

```python
>>> G = nx.Graph(e, day="Friday")
>>> G.graph
{"day": "Friday"}
```
networkx.DiGraph.add_node

DiGraph.add_node(node_for_adding, **attr)
Add a single node node_for_adding and update node attributes.

Parameters
- **node_for_adding** (node) – A node can be any hashable Python object except None.
- **attr** (keyword arguments, optional) – Set or change node attributes using key=value.

See also:
add_nodes_from()  

Examples

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_node(1)
>>> G.add_node('Hello')
>>> K3 = nx.Graph([(0, 1), (1, 2), (2, 0)])
>>> G.add_node(K3)
>>> G.number_of_nodes()
3
```

Use keywords set/change node attributes:

```python
>>> G.add_node(1, size=10)
>>> G.add_node(3, weight=0.4, UTM=('13S', 382871, 3972649))
```

Notes

A hashable object is one that can be used as a key in a Python dictionary. This includes strings, numbers, tuples of strings and numbers, etc.

On many platforms hashable items also include mutables such as NetworkX Graphs, though one should be careful that the hash doesn’t change on mutables.

networkx.DiGraph.add_nodes_from

DiGraph.add_nodes_from(nodes_for_adding, **attr)
Add multiple nodes.

Parameters
- **nodes_for_adding** (iterable container) – A container of nodes (list, dict, set, etc.). OR A container of (node, attribute dict) tuples. Node attributes are updated using the attribute dict.
- **attr** (keyword arguments, optional (default= no attributes)) – Update attributes for all nodes in nodes. Node attributes specified in nodes as a tuple take precedence over attributes specified via keyword arguments.

See also:
add_node()
Examples

```python
>>> G = nx.Graph()    # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_nodes_from('Hello')
>>> K3 = nx.Graph([(0, 1), (1, 2), (2, 0)])
>>> G.add_nodes_from(K3)
>>> sorted(G.nodes(), key=str)
[0, 1, 2, 'H', 'e', 'l', 'o']
Use keywords to update specific node attributes for every node.

```python
>>> G.add_nodes_from([1, 2], size=10)
>>> G.add_nodes_from([3, 4], weight=0.4)
Use (node, attrdict) tuples to update attributes for specific nodes.

```python
>>> G.add_nodes_from([(1, dict(size=11)), (2, {'color':'blue'})])
>>> G.nodes[1]['size']
11
>>> H = nx.Graph()
>>> H.add_nodes_from(G.nodes(data=True))
>>> H.nodes[1]['size']
11
```

```

networkx.DiGraph.remove_node

DiGraph.remove_node(n)

Remove node n.

Removes the node n and all adjacent edges. Attempting to remove a non-existent node will raise an exception.

Parameters n (node) – A node in the graph

Raises NetworkXError – If n is not in the graph.

See also:

remove_nodes_from()

Examples

```python
>>> G = nx.path_graph(3)    # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> list(G.edges)
[(0, 1), (1, 2)]
>>> G.remove_node(1)
>>> list(G.edges)
[]
```

```

networkx.DiGraph.remove_nodes_from

DiGraph.remove_nodes_from(nodes)

Remove multiple nodes.
Parameters nodes (iterable container) – A container of nodes (list, dict, set, etc.). If a node in the container is not in the graph it is silently ignored.

See also:
remove_node()

Examples

```python
>>> G = nx.path_graph(3)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> e = list(G.nodes)
>>> e
[0, 1, 2]
>>> G.remove_nodes_from(e)
>>> list(G.nodes)
[]
```

networkx.DiGraph.add_edge

DiGraph.add_edge(u_of_edge, v_of_edge, **attr)
Add an edge between u and v.
The nodes u and v will be automatically added if they are not already in the graph.

Edge attributes can be specified with keywords or by directly accessing the edge’s attribute dictionary. See examples below.

Parameters

- u, v (nodes) – Nodes can be, for example, strings or numbers. Nodes must be hashable (and not None) Python objects.
- attr (keyword arguments, optional) – Edge data (or labels or objects) can be assigned using keyword arguments.

See also:
add_edges_from() add a collection of edges

Notes

Adding an edge that already exists updates the edge data.

Many NetworkX algorithms designed for weighted graphs use an edge attribute (by default weight) to hold a numerical value.

Examples

The following all add the edge e=(1, 2) to graph G:

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> e = (1, 2)
>>> G.add_edge(1, 2)  # explicit two-node form
>>> G.add_edge(*e)  # single edge as tuple of two nodes
>>> G.add_edges_from([(1, 2)])  # add edges from iterable container
```
Associate data to edges using keywords:

```python
>>> G.add_edge(1, 2, weight=3)
>>> G.add_edge(1, 3, weight=7, capacity=15, length=342.7)
```

For non-string attribute keys, use subscript notation.

```python
>>> G.add_edge(1, 2)
>>> G[1][2].update({0: 5})
>>> G.edges[1, 2].update({0: 5})
```

**networkx.DiGraph.add_edges_from**

DiGraph.add_edges_from(ebunch_to_add, **attr)

Add all the edges in ebunch_to_add.

Parameters

- **ebunch_to_add** (container of edges) – Each edge given in the container will be added to the graph. The edges must be given as 2-tuples (u, v) or 3-tuples (u, v, d) where d is a dictionary containing edge data.
- **attr** (keyword arguments, optional) – Edge data (or labels or objects) can be assigned using keyword arguments.

See also:

- **add_edge()** add a single edge
- **add_weighted_edges_from()** convenient way to add weighted edges

Notes

Adding the same edge twice has no effect but any edge data will be updated when each duplicate edge is added. Edge attributes specified in an ebunch take precedence over attributes specified via keyword arguments.

Examples

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_edges_from(((0, 1), (1, 2)))  # using a list of edge tuples
>>> e = zip(range(0, 3), range(1, 4))
>>> G.add_edges_from(e)  # Add the path graph 0-1-2-3
```

Associate data to edges

```python
>>> G.add_edges_from(((1, 2), (2, 3)), weight=3)
>>> G.add_edges_from(((3, 4), (1, 4)), label='WN2898')
```

**networkx.DiGraph.add_weighted_edges_from**

DiGraph.add_weighted_edges_from(ebunch_to_add, weight='weight', **attr)

Add weighted edges in ebunch_to_add with specified weight attr
Parameters

- **ebunch_to_add** *(container of edges)* – Each edge given in the list or container will be added to the graph. The edges must be given as 3-tuples (u, v, w) where w is a number.
- **weight** *(string, optional (default= ‘weight’))* – The attribute name for the edge weights to be added.
- **attr** *(keyword arguments, optional (default= no attributes))* – Edge attributes to add/update for all edges.

See also:

- `add_edge()`   add a single edge
- `add_edges_from()`   add multiple edges

Notes

Adding the same edge twice for Graph/DiGraph simply updates the edge data. For MultiGraph/MultiDiGraph, duplicate edges are stored.

Examples

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_weighted_edges_from([(0, 1, 3.0), (1, 2, 7.5)])
```

`networkx.DiGraph.remove_edge`

DiGraph.remove_edge *(u, v)*

Remove the edge between u and v.

Parameters **u, v** *(nodes)* – Remove the edge between nodes u and v.

Raises `NetworkXError` – If there is not an edge between u and v.

See also:

- `remove_edges_from()`   remove a collection of edges

Examples

```python
>>> G = nx.Graph()  # or DiGraph, etc
>>> nx.add_path(G, [0, 1, 2, 3])
>>> G.remove_edge(0, 1)
>>> e = (1, 2)
>>> G.remove_edge(*e)  # unpacks e from an edge tuple
>>> e = (2, 3, {'weight':7})  # an edge with attribute data
>>> G.remove_edge(*e[:2])  # select first part of edge tuple
```
networkx.DiGraph.remove_edges_from

DiGraph.remove_edges_from(ebunch)
Remove all edges specified in ebunch.

Parameters ebunch (list or container of edge tuples) – Each edge given in the list or container will be removed from the graph. The edges can be:
* 2-tuples (u, v) edge between u and v.
* 3-tuples (u, v, k) where k is ignored.

See also:
remove_edge() remove a single edge

Notes
Will fail silently if an edge in ebunch is not in the graph.

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> ebunch = [(1, 2), (2, 3)]
>>> G.remove_edges_from(ebunch)
```

networkx.DiGraph.clear

DiGraph.clear()
Remove all nodes and edges from the graph.
This also removes the name, and all graph, node, and edge attributes.

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.clear()
>>> list(G.nodes)
[]
>>> list(G.edges)
[]
```

Reporting nodes edges and neighbors

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**networkx.DiGraph.nodes**

*DiGraph.nodes*

A NodeView of the Graph as G.nodes or G.nodes().

Can be used as `G.nodes` for data lookup and for set-like operations. Can also be used as `G.nodes(data='color', default=None)` to return a NodeDataView which reports specific node data but no set operations. It presents a dict-like interface as well with `G.nodes.items()` iterating over (node, nodedata) 2-tuples and `G.nodes[3]['foo']` providing the value of the foo attribute for node 3. In addition, a view `G.nodes.data('foo')` provides a dict-like interface to the foo attribute of each node. `G.nodes.data('foo', default=1)` provides a default for nodes that do not have attribute foo.

**Parameters**

- **data** *(string or bool, optional (default=False)) – The node attribute returned in 2-tuple (n, ddict[data]). If True, return entire node attribute dict as (n, ddict). If False, return just the nodes n.*

- **default** *(value, optional (default=None)) – Value used for nodes that don’t have the requested attribute. Only relevant if data is not True or False.*

**Returns**

Allows set-like operations over the nodes as well as node attribute dict lookup and calling to get a NodeDataView. A NodeDataView iterates over (n, data) and has no set operations. A NodeView iterates over n and includes set operations.

When called, if data is False, an iterator over nodes. Otherwise an iterator of 2-tuples (node, attribute value) where the attribute is specified in data. If data is True then the attribute becomes the entire data dictionary.

**Return type** NodeView
Notes

If your node data is not needed, it is simpler and equivalent to use the expression `for n in G`, or `list(G)`.

Examples

There are two simple ways of getting a list of all nodes in the graph:

```python
>>> G = nx.path_graph(3)
>>> list(G.nodes)
[0, 1, 2]
>>> list(G)
[0, 1, 2]
```

To get the node data along with the nodes:

```python
>>> G.add_node(1, time='5pm')
>>> G.nodes[0]['foo'] = 'bar'
>>> list(G.nodes(data=True))
[(0, {'foo': 'bar'}), (1, {'time': '5pm'}), (2, {})]
```

```python
>>> list(G.nodes(data='foo'))
[(0, 'bar'), (1, None), (2, None)]
```

```python
>>> list(G.nodes(data='time'))
[(0, None), (1, '5pm'), (2, None)]
```

```python
>>> list(G.nodes(data='time', default='Not Available'))
[(0, 'Not Available'), (1, '5pm'), (2, 'Not Available')]
```

If some of your nodes have an attribute and the rest are assumed to have a default attribute value you can create a dictionary from node/attribute pairs using the `default` keyword argument to guarantee the value is never `None`:

```python
>>> G = nx.Graph()
>>> G.add_node(0)
>>> G.add_node(1, weight=2)
>>> G.add_node(2, weight=3)
>>> dict(G.nodes(data='weight', default=1))
{0: 1, 1: 2, 2: 3}
```

**networkx.DiGraph.__iter__**

DiGraph.__iter__()

Iterate over the nodes. Use: ‘for n in G’.
Returns `niter` – An iterator over all nodes in the graph.

Return type `iterator`

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> [n for n in G]
[0, 1, 2, 3]
>>> list(G)
[0, 1, 2, 3]
```

networkx.DiGraph.has_node

DiGraph. `has_node` (n)

Return True if the graph contains the node n.

Identical to `n in G`

Parameters `n (node)`

Examples

```python
>>> G = nx.path_graph(3)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.has_node(0)
True
```

It is more readable and simpler to use

```python
>>> 0 in G
True
```

networkx.DiGraph.__contains__

DiGraph. `__contains__` (n)

Return True if n is a node, False otherwise. Use: ‘n in G’.

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> 1 in G
True
```

networkx.DiGraph.edges

DiGraph. `edges`

An OutEdgeView of the DiGraph as G.edges or G.edges().

edges(self, nbunch=None, data=False, default=None)
The OutEdgeView provides set-like operations on the edge-tuples as well as edge attribute lookup. When called, it also provides an EdgeDataView object which allows control of access to edge attributes (but does not provide set-like operations). Hence, `G.edges[u, v]['color']` provides the value of the color attribute for edge `(u, v)` while `for (u, v, c) in G.edges.data('color', default='red'):` iterates through all the edges yielding the color attribute with default 'red' if no color attribute exists.

**Parameters**

- **nbunch** (single node, container, or all nodes (default= all nodes)) – The view will only report edges incident to these nodes.
- **data** (string or bool, optional (default=False)) – The edge attribute returned in 3-tuple `(u, v, ddict[data])`. If True, return edge attribute dict in 3-tuple `(u, v, ddict)`. If False, return 2-tuple `(u, v)`.
- **default** (value, optional (default=None)) – Value used for edges that don’t have the requested attribute. Only relevant if data is not True or False.

**Returns**
edges – A view of edge attributes, usually it iterates over `(u, v)` or `(u, v, d)` tuples of edges, but can also be used for attribute lookup as `edges[u, v]['foo']`.

**Return type**
OutEdgeView

**See also:**
in_edges, out_edges

**Notes**

Nodes in nbunch that are not in the graph will be (quietly) ignored. For directed graphs this returns the out-edges.

**Examples**

```python
>>> G = nx.DiGraph()  # or MultiDiGraph, etc
>>> nx.add_path(G, [0, 1, 2])
>>> G.add_edge(2, 3, weight=5)
>>> [e for e in G.edges]
[(0, 1), (1, 2), (2, 3)]
>>> G.edges.data()  # default data is {} (empty dict)
OutEdgeDataView([(0, 1, {}), (1, 2, {}), (2, 3, {'weight': 5})])
>>> G.edges.data('weight', default=1)
OutEdgeDataView([(0, 1, 1), (1, 2, 1), (2, 3, 5)])
>>> G.edges([0, 2])  # only edges incident to these nodes
OutEdgeDataView([(0, 1), (2, 3)])
>>> G.edges(0)  # only edges incident to a single node (use G.adj[0]?)
OutEdgeDataView([(0, 1)])
```

networkx.DiGraph.out_edges

DiGraph.out_edges
An OutEdgeView of the DiGraph as G.edges or G.edges().

edges(self, nbunch=None, data=False, default=None)
The OutEdgeView provides set-like operations on the edge-tuples as well as edge attribute lookup. When called, it also provides an EdgeDataView object which allows control of access to edge attributes (but does not provide set-like operations). Hence, \( \text{G.edges}[u, v][\text{'color'}] \) provides the value of the color attribute for edge \((u, v)\) while for \((u, v, c)\) in \( \text{G.edges.data('color', default='red')} \): iterates through all the edges yielding the color attribute with default 'red' if no color attribute exists.

**Parameters**

- **nbunch** *(single node, container, or all nodes (default=all nodes)) – The view will only report edges incident to these nodes.*

- **data** *(string or bool, optional (default=False)) – The edge attribute returned in 3-tuple (u, v, ddict[data]). If True, return edge attribute dict in 3-tuple (u, v, ddict). If False, return 2-tuple (u, v).*

- **default** *(value, optional (default=None)) – Value used for edges that don’t have the requested attribute. Only relevant if data is not True or False.*

**Returns edges** – A view of edge attributes, usually it iterates over (u, v) or (u, v, d) tuples of edges, but can also be used for attribute lookup as \( \text{edges}[u, v][\text{'}foo\text{']}\).

**Return type** OutEdgeView

**See also:**

*in_edges, out_edges*

**Notes**

Nodes in nbunch that are not in the graph will be (quietly) ignored. For directed graphs this returns the out-edges.

**Examples**

```python
>>> G = nx.DiGraph()  # or MultiDiGraph, etc
>>> nx.add_path(G, [0, 1, 2])
>>> G.add_edge(2, 3, weight=5)
>>> [e for e in G.edges]
[(0, 1), (1, 2), (2, 3)]
>>> G.edges.data()  # default data is {} (empty dict)
OutEdgeDataView([(0, 1), (1, 2), (2, 3)])
>>> G.edges.data('weight', default=1)
OutEdgeDataView([(0, 1), (1, 2), (2, 3, {'weight': 5})])
>>> G.edges((0, 2))  # only edges incident to these nodes
OutEdgeDataView([(0, 1), (2, 3)])
>>> G.edges(0)  # only edges incident to a single node (use G.adj[0]?)
OutEdgeDataView([(0, 1)])
```

**networkx.DiGraph.in_edges**

*DiGraph.in_edges*

An InEdgeView of the Graph as G.in_edges or G.in_edges().

in_edges(self, nbunch=None, data=False, default=None):

**Parameters**
• **nbunch** *(single node, container, or all nodes (default=all nodes))* – The view will only report edges incident to these nodes.

• **data** *(string or bool, optional (default=False))* – The edge attribute returned in 3-tuple (u, v, ddict[data]). If True, return edge attribute dict in 3-tuple (u, v, ddict). If False, return 2-tuple (u, v).

• **default** *(value, optional (default=None))* – Value used for edges that don’t have the requested attribute. Only relevant if data is not True or False.

**Returns** in_edges – A view of edge attributes, usually it iterates over (u, v) or (u, v, d) tuples of edges, but can also be used for attribute lookup as edges[u, v]['foo'].

**Return type** InEdgeView

See also:

edges

networkx.DiGraph.has_edge

DiGraph.**has_edge**(u, v)

Return True if the edge (u, v) is in the graph.

This is the same as `v in G[u]` without KeyError exceptions.

**Parameters** u, v *(nodes)* – Nodes can be, for example, strings or numbers. Nodes must be hashable (and not None) Python objects.

**Returns** edge_ind – True if edge is in the graph, False otherwise.

**Return type** bool

**Examples**

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.has_edge(0, 1)  # using two nodes
True
>>> e = (0, 1)
>>> G.has_edge(*e)  # e is a 2-tuple (u, v)
True
>>> e = (0, 1, {'weight':7})
>>> G.has_edge(*e[:2])  # e is a 3-tuple (u, v, data_dictionary)
True
```

The following syntax are equivalent:

```python
>>> G.has_edge(0, 1)
True
>>> 1 in G[0]  # though this gives KeyError if 0 not in G
True
```

networkx.DiGraph.get_edge_data

DiGraph.**get_edge_data**(u, v, default=None)

Return the attribute dictionary associated with edge (u, v).
This is identical to $G[u][v]$ except the default is returned instead of an exception if the edge doesn’t exist.

**Parameters**

- **u, v** (nodes)
- **default** (any Python object (default=None)) – Value to return if the edge $(u, v)$ is not found.

**Returns** edge_dict – The edge attribute dictionary.

**Return type** dictionary

**Examples**

```python
>>> G = nx.path_graph(4) # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G[0][1]
{}
```

Warning: Assigning to $G[u][v]$ is not permitted. But it is safe to assign attributes $G[u][v][\text{'foo']}$

```python
>>> G[0][1][\text{'weight']} = 7
>>> G[0][1][\text{'weight'}]
7
>>> G[1][0][\text{'weight'}]
7
```

```python
>>> G = nx.path_graph(4) # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.get_edge_data(0, 1) # default edge data is {}
{}
>>> e = (0, 1)
>>> G.get_edge_data(*e) # tuple form
{}
>>> G.get_edge_data('a', 'b', default=0) # edge not in graph, return 0
0
```

**networkx.DiGraph.neighbors**

`DiGraph.neighbors(n)`

Return an iterator over successor nodes of n.

neighbors() and successors() are the same.

**networkx.DiGraph.adj**

`DiGraph.adj`

Graph adjacency object holding the neighbors of each node.

This object is a read-only dict-like structure with node keys and neighbor-dict values. The neighbor-dict is keyed by neighbor to the edge-data-dict. So $G.adj[3][2][\text{'color']} = \text{'blue'}$ sets the color of the edge $(3, 2)$ to "blue".

Iterating over $G.adj$ behaves like a dict. Useful idioms include `for nbr, datadict in G.adj[n].items():`

The neighbor information is also provided by subscripting the graph. So `for nbr, foovalue in G[node].data('foo', default=1):` works.

### 2.2. Basic graph types
For directed graphs, `G.adj` holds outgoing (successor) info.

**networkx.DiGraph.__getitem__**

```python
DiGraph.__getitem__(n)
```

Return a dict of neighbors of node `n`. Use: ‘G[n]’.

**Parameters**

- `n` *(node)* – A node in the graph.

**Returns**

- `adj_dict` – The adjacency dictionary for nodes connected to `n`.

**Return type**

dictionary

**Notes**

`G[n]` is the same as `G.adj[n]` and similar to `G.neighbors(n)` (which is an iterator over `G.adj[n]`)

**Examples**

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G[0]
AtlasView({1: {}})
```

**networkx.DiGraph.successors**

```python
DiGraph.successors(n)
```

Return an iterator over successor nodes of `n`.

`neighbors()` and `successors()` are the same.

**networkx.DiGraph.succ**

```python
DiGraph.succ
```

Graph adjacency object holding the successors of each node.

This object is a read-only dict-like structure with node keys and neighbor-dict values. The neighbor-dict is keyed by neighbor to the edge-data-dict. So `G.succ[3][2]['color'] = 'blue'` sets the color of the edge `(3, 2)` to "blue".

Iterating over `G.succ` behaves like a dict. Useful idioms include for `nbr, datadict` in `G.succ[n]`. `items()`:: A data-view not provided by dicts also exists: for `nbr, foovalue` in `G.succ[node]`. `data('foo')`: and a default can be set via a default argument to the `data` method.

The neighbor information is also provided by subscripting the graph. So for `nbr, foovalue in G[node].data('foo', default=1)`: works.

For directed graphs, `G.adj` is identical to `G.succ`.

**networkx.DiGraph.predecessors**

```python
DiGraph.predecessors(n)
```

Return an iterator over predecessor nodes of `n`.
networkx.DiGraph.pred

DiGraph.pred
Graph adjacency object holding the predecessors of each node.

This object is a read-only dict-like structure with node keys and neighbor-dict values. The neighbor-dict is keyed by neighbor to the edge-data-dict. So \( G.pred[2][3][\text{'color']} = \text{'blue'} \) sets the color of the edge \((3, 2)\) to "blue".

Iterating over \( G.pred \) behaves like a dict. Useful idioms include for \( \text{nbr}, \text{datadict} \) in \( G.pred[n] \). items(). A data-view not provided by dicts also exists: for \( \text{nbr}, \text{foovalue} \) in \( G.pred[\text{node}] \). data('foo'): A default can be set via a default argument to the data method.

networkx.DiGraph.adjacency

DiGraph.adjacency()
Return an iterator over (node, adjacency dict) tuples for all nodes.

For directed graphs, only outgoing neighbors/adjacencies are included.

Returns adj_iter – An iterator over (node, adjacency dictionary) for all nodes in the graph.

Return type iterator

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> [(n, nbrdict) for n, nbrdict in G.adjacency()]
[(0, {1: {}}), (1, {0: {}, 2: {}}), (2, {1: {}, 3: {}}), (3, {2: {}})]
```

networkx.DiGraph.nbunch_iter

DiGraph.nbunch_iter (nbunch=None)
Return an iterator over nodes contained in nbunch that are also in the graph.

The nodes in nbunch are checked for membership in the graph and if not are silently ignored.

Parameters nbunch (single node, container, or all nodes (default= all nodes)) – The view will only report edges incident to these nodes.

Returns niter – An iterator over nodes in nbunch that are also in the graph. If nbunch is None, iterate over all nodes in the graph.

Return type iterator

Raises NetworkXError – If nbunch is not a node or or sequence of nodes. If a node in nbunch is not hashable.

See also:

Graph.__iter__()
Notes

When nbunch is an iterator, the returned iterator yields values directly from nbunch, becoming exhausted when nbunch is exhausted.

To test whether nbunch is a single node, one can use “if nbunch in self:”, even after processing with this routine.

If nbunch is not a node or a (possibly empty) sequence/iterator or None, a `NetworkXError` is raised. Also, if any object in nbunch is not hashable, a `NetworkXError` is raised.

Counting nodes edges and neighbors

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<td>Return the number of edges between two nodes.</td>
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networkx.DiGraph.order

DiGraph.order()

Return the number of nodes in the graph.

Returns nnodes – The number of nodes in the graph.

Return type int

See also:

`number_of_nodes()`, `__len__()`

networkx.DiGraph.number_of_nodes

DiGraph.number_of_nodes()

Return the number of nodes in the graph.

Returns nnodes – The number of nodes in the graph.

Return type int

See also:

`order()`, `__len__()`

Examples

```python
>>> G = nx.path_graph(3)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> len(G)
3
```
networkx.DiGraph.__len__

DiGraph.__len__()

Return the number of nodes. Use: ‘len(G)’.

Returns nnodes – The number of nodes in the graph.

Return type int

Examples

```python
g = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
len(g)
```

networkx.DiGraph.degree

DiGraph.degree

A DegreeView for the Graph as G.degree or G.degree().

The node degree is the number of edges adjacent to the node. The weighted node degree is the sum of the edge weights for edges incident to that node.

This object provides an iterator for (node, degree) as well as lookup for the degree for a single node.

Parameters

- nbunch (single node, container, or all nodes (default= all nodes)) – The view will only report edges incident to these nodes.
- weight (string or None, optional (default=None)) – The name of an edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1. The degree is the sum of the edge weights adjacent to the node.

Returns

- If a single node is requested
- deg (int) – Degree of the node
- OR if multiple nodes are requested
- nd_iter (iterator) – The iterator returns two-tuples of (node, degree).

See also:
in_degree, out_degree

Examples

```python
g = nx.DiGraph()
# or MultiDiGraph
nx.add_path(G, [0, 1, 2, 3])
g.degree(0)  # node 0 with degree 1
1
list(g.degree([0, 1, 2]))
[(0, 1), (1, 2), (2, 2)]
```
networkx.DiGraph.in_degree

DiGraph.in_degree
An InDegreeView for (node, in_degree) or in_degree for single node.

The node in_degree is the number of edges pointing to the node. The weighted node degree is the sum of the
edge weights for edges incident to that node.

This object provides an iteration over (node, in_degree) as well as lookup for the degree for a single node.

Parameters
• nbunch (single node, container, or all nodes (default= all nodes)) – The view will only
  report edges incident to these nodes.
• weight (string or None, optional (default=None)) – The name of an edge attribute that holds
  the numerical value used as a weight. If None, then each edge has weight 1. The degree is
  the sum of the edge weights adjacent to the node.

Returns
• If a single node is requested
  • deg (int) – In-degree of the node
• OR if multiple nodes are requested
  • nd_iter (iterator) – The iterator returns two-tuples of (node, in-degree).

See also:
degree, out_degree

Examples

```python
>>> G = nx.DiGraph()
>>> nx.add_path(G, [0, 1, 2, 3])
>>> G.in_degree(0) # node 0 with degree 0
0
>>> list(G.in_degree([0, 1, 2]))
[(0, 0), (1, 1), (2, 1)]
```

networkx.DiGraph.out_degree

DiGraph.out_degree
An OutDegreeView for (node, out_degree)

The node out_degree is the number of edges pointing out of the node. The weighted node degree is the sum of
the edge weights for edges incident to that node.

This object provides an iterator over (node, out_degree) as well as lookup for the degree for a single node.

Parameters
• nbunch (single node, container, or all nodes (default= all nodes)) – The view will only
  report edges incident to these nodes.
• weight (string or None, optional (default=None)) – The name of an edge attribute that holds
  the numerical value used as a weight. If None, then each edge has weight 1. The degree is
  the sum of the edge weights adjacent to the node.
Returns

• If a single node is requested
• \texttt{deg (int)} – Out-degree of the node
• OR if multiple nodes are requested
• \texttt{nd_iter (iterator)} – The iterator returns two-tuples of (node, out-degree).

See also:
\texttt{degree, in_degree}

Examples

```python
>>> G = nx.DiGraph()
>>> nx.add_path(G, [0, 1, 2, 3])
>>> G.out_degree(0)  # node 0 with degree 1
1
>>> list(G.out_degree([0, 1, 2]))
[(0, 1), (1, 1), (2, 1)]
```

\texttt{networkx.DiGraph.size}

\texttt{DiGraph.size (weight=None)}

Return the number of edges or total of all edge weights.

Parameters weight (string or None, optional (default=None)) – The edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1.

Returns

size – The number of edges or (if weight keyword is provided) the total weight sum.

If weight is None, returns an int. Otherwise a float (or more general numeric if the weights are more general).

Return type numeric

See also:
\texttt{number_of_edges()}

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.size()
3
```

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_edge('a', 'b', weight=2)
>>> G.add_edge('b', 'c', weight=4)
>>> G.size()
2
>>> G.size(weight='weight')
6.0
```
networkx.DiGraph.number_of_edges

DiGraph.number_of_edges(u=None, v=None)

Return the number of edges between two nodes.

Parameters u, v (nodes, optional (default=all edges)) – If u and v are specified, return the number of edges between u and v. Otherwise return the total number of all edges.

Returns nedges – The number of edges in the graph. If nodes u and v are specified return the number of edges between those nodes. If the graph is directed, this only returns the number of edges from u to v.

Return type  int

See also:  
size()

Examples

For undirected graphs, this method counts the total number of edges in the graph:

```python
>>> G = nx.path_graph(4)
>>> G.number_of_edges()
3
```

If you specify two nodes, this counts the total number of edges joining the two nodes:

```python
>>> G.number_of_edges(0, 1)
1
```

For directed graphs, this method can count the total number of directed edges from u to v:

```python
>>> G = nx.DiGraph()
>>> G.add_edge(0, 1)
>>> G.add_edge(1, 0)
>>> G.number_of_edges(0, 1)
1
```

Making copies and subgraphs

- `DiGraph.copy([as_view])` Return a copy of the graph.
- `DiGraph.to_undirected([reciprocal, as_view])` Return an undirected representation of the digraph.
- `DiGraph.to_directed([as_view])` Return a directed representation of the graph.
- `DiGraph.subgraph(nodes)` Return a SubGraph view of the subgraph induced on nodes.
- `DiGraph.edge_subgraph(edges)` Returns the subgraph induced by the specified edges.
- `DiGraph.reverse([copy])` Return the reverse of the graph.
- `DiGraph.fresh_copy()` Return a fresh copy graph with the same data structure.
DiGraph.copy

Return a copy of the graph.

The copy method by default returns a shallow copy of the graph and attributes. That is, if an attribute is a container, that container is shared by the original and the copy. Use Python’s copy.deepcopy for new containers.

If as_view is True then a view is returned instead of a copy.

Notes

All copies reproduce the graph structure, but data attributes may be handled in different ways. There are four types of copies of a graph that people might want.

Deepcopy – The default behavior is a “deepcopy” where the graph structure as well as all data attributes and any objects they might contain are copied. The entire graph object is new so that changes in the copy do not affect the original object. (see Python’s copy.deepcopy)

Data Reference (Shallow) – For a shallow copy the graph structure is copied but the edge, node and graph attribute dicts are references to those in the original graph. This saves time and memory but could cause confusion if you change an attribute in one graph and it changes the attribute in the other. NetworkX does not provide this level of shallow copy.

Independent Shallow – This copy creates new independent attribute dicts and then does a shallow copy of the attributes. That is, any attributes that are containers are shared between the new graph and the original. This is exactly what dict.copy() provides. You can obtain this style copy using:

```python
>>> G = nx.path_graph(5)
>>> H = G.copy()
>>> H = G.copy(as_view=False)
>>> H = nx.Graph(G)
>>> H = G.fresh_copy().__class__(G)
```

Fresh Data – For fresh data, the graph structure is copied while new empty data attribute dicts are created. The resulting graph is independent of the original and it has no edge, node or graph attributes. Fresh copies are not enabled. Instead use:

```python
>>> H = G.fresh_copy()
>>> H.add_nodes_from(G)
>>> H.add_edges_from(G.edges)
```

View – Inspired by dict-views, graph-views act like read-only versions of the original graph, providing a copy of the original structure without requiring any memory for copying the information.

See the Python copy module for more information on shallow and deep copies, https://docs.python.org/2/library/copy.html.

Parameters

- **as_view (bool, optional (default=False))** – If True, the returned graph-view provides a read-only view of the original graph without actually copying any data.

Returns

- **G** – A copy of the graph.

See also:

to_directed() return a directed copy of the graph.
Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> H = G.copy()
```

**networkx.DiGraph.to_undirected**

DiGraph.to_undirected(reciprocal=False, as_view=False)

Return an undirected representation of the digraph.

**Parameters**

- **reciprocal** (bool (optional)) – If True only keep edges that appear in both directions in the original digraph.
- **as_view** (bool (optional, default=False)) – If True return an undirected view of the original directed graph.

**Returns** G – An undirected graph with the same name and nodes and with edge (u, v, data) if either (u, v, data) or (v, u, data) is in the digraph. If both edges exist in digraph and their edge data is different, only one edge is created with an arbitrary choice of which edge data to use. You must check and correct for this manually if desired.

**Return type** Graph

**See also:**

Graph(), copy(), add_edge(), add_edges_from()

**Notes**

If edges in both directions (u, v) and (v, u) exist in the graph, attributes for the new undirected edge will be a combination of the attributes of the directed edges. The edge data is updated in the (arbitrary) order that the edges are encountered. For more customized control of the edge attributes use add_edge().

This returns a “deepcopy” of the edge, node, and graph attributes which attempts to completely copy all of the data and references.

This is in contrast to the similar G=DiGraph(D) which returns a shallow copy of the data.

See the Python copy module for more information on shallow and deep copies, https://docs.python.org/2/library/copy.html.

Warning: If you have subclassed DiGraph to use dict-like objects in the data structure, those changes do not transfer to the Graph created by this method.

**Examples**

```python
>>> G = nx.path_graph(2)  # or MultiGraph, etc
>>> H = G.to_directed()
>>> list(H.edges)
[(0, 1), (1, 0)]
>>> G2 = H.to_undirected()
>>> list(G2.edges)
[(0, 1)]
```
networkx.DiGraph.to_directed

DiGraph.to_directed(as_view=False)
Return a directed representation of the graph.

Returns G – A directed graph with the same name, same nodes, and with each edge (u, v, data)
replaced by two directed edges (u, v, data) and (v, u, data).

Return type DiGraph

Notes

This returns a “deepcopy” of the edge, node, and graph attributes which attempts to completely copy all of the
data and references.

This is in contrast to the similar D=DiGraph(G) which returns a shallow copy of the data.

See the Python copy module for more information on shallow and deep copies, https://docs.python.org/2/library/
copy.html.

Warning: If you have subclassed Graph to use dict-like objects in the data structure, those changes do not
transfer to the DiGraph created by this method.

Examples

```python
>>> G = nx.Graph()  # or MultiGraph, etc
>>> G.add_edge(0, 1)
>>> H = G.to_directed()
>>> list(H.edges)
[(0, 1), (1, 0)]
```

If already directed, return a (deep) copy

```python
>>> G = nx.DiGraph()  # or MultiDiGraph, etc
>>> G.add_edge(0, 1)
>>> H = G.to_directed()
>>> list(H.edges)
[(0, 1)]
```

networkx.DiGraph.subgraph

DiGraph.subgraph(nodes)
Return a SubGraph view of the subgraph induced on nodes.

The induced subgraph of the graph contains the nodes in nodes and the edges between those nodes.

Parameters nodes (list, iterable) – A container of nodes which will be iterated through once.

Returns G – A subgraph view of the graph. The graph structure cannot be changed but node/edge
attributes can and are shared with the original graph.

Return type SubGraph View
Notes

The graph, edge and node attributes are shared with the original graph. Changes to the graph structure is ruled out by the view, but changes to attributes are reflected in the original graph.

To create a subgraph with its own copy of the edge/node attributes use: `G.subgraph(nodes).copy()`

For an inplace reduction of a graph to a subgraph you can remove nodes: `G.remove_nodes_from([n for n in G if n not in set(nodes)])`

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> H = G.subgraph([0, 1, 2])
>>> list(H.edges)
[(0, 1), (1, 2)]
```

networkx.DiGraph.edge_subgraph

DiGraph.edge_subgraph(edges)

Returns the subgraph induced by the specified edges.

The induced subgraph contains each edge in `edges` and each node incident to any one of those edges.

Parameters

- `edges` (iterable) – An iterable of edges in this graph.

Returns

- `G` – An edge-induced subgraph of this graph with the same edge attributes.

Return type

Graph

Notes

The graph, edge, and node attributes in the returned subgraph view are references to the corresponding attributes in the original graph. The view is read-only.

To create a full graph version of the subgraph with its own copy of the edge or node attributes, use:

```python
>>> G.edge_subgraph(edges).copy()
```

Examples

```python
>>> G = nx.path_graph(5)
>>> H = G.edge_subgraph([(0, 1), (3, 4)])
>>> list(H.nodes)
[0, 1, 3, 4]
>>> list(H.edges)
[(0, 1), (3, 4)]
```
networkx.DiGraph.reverse

DiGraph.reverse(copy=True)
Return the reverse of the graph.

The reverse is a graph with the same nodes and edges but with the directions of the edges reversed.

Parameters copy (bool optional (default=True)) – If True, return a new DiGraph holding the reversed edges. If False, the reverse graph is created using a view of the original graph.

networkx.DiGraph.fresh_copy

DiGraph.fresh_copy()
Return a fresh copy graph with the same data structure.

A fresh copy has no nodes, edges or graph attributes. It is the same data structure as the current graph. This method is typically used to create an empty version of the graph.

Notes

If you subclass the base class you should overwrite this method to return your class of graph.

2.2.3 MultiGraph—Undirected graphs with self loops and parallel edges

Overview

class MultiGraph(incoming_graph_data=None, **attr)
An undirected graph class that can store multiedges.

Multiedges are multiple edges between two nodes. Each edge can hold optional data or attributes.

A MultiGraph holds undirected edges. Self loops are allowed.

Nodes can be arbitrary (hashable) Python objects with optional key/value attributes. By convention None is not used as a node.

Edges are represented as links between nodes with optional key/value attributes.

Parameters

- incoming_graph_data (input graph (optional, default: None)) – Data to initialize graph. If None (default) an empty graph is created. The data can be any format that is supported by the to_networkx_graph() function, currently including edge list, dict of dicts, dict of lists, NetworkX graph, NumPy matrix or 2d ndarray, SciPy sparse matrix, or PyGraphviz graph.

- attr (keyword arguments, optional (default= no attributes)) – Attributes to add to graph as key=value pairs.

See also:

Graph, DiGraph, MultiDiGraph, OrderedMultiGraph
Examples

Create an empty graph structure (a “null graph”) with no nodes and no edges.

```python
>>> G = nx.MultiGraph()
```

G can be grown in several ways.

**Nodes:**

Add one node at a time:

```python
>>> G.add_node(1)
```

Add the nodes from any container (a list, dict, set or even the lines from a file or the nodes from another graph).

```python
>>> G.add_nodes_from([2, 3])
>>> G.add_nodes_from(range(100, 110))
>>> H = nx.path_graph(10)
>>> G.add_nodes_from(H)
```

In addition to strings and integers any hashable Python object (except None) can represent a node, e.g. a customized node object, or even another Graph.

```python
>>> G.add_node(H)
```

**Edges:**

G can also be grown by adding edges.

Add one edge,

```python
>>> key = G.add_edge(1, 2)
```

a list of edges,

```python
>>> keys = G.add_edges_from([(1, 2), (1, 3)])
```

or a collection of edges,

```python
>>> keys = G.add_edges_from(H.edges)
```

If some edges connect nodes not yet in the graph, the nodes are added automatically. If an edge already exists, an additional edge is created and stored using a key to identify the edge. By default the key is the lowest unused integer.

```python
>>> keys = G.add_edges_from([(4,5,{'route':28}), (4,5,{'route':37})])
>>> G[4]
AdjacencyView({3: {0: {}}, 5: {0: {}, 1: {'route': 28}, 2: {'route': 37}}})
```

**Attributes:**

Each graph, node, and edge can hold key/value attribute pairs in an associated attribute dictionary (the keys must be hashable). By default these are empty, but can be added or changed using add_edge, add_node or direct manipulation of the attribute dictionaries named graph, node and edge respectively.

```python
>>> G = nx.MultiGraph(day="Friday")
>>> G.graph
{'day': 'Friday'}
```
Add node attributes using add_node(), add_nodes_from() or G.nodes

```python
>>> G.add_node(1, time='5pm')
>>> G.add_nodes_from([3], time='2pm')
>>> G.nodes[1]
{'time': '5pm'}
>>> G.nodes[1]['room'] = 714
>>> del G.nodes[1]['room']  # remove attribute
>>> list(G.nodes(data=True))
[(1, {'time': '5pm'}), (3, {'time': '2pm'})]
```

Add edge attributes using add_edge(), add_edges_from(), subscript notation, or G.edges.

```python
>>> key = G.add_edge(1, 2, weight=4.7)
>>> keys = G.add_edges_from([(3, 4), (4, 5)], color='red')
>>> keys = G.add_edges_from([(1, 2, {'color': 'blue'}), (2, 3, {'weight': 8})])
>>> G[1][2][0]['weight'] = 4.7
>>> G.edges[1, 2, 0]['weight'] = 4
```

Warning: we protect the graph data structure by making G.edges[1, 2] a read-only dict-like structure. However, you can assign to attributes in e.g. G.edges[1, 2]. Thus, use 2 sets of brackets to add/change data attributes: G.edges[1, 2]['weight'] = 4 (For multigraphs: MG.edges[u, v, key][name] = value).

Shortcuts:

Many common graph features allow python syntax to speed reporting.

```python
>>> 1 in G  # check if node in graph
True
>>> [n for n in G if n<3]  # iterate through nodes
[1, 2]
>>> len(G)  # number of nodes in graph
5
>>> G[1]  # adjacency dict-like view keyed by neighbor to edge attributes
AdjacencyView({2: {0: {'weight': 4}, 1: {'color': 'blue'}}})
```

Often the best way to traverse all edges of a graph is via the neighbors. The neighbors are reported as an adjacency-dict G.adj or as G.adjacency().

```python
>>> for n, nbrdict in G.adjacency():
...     for nbr, keydict in nbrdict.items():
...         for key, eattr in keydict.items():
...             if 'weight' in eattr:
...                 # Do something useful with the edges
...                 pass
```

But the edges() method is often more convenient:

```python
>>> for u, v, keys, weight in G.edges(data='weight', keys=True):
...     if weight is not None:
...         # Do something useful with the edges
...         pass
```

Reporting:

Simple graph information is obtained using methods and object-attributes. Reporting usually provides views instead of containers to reduce memory usage. The views update as the graph is updated similarly to dict-views. The objects nodes, `edges and adj provide access to data attributes via lookup
(e.g. `nodes[n]`, `edges[u, v]`, `adj[u][v]`) and iteration (e.g. `nodes.items()`, `nodes.data('color')`, `nodes.data('color', default='blue')`) and similarly for `edges` Views exist for `nodes`, `edges`, `neighbors()`, `adj` and `degree`.

For details on these and other miscellaneous methods, see below.

**Subclasses (Advanced):**

The MultiGraph class uses a dict-of-dict-of-dict-of-dict data structure. The outer dict (`node_dict`) holds adjacency information keyed by node. The next dict (`adjlist_dict`) represents the adjacency information and holds edge_key dicts keyed by neighbor. The edge_key dict holds each edge_attr dict keyed by edge key. The inner dict (`edge_attr_dict`) represents the edge data and holds edge attribute values keyed by attribute names.

Each of these four dicts in the dict-of-dict-of-dict-of-dict structure can be replaced by a user defined dict-like object. In general, the dict-like features should be maintained but extra features can be added. To replace one of the dicts create a new graph class by changing the class(!) variable holding the factory for that dict-like structure. The variable names are `node_dict_factory`, `adjlist_inner_dict_factory`, `adjlist_outer_dict_factory`, and `edge_attr_dict_factory`.

**node_dict_factory** [function, (default: dict)] Factory function to be used to create the dict containing node attributes, keyed by node id. It should require no arguments and return a dict-like object

**adjlist_outer_dict_factory** [function, (default: dict)] Factory function to be used to create the outer-most dict in the data structure that holds adjacency info keyed by node. It should require no arguments and return a dict-like object.

**adjlist_inner_dict_factory** [function, (default: dict)] Factory function to be used to create the adjacency list dict which holds multiedge key dicts keyed by neighbor. It should require no arguments and return a dict-like object.

**edge_key_dict_factory** [function, (default: dict)] Factory function to be used to create the edge key dict which holds edge data keyed by edge key. It should require no arguments and return a dict-like object.

**edge_attr_dict_factory** [function, (default: dict)] Factory function to be used to create the edge attribute dict which holds attribute values keyed by attribute name. It should require no arguments and return a dict-like object.

**Examples**

Please see `ordered` for examples of creating graph subclasses by overwriting the base class `dict` with a dictionary-like object.

**Methods**

**Adding and removing nodes and edges**

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</tr>
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`networkx.MultiGraph.__init__`

`MultiGraph.__init__(incoming_graph_data=None, **attr)`

Initialize a graph with edges, name, or graph attributes.

Parameters

- `incoming_graph_data` (input graph) – Data to initialize graph. If `incoming_graph_data=None` (default) an empty graph is created. The data can be an edge list, or any NetworkX graph object. If the corresponding optional Python packages are installed the data can also be a NumPy matrix or 2d ndarray, a SciPy sparse matrix, or a PyGraphviz graph.

- `attr` (keyword arguments, optional (default= no attributes)) – Attributes to add to graph as key=value pairs.

See also:

`convert()`

Examples

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G = nx.Graph(name='my graph')
>>> e = [(1, 2), (2, 3), (3, 4)]  # list of edges
>>> G = nx.Graph(e)
```

Arbitrary graph attribute pairs (key=value) may be assigned

```python
>>> G = nx.Graph(e, day="Friday")
>>> G.graph
{'day': 'Friday'}
```

`networkx.MultiGraph.add_node`

`MultiGraph.add_node(node_for_adding, **attr)`

Add a single node `node_for_adding` and update node attributes.

Parameters

- `node_for_adding` (node) – A node can be any hashable Python object except None.

- `attr` (keyword arguments, optional) – Set or change node attributes using key=value.

See also:

`add_nodes_from()`

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Examples

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_node(1)
>>> G.add_node('Hello')
>>> K3 = nx.Graph([(0, 1), (1, 2), (2, 0)])
>>> G.add_node(K3)
>>> G.number_of_nodes()
3

Use keywords set/change node attributes:

```python
>>> G.add_node(1, size=10)
>>> G.add_node(3, weight=0.4, UTM=('13S', 382871, 3972649))
```

Notes

A hashable object is one that can be used as a key in a Python dictionary. This includes strings, numbers, tuples of strings and numbers, etc.

On many platforms hashable items also include mutables such as NetworkX Graphs, though one should be careful that the hash doesn’t change on mutables.

networkx.MultiGraph.add_nodes_from

MultiGraph.add_nodes_from(nodes_for_adding, **attr)
Add multiple nodes.

Parameters

• **nodes_for_adding** (iterable container) – A container of nodes (list, dict, set, etc.). OR A container of (node, attribute dict) tuples. Node attributes are updated using the attribute dict.

• **attr** (keyword arguments, optional (default= no attributes)) – Update attributes for all nodes in nodes. Node attributes specified in nodes as a tuple take precedence over attributes specified via keyword arguments.

See also:

add_node()

Examples

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_nodes_from('Hello')
>>> K3 = nx.Graph([(0, 1), (1, 2), (2, 0)])
>>> G.add_nodes_from(K3)
>>> sorted(G.nodes(), key=str)
[0, 1, 2, 'H', 'e', 'l', 'o']

Use keywords to update specific node attributes for every node.

```python
>>> G.add_nodes_from([(1, 2), size=10])
>>> G.add_nodes_from([(3, 4), weight=0.4])
```
Use (node, attrdict) tuples to update attributes for specific nodes.

```python
>>> G.add_nodes_from(((1, dict(size=11)), (2, {'color':'blue'})))
>>> G.nodes[1]['size']
11
>>> H = nx.Graph()
>>> H.add_nodes_from(G.nodes(data=True))
>>> H.nodes[1]['size']
11
```

**networkx.MultiGraph.remove_node**

`MultiGraph.remove_node(n)`

Remove node n.

Removes the node n and all adjacent edges. Attempting to remove a non-existent node will raise an exception.

**Parameters**

- `n (node)` – A node in the graph

**Raises**

- `NetworkXError` – If n is not in the graph.

**See also:**

- `remove_nodes_from()`

**Examples**

```python
>>> G = nx.path_graph(3)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> list(G.edges)
[(0, 1), (1, 2)]
>>> G.remove_node(1)
>>> list(G.edges)
[]
```

**networkx.MultiGraph.remove_nodes_from**

`MultiGraph.remove_nodes_from(nodes)`

Remove multiple nodes.

**Parameters**

- `nodes (iterable container)` – A container of nodes (list, dict, set, etc.). If a node in the container is not in the graph it is silently ignored.

**See also:**

- `remove_node()`

**Examples**

```python
>>> G = nx.path_graph(3)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> e = list(G.nodes)
>>> e
[0, 1, 2]
>>> G.remove_nodes_from(e)
(continues on next page)```
networkx.MultiGraph.add_edge

Multigraph.add_edge(u_for_edge, v_for_edge, key=None, **attr)

Add an edge between u and v.

The nodes u and v will be automatically added if they are not already in the graph.

Edge attributes can be specified with keywords or by directly accessing the edge’s attribute dictionary. See examples below.

Parameters

- **u_for_edge, v_for_edge (nodes)** – Nodes can be, for example, strings or numbers. Nodes must be hashable (and not None) Python objects.
- **key (hashable identifier, optional (default=lowest unused integer))** – Used to distinguish multiedges between a pair of nodes.
- **attr (keyword arguments, optional)** – Edge data (or labels or objects) can be assigned using keyword arguments.

Returns

Return type The edge key assigned to the edge.

See also:

add_edges_from() add a collection of edges

Notes

To replace/update edge data, use the optional key argument to identify a unique edge. Otherwise a new edge will be created.

NetworkX algorithms designed for weighted graphs cannot use multigraphs directly because it is not clear how to handle multiedge weights. Convert to Graph using edge attribute ‘weight’ to enable weighted graph algorithms.

Default keys are generated using the method new_edge_key(). This method can be overridden by subclassing the base class and providing a custom new_edge_key() method.

Examples

The following all add the edge e=(1, 2) to graph G:

```python
>>> G = nx.MultiGraph()
>>> e = (1, 2)
>>> ekey = G.add_edge(1, 2)  # explicit two-node form
>>> G.add_edge(*e)  # single edge as tuple of two nodes
1
>>> G.add_edges_from([(1, 2)])  # add edges from iterable container
[2]
```
Associate data to edges using keywords:

```python
>>> ekey = G.add_edge(1, 2, weight=3)
>>> ekey = G.add_edge(1, 2, key=0, weight=4)  # update data for key=0
>>> ekey = G.add_edge(1, 3, weight=7, capacity=15, length=342.7)
```

For non-string attribute keys, use subscript notation.

```python
>>> ekey = G.add_edge(1, 2)
>>> G[1][2][0].update({0: 5})
>>> G.edges[1, 2, 0].update({0: 5})
```

**networkx.MultiGraph.add_edges_from**

`MultiGraph.add_edges_from(ebunch_to_add, **attr)`

Add all the edges in `ebunch_to_add`.

**Parameters**

- `ebunch_to_add` (*container of edges*) – Each edge given in the container will be added to the graph. The edges can be:
  - 2-tuples (u, v) or
  - 3-tuples (u, v, d) for an edge data dict d, or
  - 3-tuples (u, v, k) for not iterable key k, or
  - 4-tuples (u, v, k, d) for an edge with data and key k

- `attr` (*keyword arguments, optional*) – Edge data (or labels or objects) can be assigned using keyword arguments.

**Returns**

- `Return type` – A list of edge keys assigned to the edges in `ebunch`.

**See also:**

- `add_edge()` add a single edge
- `add_weighted_edges_from()` convenient way to add weighted edges

**Notes**

Adding the same edge twice has no effect but any edge data will be updated when each duplicate edge is added. Edge attributes specified in an ebunch take precedence over attributes specified via keyword arguments. Default keys are generated using the method `new_edge_key()`. This method can be overridden by subclassing the base class and providing a custom `new_edge_key()` method.

**Examples**

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_edges_from([(0, 1), (1, 2)])  # using a list of edge tuples
>>> e = zip(range(0, 3), range(1, 4))
>>> G.add_edges_from(e)  # Add the path graph 0-1-2-3
```
Associate data to edges

```python
>>> G.add_edges_from([(1, 2), (2, 3)], weight=3)
>>> G.add_edges_from([(3, 4), (1, 4)], label='WN2898')
```

`networkx.MultiGraph.add_weighted_edges_from`

`MultiGraph.add_weighted_edges_from(ebunch_to_add, weight='weight', **attr)`

Add weighted edges in `ebunch_to_add` with specified weight `attr`

**Parameters**

- `ebunch_to_add (container of edges)` – Each edge given in the list or container will be added to the graph. The edges must be given as 3-tuples (u, v, w) where w is a number.
- `weight (string, optional (default='weight'))` – The attribute name for the edge weights to be added.
- `attr (keyword arguments, optional (default= no attributes))` – Edge attributes to add/update for all edges.

**See also:**

- `add_edge()` add a single edge
- `add_edges_from()` add multiple edges

**Notes**

Adding the same edge twice for Graph/DiGraph simply updates the edge data. For MultiGraph/MultiDiGraph, duplicate edges are stored.

**Examples**

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_weighted_edges_from([(0, 1, 3.0), (1, 2, 7.5)])
```

`networkx.MultiGraph.new_edge_key`

`MultiGraph.new_edge_key(u, v)`

Return an unused key for edges between nodes u and v.

The nodes u and v do not need to be already in the graph.

**Notes**

In the standard MultiGraph class the new key is the number of existing edges between u and v (increased if necessary to ensure unused). The first edge will have key 0, then 1, etc. If an edge is removed further new_edge_keys may not be in this order.

**Parameters** u, v (nodes)

**Returns** key
Return type  int

networkx.MultiGraph.remove_edge

MultiGraph.remove_edge(u, v, key=None)

Remove an edge between u and v.

Parameters

• u, v (nodes) – Remove an edge between nodes u and v.
• key (hashable identifier, optional (default=None)) – Used to distinguish multiple edges between a pair of nodes. If None remove a single (arbitrary) edge between u and v.

Raises NetworkXError – If there is not an edge between u and v, or if there is no edge with the specified key.

See also:

remove_edges_from()  remove a collection of edges

Examples

>>> G = nx.MultiGraph()
>>> nx.add_path(G, [0, 1, 2, 3])
>>> G.remove_edge(0, 1)
>>> e = (1, 2)
>>> G.remove_edge(*e)  # unpacks e from an edge tuple

For multiple edges

>>> G = nx.MultiGraph()  # or MultiDiGraph, etc
>>> G.add_edges_from([(1, 2), (1, 2), (1, 2)])  # key_list returned
[0, 1, 2]
>>> G.remove_edge(1, 2)  # remove a single (arbitrary) edge

For edges with keys

>>> G = nx.MultiGraph()  # or MultiDiGraph, etc
>>> G.add_edge(1, 2, key='first')
'first'
>>> G.add_edge(1, 2, key='second')
'second'
>>> G.remove_edge(1, 2, key='second')

networkx.MultiGraph.remove_edges_from

MultiGraph.remove_edges_from(ebunch)

Remove all edges specified in ebunch.

Parameters ebunch (list or container of edge tuples) – Each edge given in the list or container will be removed from the graph. The edges can be:

• 2-tuples (u, v) All edges between u and v are removed.
• 3-tuples (u, v, key) The edge identified by key is removed.
• 4-tuples (u, v, key, data) where data is ignored.

See also:

\texttt{remove\_edge()} remove a single edge

Notes

Will fail silently if an edge in \texttt{ebunch} is not in the graph.

Examples

\begin{verbatim}
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> ebunch = [(1, 2), (2, 3)]
>>> G.remove_edges_from(ebunch)

Removing multiple copies of edges

>>> G = nx.MultiGraph()
>>> keys = G.add_edges_from([(1, 2), (1, 2), (1, 2)])
>>> G.remove_edges_from([(1, 2), (1, 2)])
>>> list(G.edges())
[(1, 2)]
>>> G.remove_edges_from([(1, 2), (1, 2)])  # silently ignore extra copy
>>> list(G.edges)  # now empty graph
[]
\end{verbatim}

\texttt{networkx.MultiGraph.clear}

\begin{verbatim}
MultiGraph.\texttt{clear}()
Remove all nodes and edges from the graph.
This also removes the name, and all graph, node, and edge attributes.

Examples

\begin{verbatim}
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.clear()
>>> list(G.nodes)
[]
>>> list(G.edges)
[]
\end{verbatim}

Reporting nodes edges and neighbors

\begin{tabular}{ll}
| \texttt{MultiGraph.nodes} | A NodeView of the Graph as \texttt{G}. \\
| \texttt{MultiGraph.__iter__()} | Iterate over the nodes. \\
| \texttt{MultiGraph.has_node(n)} | Return True if the graph contains the node \texttt{n}. |
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networkx.MultiGraph.nodes

`MultiGraph.nodes` is a NodeView of the Graph as `G.nodes` or `G.nodes()`. It can be used as `G.nodes` for data lookup and for set-like operations. It can also be used as `G.nodes(data='color', default=None)` to return a NodeDataView which reports specific node data but no set operations. It presents a dict-like interface as well with `G.nodes.items()` iterating over `(node, nodedata)` 2-tuples and `G.nodes[3]['foo']` providing the value of the `foo` attribute for node 3. In addition, a view `G.nodes.data('foo')` provides a dict-like interface to the `foo` attribute of each node. `G.nodes.data('foo', default=1)` provides a default for nodes that do not have attribute `foo`.

Parameters

- `data` *(string or bool, optional (default=False)) – The node attribute returned in 2-tuple (n, ddict[data]). If True, return entire node attribute dict as (n, ddict). If False, return just the nodes n.
- `default` *(value, optional (default=None)) – Value used for nodes that don’t have the requested attribute. Only relevant if data is not True or False.

Returns

Allows set-like operations over the nodes as well as node attribute dict lookup and calling to get a NodeDataView. A NodeDataView iterates over `(n, data)` and has no set operations. A NodeView iterates over `n` and includes set operations.

When called, if data is False, an iterator over nodes. Otherwise an iterator of 2-tuples (node, attribute value) where the attribute is specified in `data`. If data is True then the attribute becomes the entire data dictionary.

**Return type** NodeView

Notes

If your node data is not needed, it is simpler and equivalent to use the expression `for n in G, or list(G)`.

Examples

There are two simple ways of getting a list of all nodes in the graph:
To get the node data along with the nodes:

```python
>>> G.add_node(1, time='5pm')
>>> G.nodes[0]['foo'] = 'bar'
>>> list(G.nodes(data=True))
[(0, {'foo': 'bar'}), (1, {'time': '5pm'}), (2, {})]
>>> list(G.nodes.data('foo'))
[(0, 'bar'), (1, None), (2, None)]

>>> list(G.nodes(data='time'))
[(0, None), (1, '5pm'), (2, None)]
>>> list(G.nodes.data('time'))
[(0, None), (1, '5pm'), (2, None)]

>>> list(G.nodes(data='time', default='Not Available'))
[(0, 'Not Available'), (1, '5pm'), (2, 'Not Available')]
>>> list(G.nodes.data('time', default='Not Available'))
[(0, 'Not Available'), (1, '5pm'), (2, 'Not Available')]
```

If some of your nodes have an attribute and the rest are assumed to have a default attribute value you can create a dictionary from node/attribute pairs using the `default` keyword argument to guarantee the value is never `None`:

```python
>>> G = nx.Graph()
>>> G.add_node(0)
>>> G.add_node(1, weight=2)
>>> G.add_node(2, weight=3)
>>> dict(G.nodes(data='weight', default=1))
{0: 1, 1: 2, 2: 3}
```

### `networkx.MultiGraph.__iter__`

`MultiGraph.__iter__()`

Iterate over the nodes. Use: `for n in G`.

Returns `niter` – An iterator over all nodes in the graph.

Return type `iterator`

**Examples**
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> [n for n in G]
[0, 1, 2, 3]
>>> list(G)
[0, 1, 2, 3]

networkx.MultiGraph.has_node

MultiGraph.has_node(n)
Return True if the graph contains the node n.
Identical to n in G

Parameters n (node)

Examples

>>> G = nx.path_graph(3)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.has_node(0)
True

It is more readable and simpler to use

>>> 0 in G
True

networkx.MultiGraph.__contains__

MultiGraph.__contains__(n)
Return True if n is a node, False otherwise. Use: ‘n in G’.

Examples

>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> 1 in G
True

networkx.MultiGraph.edges

MultiGraph.edges
Return an iterator over the edges.

edges(self, nbunch=None, data=False, keys=False, default=None)
The EdgeView provides set-like operations on the edge-tuples as well as edge attribute lookup. When called, it also provides an EdgeDataView object which allows control of access to edge attributes (but does not provide set-like operations). Hence, G.edges[u, v]['color'] provides the value of the color attribute for edge (u, v) while for (u, v, c) in G.edges(data='color', default='red'): iterates through all the edges yielding the color attribute.

2.2. Basic graph types
Edges are returned as tuples with optional data and keys in the order (node, neighbor, key, data).

**Parameters**

- **nbunch** (single node, container, or all nodes (default= all nodes)) – The view will only report edges incident to these nodes.

- **data** (string or bool, optional (default=False)) – The edge attribute returned in 3-tuple (u, v, ddict[data]). If True, return edge attribute dict in 3-tuple (u, v, ddict). If False, return 2-tuple (u, v).

- **keys** (bool, optional (default=False)) – If True, return edge keys with each edge.

- **default** (value, optional (default=None)) – Value used for edges that don’t have the requested attribute. Only relevant if data is not True or False.

**Returns edges** – A view of edge attributes, usually it iterates over (u, v) (u, v, k) or (u, v, k, d) tuples of edges, but can also be used for attribute lookup as edges[u, v, k]['foo'].

**Return type** MultiEdgeView

**Notes**

Nodes in nbunch that are not in the graph will be (quietly) ignored. For directed graphs this returns the out-edges.

**Examples**

```python
>>> G = nx.MultiGraph()  # or MultiDiGraph
>>> nx.add_path(G, [0, 1, 2])
>>> key = G.add_edge(2, 3, weight=5)
>>> [e for e in G.edges()]
[(0, 1), (1, 2), (2, 3)]
>>> G.edges.data()  # default data is {} (empty dict)
MultiEdgeDataView([(0, 1, {}), (1, 2, {}), (2, 3, {'weight': 5})])
>>> G.edges.data('weight', default=1)
MultiEdgeDataView([(0, 1, 1), (1, 2, 1), (2, 3, 5)])
>>> G.edges(keys=True)  # default keys are integers
MultiEdgeView([(0, 1, 0), (1, 2, 0), (2, 3, 0)])
>>> G.edges.data(keys=True)
MultiEdgeDataView([(0, 1, 0, {}), (1, 2, 0, {}), (2, 3, 0, {'weight': 5})])
>>> G.edges.data('weight', default=1, keys=True)
MultiEdgeDataView([(0, 1, 0, 1), (1, 2, 0, 1), (2, 3, 0, 5)])
>>> G.edges([0, 3])
MultiEdgeDataView([(0, 1), (3, 2)])
>>> G.edges(0)
MultiEdgeDataView([(0, 1)])
```

**networkx.MultiGraph.has_edge**

MultiGraph has_edge(u, v, key=None)

Return True if the graph has an edge between nodes u and v.

This is the same as v in G[u] or key in G[u][v] without KeyError exceptions.

**Parameters**

- **u, v** (nodes) – Nodes can be, for example, strings or numbers.
• key (hashable identifier, optional (default=None)) – If specified return True only if the edge with key is found.

Returns edge_ind – True if edge is in the graph, False otherwise.

Return type bool

Examples

Can be called either using two nodes u, v, an edge tuple (u, v), or an edge tuple (u, v, key).

```python
>>> G = nx.MultiGraph()  # or MultiDiGraph
>>> nx.add_path(G, [0, 1, 2, 3])
>>> G.has_edge(0, 1)  # using two nodes
True
>>> e = (0, 1)  
>>> G.has_edge(*e)  # e is a 2-tuple (u, v)
True
>>> G.add_edge(0, 1, key='a')
'a'
>>> G.has_edge(0, 1, key='a')  # specify key
True
>>> e=(0, 1, 'a')
>>> G.has_edge(*e)  # e is a 3-tuple (u, v, 'a')
True
```

The following syntax are equivalent:

```python
>>> G.has_edge(0, 1)
True
>>> 1 in G[0]  # though this gives :exc:`KeyError` if 0 not in G
True
```

networkx.MultiGraph.get_edge_data

MultiGraph.get_edge_data (u, v, key=None, default=None)

Return the attribute dictionary associated with edge (u, v).

This is identical to G[u][v][key] except the default is returned instead of an exception is the edge doesn’t exist.

Parameters

• u, v (nodes)
• default (any Python object (default=None)) – Value to return if the edge (u, v) is not found.
• key (hashable identifier, optional (default=None)) – Return data only for the edge with specified key.

Returns edge_dict – The edge attribute dictionary.

Return type dictionary

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Examples

```python
>>> G = nx.MultiGraph()  # or MultiDiGraph
>>> key = G.add_edge(0, 1, key='a', weight=7)
>>> G[0][1]['a']  # key='a'
{'weight': 7}
>>> G.edges[0, 1, 'a']  # key='a'
{'weight': 7}
```

Warning: we protect the graph data structure by making `G.edges` and `G[1][2]` read-only dict-like structures. However, you can assign values to attributes in e.g. `G.edges[1, 2, 'a']` or `G[1][2]['a']` using an additional bracket as shown next. You need to specify all edge info to assign to the edge data associated with an edge.

```python
>>> G[0][1]['a']['weight'] = 10
>>> G.edges[0, 1, 'a']['weight'] = 10
>>> G[0][1]['a']['weight']
10
>>> G.edges[1, 0, 'a']['weight']
10
```

```python
>>> G = nx.MultiGraph()  # or MultiDiGraph
>>> nx.add_path(G, [0, 1, 2, 3])
>>> G.get_edge_data(0, 1)
{0: {}}
>>> e = (0, 1)
>>> G.get_edge_data(*e)  # tuple form
{0: {}}
>>> G.get_edge_data('a', 'b', default=0)  # edge not in graph, return 0
0
```

`networkx.MultiGraph.neighbors`

`MultiGraph.neighbors(n)`

Return an iterator over all neighbors of node n.

This is identical to `iter(G[n])`

Parameters `n (node)` – A node in the graph

Returns `neighbors` – An iterator over all neighbors of node n

Return type `iterator`

Raises `NetworkXError` – If the node n is not in the graph.

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> [n for n in G.neighbors(0)]
[1]
```
Notes

It is usually more convenient (and faster) to access the adjacency dictionary as `G[n]`:

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_edge('a', 'b', weight=7)
>>> G['a']
AtlasView({'b': {'weight': 7}})
>>> G = nx.path_graph(4)
>>> [n for n in G[0]]
[1]
```

`networkx.MultiGraph.adj`

`MultiGraph.adj`

Graph adjacency object holding the neighbors of each node.

This object is a read-only dict-like structure with node keys and neighbor-dict values. The neighbor-dict is keyed by neighbor to the edgekey-data-dict. So `G.adj[3][2][0]['color'] = 'blue'` sets the color of the edge `(3, 2, 0)` to "blue".

Iterating over `G.adj` behaves like a dict. Useful idioms include `for nbr, nbrdict in G.adj[n].items()`.

The neighbor information is also provided by subscripting the graph. So `for nbr, foovalue in G[node].data('foo', default=1)` works.

For directed graphs, `G.adj` holds outgoing (successor) info.

`networkx.MultiGraph.__getitem__`

`MultiGraph.__getitem__(n)`

Return a dict of neighbors of node n. Use: `G[n]`.

Parameters:
- `n (node)` – A node in the graph.

Returns:
- `adj_dict` – The adjacency dictionary for nodes connected to n.

Return type:
- dictionary

Notes

`G[n]` is the same as `G.adj[n]` and similar to `G.neighbors(n)` (which is an iterator over `G.adj[n]`)

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G[0]
AtlasView({1: {}})
```
networkx.MultiGraph.adjacency

MultiGraph.adjacency()

Return an iterator over (node, adjacency dict) tuples for all nodes.

For directed graphs, only outgoing neighbors/adjacencies are included.

Returns adj_iter – An iterator over (node, adjacency dictionary) for all nodes in the graph.

Return type iterator

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> [(n, nbrdict) for n, nbrdict in G.adjacency()]
[(0, {1: {}}), (1, {0: {}, 2: {}}), (2, {1: {}, 3: {}}), (3, {2: {}})]
```

networkx.MultiGraph.nbunch_iter

MultiGraph.nbunch_iter(nbunch=None)

Return an iterator over nodes contained in nbunch that are also in the graph.

The nodes in nbunch are checked for membership in the graph and if not are silently ignored.

Parameters nbunch (single node, container, or all nodes (default= all nodes)) – The view will only report edges incident to these nodes.

Returns niter – An iterator over nodes in nbunch that are also in the graph. If nbunch is None, iterate over all nodes in the graph.

Return type iterator

Raises NetworkXError – If nbunch is not a node or or sequence of nodes. If a node in nbunch is not hashable.

See also:

Graph.__iter__()  

Notes

When nbunch is an iterator, the returned iterator yields values directly from nbunch, becoming exhausted when nbunch is exhausted.

To test whether nbunch is a single node, one can use “if nbunch in self.”, even after processing with this routine.

If nbunch is not a node or a (possibly empty) sequence/iterator or None, a NetworkXError is raised. Also, if any object in nbunch is not hashable, a NetworkXError is raised.

Counting nodes edges and neighbors

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<td><code>MultiGraph.size([weight])</code></td>
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<td>Return the number of edges between two nodes.</td>
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**networkx.MultiGraph.order**

`MultiGraph.order()`  
Return the number of nodes in the graph.  

*Returns* nnodes – The number of nodes in the graph.  

*Return type* int  

*See also:*  
`number_of_nodes()`, `__len__()`

**networkx.MultiGraph.number_of_nodes**

`MultiGraph.number_of_nodes()`  
Return the number of nodes in the graph.  

*Returns* nnodes – The number of nodes in the graph.  

*Return type* int  

*See also:*  
`order()`, `__len__()`

**Examples**

```python  
>>> G = nx.path_graph(3)  # or DiGraph, MultiGraph, MultiDiGraph, etc  
>>> len(G)  
3  
```

**networkx.MultiGraph.__len__**

`MultiGraph.__len__()`  
Return the number of nodes. Use: ‘len(G)’.  

*Returns* nnodes – The number of nodes in the graph.  

*Return type* int  

**Examples**

```python  
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc  
>>> len(G)  
4  
```
networkx.MultiGraph.degree

MultiGraph.degree
A DegreeView for the Graph as G.degree or G.degree().

The node degree is the number of edges adjacent to the node. The weighted node degree is the sum of the edge weights for edges incident to that node.

This object provides an iterator for (node, degree) as well as lookup for the degree for a single node.

Parameters

• nbunch (single node, container, or all nodes (default=all nodes)) – The view will only report edges incident to these nodes.

• weight (string or None, optional (default=None)) – The name of an edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1. The degree is the sum of the edge weights adjacent to the node.

Returns

• If a single node is requested
  • deg (int) – Degree of the node, if a single node is passed as argument.

• OR if multiple nodes are requested
  • nd_iter (iterator) – The iterator returns two-tuples of (node, degree).

Examples

```python
g = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> nx.add_path(G, [0, 1, 2, 3])
>>> G.degree(0)  # node 0 with degree 1
1
>>> list(G.degree([0, 1]))
[(0, 1), (1, 2)]
```

networkx.MultiGraph.size

MultiGraph.size(weight=None)
Return the number of edges or total of all edge weights.

Parameters weight (string or None, optional (default=None)) – The edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1.

Returns

size – The number of edges or (if weight keyword is provided) the total weight sum.

If weight is None, returns an int. Otherwise a float (or more general numeric if the weights are more general).

Return type numeric

See also:

number_of_edges()
Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.size()
3

>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_edge('a', 'b', weight=2)
>>> G.add_edge('b', 'c', weight=4)
>>> G.size()
2
>>> G.size(weight='weight')
6.0
```

networkx.MultiGraph.number_of_edges

`MultiGraph.number_of_edges(u=None, v=None)`

Return the number of edges between two nodes.

Parameters

- `u` *(nodes, optional (default=all edges)) – If *u* and *v* are specified, return the number of edges between *u* and *v*. Otherwise return the total number of all edges.*

- `v` *(nodes, optional (default=all edges)) – If *u* and *v* are specified, return the number of edges between *u* and *v*. Otherwise return the total number of all edges.*

Returns `nedges` – The number of edges in the graph. If nodes *u* and *v* are specified return the number of edges between those nodes. If the graph is directed, this only returns the number of edges from *u* to *v*.

Return type

- `int`

See also:

- `size()`

Examples

For undirected multigraphs, this method counts the total number of edges in the graph:

```python
>>> G = nx.MultiGraph()
>>> G.add_edges_from([[0, 1], (0, 1), (1, 2)])
[0, 1, 0]
>>> G.number_of_edges()
3
```

If you specify two nodes, this counts the total number of edges joining the two nodes:

```python
>>> G.number_of_edges(0, 1)
2
```

For directed multigraphs, this method can count the total number of directed edges from *u* to *v*:

```python
>>> G = nx.MultiDiGraph()
>>> G.add_edges_from([[0, 1], (0, 1), (1, 0)])
[0, 1, 0]
>>> G.number_of_edges(0, 1)
2
```
Making copies and subgraphs

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networkx.MultiGraph.copy

MultiGraph.copy (as_view=False)
Return a copy of the graph.

The copy method by default returns a shallow copy of the graph and attributes. That is, if an attribute is a container, that container is shared by the original an the copy. Use Python’s copy.deepcopy for new containers.

If as_view is True then a view is returned instead of a copy.

Notes

All copies reproduce the graph structure, but data attributes may be handled in different ways. There are four types of copies of a graph that people might want.

Deepcopy – The default behavior is a “deepcopy” where the graph structure as well as all data attributes and any objects they might contain are copied. The entire graph object is new so that changes in the copy do not affect the original object. (see Python’s copy.deepcopy)

Data Reference (Shallow) – For a shallow copy the graph structure is copied but the edge, node and graph attribute dicts are references to those in the original graph. This saves time and memory but could cause confusion if you change an attribute in one graph and it changes the attribute in the other. NetworkX does not provide this level of shallow copy.

Independent Shallow – This copy creates new independent attribute dicts and then does a shallow copy of the attributes. That is, any attributes that are containers are shared between the new graph and the original. This is exactly what dict.copy() provides. You can obtain this style copy using:

```python
>>> G = nx.path_graph(5)
>>> H = G.copy()
>>> H = G.copy(as_view=False)
>>> H = nx.Graph(G)
>>> H = G.fresh_copy().__class__(G)
```

Fresh Data – For fresh data, the graph structure is copied while new empty data attribute dicts are created. The resulting graph is independent of the original and it has no edge, node or graph attributes. Fresh copies are not enabled. Instead use:
View – Inspired by dict-views, graph-views act like read-only versions of the original graph, providing a copy of the original structure without requiring any memory for copying the information.

See the Python copy module for more information on shallow and deep copies, https://docs.python.org/2/library/copy.html.

Parameters

- **as_view** *(bool, optional (default=False)) – If True, the returned graph-view provides a read-only view of the original graph without actually copying any data.*

Returns

- **G** – A copy of the graph.

Return type

- **Graph**

See also:

- **to_directed()** return a directed copy of the graph.

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
```
Examples

```python
>>> G = nx.path_graph(2)  # or MultiGraph, etc
>>> H = G.to_directed()
>>> list(H.edges)
[(0, 1), (1, 0)]
>>> G2 = H.to_undirected()
>>> list(G2.edges)
[(0, 1)]
```

networkx.MultiGraph.to_directed

```
MultiGraph.to_directed(as_view=False)
Return a directed representation of the graph.

Returns

- **G** – A directed graph with the same name, same nodes, and with each edge \((u, v, \text{data})\) replaced by two directed edges \((u, v, \text{data})\) and \((v, u, \text{data})\).

Return type: MultiDiGraph
```

Notes

This returns a “deepcopy” of the edge, node, and graph attributes which attempts to completely copy all of the data and references.

This is in contrast to the similar D=DiGraph(G) which returns a shallow copy of the data.

See the Python copy module for more information on shallow and deep copies, [https://docs.python.org/2/library/copy.html](https://docs.python.org/2/library/copy.html).

Warning: If you have subclassed MultiGraph to use dict-like objects in the data structure, those changes do not transfer to the MultiDiGraph created by this method.

Examples

```python
>>> G = nx.Graph()  # or MultiGraph, etc
>>> G.add_edge(0, 1)
>>> H = G.to_directed()
>>> list(H.edges)
[(0, 1), (1, 0)]
```

If already directed, return a (deep) copy

```python
>>> G = nx.DiGraph()  # or MultiDiGraph, etc
>>> G.add_edge(0, 1)
>>> H = G.to_directed()
>>> list(H.edges)
[(0, 1)]
```

networkx.MultiGraph.subgraph

```
MultiGraph.subgraph(nodes)
Return a SubGraph view of the subgraph induced on nodes in nodes.
```
The induced subgraph of the graph contains the nodes in \texttt{nodes} and the edges between those nodes.

**Parameters** \texttt{nodes} (list, iterable) – A container of nodes which will be iterated through once.

**Returns** \(G\) – A subgraph view of the graph. The graph structure cannot be changed but node/edge attributes can and are shared with the original graph.

**Return type** SubGraph View

**Notes**

The graph, edge and node attributes are shared with the original graph. Changes to the graph structure is ruled out by the view, but changes to attributes are reflected in the original graph.

To create a subgraph with its own copy of the edge/node attributes use: \(G\).subgraph\(\texttt{nodes}\).\texttt{copy()}.

For an inplace reduction of a graph to a subgraph you can remove nodes: \(G\).remove\_nodes\_from\(\{n\text{ for }n\text{ in }G\text{ if }n\text{ not in set}(\texttt{nodes})\}\).

**Examples**

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> nx.add_path(G, [0, 1, 2, 3])
>>> H = G.subgraph([0, 1, 2])
>>> list(H.edges)
[(0, 1), (1, 2)]
```

```python
>>> G = nx.MultiGraph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> nx.add_path(G, [0, 1, 2, 3])
>>> H = G.edge_subgraph([(0, 1, 2)])
>>> list(H.edges)
[(0, 1), (1, 2)]
```

**networkx.MultiGraph.edge_subgraph**

\texttt{MultiGraph.edge\_subgraph(edges)}

Returns the subgraph induced by the specified edges.

The induced subgraph contains each edge in \texttt{edges} and each node incident to any one of those edges.

**Parameters** \texttt{edges} (iterable) – An iterable of edges in this graph.

**Returns** \(G\) – An edge-induced subgraph of this graph with the same edge attributes.

**Return type** Graph

**Notes**

The graph, edge, and node attributes in the returned subgraph view are references to the corresponding attributes in the original graph. The view is read-only.

To create a full graph version of the subgraph with its own copy of the edge or node attributes, use:

```python
>>> G.edge_subgraph(edges).copy()
```

**Examples**
>>> G = nx.path_graph(5)
>>> H = G.edge_subgraph([(0, 1), (3, 4)])
>>> list(H.nodes)
[0, 1, 3, 4]
>>> list(H.edges)
[(0, 1), (3, 4)]

networkx.MultiGraph.fresh_copy

MultiGraph.fresh_copy()

Return a fresh copy graph with the same data structure.

A fresh copy has no nodes, edges or graph attributes. It is the same data structure as the current graph. This method is typically used to create an empty version of the graph.

Notes

If you subclass the base class you should overwrite this method to return your class of graph.

2.2.4 MultiDiGraph—Directed graphs with self loops and parallel edges

Overview

class MultiDiGraph (incoming_graph_data=None, **attr)

A directed graph class that can store multiedges.

Multiedges are multiple edges between two nodes. Each edge can hold optional data or attributes.

A MultiDiGraph holds directed edges. Self loops are allowed.

Nodes can be arbitrary (hashable) Python objects with optional key/value attributes. By convention None is not used as a node.

Edges are represented as links between nodes with optional key/value attributes.

Parameters

- **incoming_graph_data** (input graph (optional, default: None)) – Data to initialize graph. If None (default) an empty graph is created. The data can be any format that is supported by the to_networkx_graph() function, currently including edge list, dict of dicts, dict of lists, NetworkX graph, NumPy matrix or 2d ndarray, SciPy sparse matrix, or PyGraphviz graph.
- **attr** (keyword arguments, optional (default= no attributes)) – Attributes to add to graph as key=value pairs.

See also:

Graph, DiGraph, MultiGraph, OrderedMultiDiGraph

Examples

Create an empty graph structure (a “null graph”) with no nodes and no edges.

```python
>>> G = nx.MultiDiGraph()
```
G can be grown in several ways.

**Nodes:**
Add one node at a time:

```python
>>> G.add_node(1)
```

Add the nodes from any container (a list, dict, set or even the lines from a file or the nodes from another graph).

```python
>>> G.add_nodes_from([2, 3])
>>> G.add_nodes_from(range(100, 110))
>>> H = nx.path_graph(10)
>>> G.add_nodes_from(H)
```

In addition to strings and integers any hashable Python object (except None) can represent a node, e.g. a customized node object, or even another Graph.

```python
>>> G.add_node(H)
```

**Edges:**
G can also be grown by adding edges.

Add one edge,

```python
>>> key = G.add_edge(1, 2)
```

a list of edges,

```python
>>> keys = G.add_edges_from([(1, 2), (1, 3)])
```

or a collection of edges,

```python
>>> keys = G.add_edges_from(H.edges)
```

If some edges connect nodes not yet in the graph, the nodes are added automatically. If an edge already exists, an additional edge is created and stored using a key to identify the edge. By default the key is the lowest unused integer.

```python
>>> keys = G.add_edges_from([(4,5,dict(route=282)), (4,5,dict(route=37))])
>>> G[4]
```

```
AdjacencyView({5: {0: {}, 1: {'route': 282}, 2: {'route': 37}}})
```

**Attributes:**
Each graph, node, and edge can hold key/value attribute pairs in an associated attribute dictionary (the keys must be hashable). By default these are empty, but can be added or changed using add_edge, add_node or direct manipulation of the attribute dictionaries named graph, node and edge respectively.

```python
>>> G = nx.MultiDiGraph(day="Friday")
>>> G.graph
{'day': 'Friday'}
```

Add node attributes using add_node(), add_nodes_from() or G.nodes

```python
>>> G.add_node(1, time='5pm')
>>> G.add_nodes_from([3], time='2pm')
>>> G.nodes[1]
```

(continues on next page)
```python
G.nodes[1]['room'] = 714
>>> del G.nodes[1]['room']  # remove attribute
>>> list(G.nodes(data=True))
[(1, {'time': '5pm'}), (3, {'time': '2pm'})]
```

Add edge attributes using add_edge(), add_edges_from(), subscript notation, or G.edges.

```python
key = G.add_edge(1, 2, weight=4.7)
>>>
keys = G.add_edges_from([(3, 4), (4, 5)], color='red')
>>> keys = G.add_edges_from([(1, 2, {'color': 'blue'}), (2, 3, {'weight': 8})])
>>> G[1][2][0]['weight'] = 4.7
>>> G.edges[1, 2, 0]['weight'] = 4
```

Warning: we protect the graph data structure by making `G.edges[1, 2]` a read-only dict-like structure. However, you can assign to attributes in e.g. `G.edges[1, 2]`. Thus, use 2 sets of brackets to add/change data attributes: `G.edges[1, 2]['weight'] = 4` (For multigraphs: `MG.edges[u, v, key][name] = value`).

**Shortcuts:**

Many common graph features allow python syntax to speed reporting.

```python
1 in G  # check if node in graph
True
>>> [n for n in G if n<3]  # iterate through nodes
[1, 2]
>>> len(G)  # number of nodes in graph
5
>>> G[1]  # adjacency dict-like view keyed by neighbor to edge attributes
AdjacencyView({2: {0: {'weight': 4}, 1: {'color': 'blue'}}})
```

Often the best way to traverse all edges of a graph is via the neighbors. The neighbors are available as an adjacency-view `G.adj` object or via the method `G.adjacency()`.

```python
>>> for n, nbrsdict in G.adjacency():
...     for nbr, keydict in nbrsdict.items():
...         for key, eattr in keydict.items():
...             if 'weight' in eattr:
...                 # Do something useful with the edges
...                 pass
```

But the `edges()` method is often more convenient:

```python
>>> for u, v, keys, weight in G.edges(data='weight', keys=True):
...     if weight is not None:
...         # Do something useful with the edges
...         pass
```

**Reporting:**

Simple graph information is obtained using methods and object-attributes. Reporting usually provides views instead of containers to reduce memory usage. The views update as the graph is updated similarly to dict-views. The objects `nodes`, `edges` and `adj` provide access to data attributes via lookup (e.g. `nodes[n]`, `edges[u, v]`, `adj[u][v]`) and iteration (e.g. `nodes.items()`, `nodes.data('color')`, `nodes.data('color', default='blue')` and similarly for `edges`) Views exist for `nodes`, `edges`, `neighbors()`/`adj` and `degree`.  

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For details on these and other miscellaneous methods, see below.

**Subclasses (Advanced):**

The MultiDiGraph class uses a dict-of-dict-of-dict-of-dict structure. The outer dict (node_dict) holds adjacency information keyed by node. The next dict (adjlist_dict) represents the adjacency information and holds edge_key dicts keyed by neighbor. The edge_key dict holds each edge_attr dict keyed by edge key. The inner dict (edge_attr_dict) represents the edge data and holds edge attribute values keyed by attribute names.

Each of these four dicts in the dict-of-dict-of-dict-of-dict structure can be replaced by a user defined dict-like object. In general, the dict-like features should be maintained but extra features can be added. To replace one of the dicts create a new graph class by changing the class(!) variable holding the factory for that dict-like structure. The variable names are node_dict_factory, adjlist_inner_dict_factory, adjlist_outer_dict_factory, and edge_attr_dict_factory.

**node_dict_factory** [function, (default: dict)] Factory function to be used to create the dict containing node attributes, keyed by node id. It should require no arguments and return a dict-like object.

**adjlist_outer_dict_factory** [function, (default: dict)] Factory function to be used to create the outer-most dict in the data structure that holds adjacency info keyed by node. It should require no arguments and return a dict-like object.

**adjlist_inner_dict_factory** [function, (default: dict)] Factory function to be used to create the adjacency list dict which holds multiedge key dicts keyed by neighbor. It should require no arguments and return a dict-like object.

**edge_key_dict_factory** [function, (default: dict)] Factory function to be used to create the edge key dict which holds edge data keyed by edge key. It should require no arguments and return a dict-like object.

**edge_attr_dict_factory** [function, (default: dict)] Factory function to be used to create the edge attribute dict which holds attribute values keyed by attribute name. It should require no arguments and return a dict-like object.

**Examples**

Please see ordered for examples of creating graph subclasses by overwriting the base class dict with a dictionary-like object.

**Methods**

**Adding and Removing Nodes and Edges**

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networkx.MultiDiGraph.__init__

MultiDiGraph.__init__ (incoming_graph_data=None, **attr)

Initialize a graph with edges, name, or graph attributes.

Parameters

• incoming_graph_data (input graph) – Data to initialize graph. If incoming_graph_data=None (default) an empty graph is created. The data can be an edge list, or any NetworkX graph object. If the corresponding optional Python packages are installed the data can also be a NumPy matrix or 2d ndarray, a SciPy sparse matrix, or a PyGraphviz graph.

• attr (keyword arguments, optional (default= no attributes)) – Attributes to add to graph as key=value pairs.

See also:

convert()

Examples

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G = nx.Graph(name='my graph')
>>> e = [(1, 2), (2, 3), (3, 4)]  # list of edges
>>> G = nx.Graph(e)
```

Arbitrary graph attribute pairs (key=value) may be assigned

```python
>>> G = nx.Graph(e, day="Friday")
>>> G.graph
{'day': 'Friday'}
```

networkx.MultiDiGraph.add_node

MultiDiGraph.add_node (node_for_adding, **attr)

Add a single node node_for_adding and update node attributes.

Parameters

• node_for_adding (node) – A node can be any hashable Python object except None.

• attr (keyword arguments, optional) – Set or change node attributes using key=value.

See also:

add_nodes_from()
Examples

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_node(1)
>>> G.add_node('Hello')
>>> K3 = nx.Graph([(0, 1), (1, 2), (2, 0)])
>>> G.add_node(K3)
>>> G.number_of_nodes()
3
```

Use keywords set/change node attributes:

```python
>>> G.add_node(1, size=10)
>>> G.add_node(3, weight=0.4, UTM=('13S', 382871, 3972649))
```

Notes

A hashable object is one that can be used as a key in a Python dictionary. This includes strings, numbers, tuples of strings and numbers, etc.

On many platforms hashable items also include mutables such as NetworkX Graphs, though one should be careful that the hash doesn’t change on mutables.

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_nodes_from('Hello')
>>> K3 = nx.Graph([(0, 1), (1, 2), (2, 0)])
>>> G.add_nodes_from(K3)
>>> sorted(G.nodes(), key=str)
[0, 1, 2, 'H', 'e', 'l', 'o']
```

Use keywords to update specific node attributes for every node.

```python
>>> G.add_nodes_from([(1, 2), size=10])
>>> G.add_nodes_from([(3, 4), weight=0.4])
```
Use (node, attrdict) tuples to update attributes for specific nodes.

```python
>>> G.add_nodes_from([(1, dict(size=11)), (2, {'color':'blue'})])
>>> G.nodes[1]['size']
11
>>> H = nx.Graph()
>>> H.add_nodes_from(G.nodes(data=True))
>>> H.nodes[1]['size']
11
```

networkx.MultiDiGraph.remove_node

**networkx.MultiDiGraph.remove_node**

`MultiDiGraph.remove_node(n)`

Remove node n.

Removes the node n and all adjacent edges. Attempting to remove a non-existent node will raise an exception.

**Parameters**

- **n (node)** – A node in the graph

**Raises**

NetworkXError – If n is not in the graph.

**Examples**

```python
>>> G = nx.path_graph(3)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> list(G.edges)
[(0, 1), (1, 2)]
>>> G.remove_node(1)
>>> list(G.edges)
[]
```

networkx.MultiDiGraph.remove_nodes_from

**networkx.MultiDiGraph.remove_nodes_from**

`MultiDiGraph.remove_nodes_from(nodes)`

Remove multiple nodes.

**Parameters**

- **nodes (iterable container)** – A container of nodes (list, dict, set, etc.). If a node in the container is not in the graph it is silently ignored.

**Examples**

```python
>>> G = nx.path_graph(3)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> e = list(G.nodes)
>>> e
[0, 1, 2]
>>> G.remove_nodes_from(e)
```
networkx.MultiDiGraph.add_edge

MultiDiGraph.add_edge(u_for_edge, v_for_edge, key=None, **attr)
Add an edge between u and v.

The nodes u and v will be automatically added if they are not already in the graph.

Edge attributes can be specified with keywords or by directly accessing the edge’s attribute dictionary. See examples below.

Parameters

• u_for_edge, v_for_edge (nodes) – Nodes can be, for example, strings or numbers. Nodes must be hashable (and not None) Python objects.

• key (hashable identifier, optional (default=lowest unused integer)) – Used to distinguish multiedges between a pair of nodes.

• attr_dict (dictionary, optional (default= no attributes)) – Dictionary of edge attributes. Key/value pairs will update existing data associated with the edge.

• attr (keyword arguments, optional) – Edge data (or labels or objects) can be assigned using keyword arguments.

Returns

Return type The edge key assigned to the edge.

See also:

add_edges_from() add a collection of edges

Notes

To replace/update edge data, use the optional key argument to identify a unique edge. Otherwise a new edge will be created.

NetworkX algorithms designed for weighted graphs cannot use multigraphs directly because it is not clear how to handle multiedge weights. Convert to Graph using edge attribute ‘weight’ to enable weighted graph algorithms.

Default keys are generated using the method new_edge_key(). This method can be overridden by subclassing the base class and providing a custom new_edge_key() method.

Examples

The following all add the edge e=(1, 2) to graph G:

```python
>>> G = nx.MultiDiGraph()
>>> e = (1, 2)
>>> key = G.add_edge(1, 2)  # explicit two-node form
>>> G.add_edge(*e)  # single edge as tuple of two nodes
```
1
>>> G.add_edges_from( [(1, 2)] ) # add edges from iterable container
[2]

Associate data to edges using keywords:

>>> key = G.add_edge(1, 2, weight=3)
>>> key = G.add_edge(1, 2, key=0, weight=4) # update data for key=0
>>> key = G.add_edge(1, 3, weight=7, capacity=15, length=342.7)

For non-string attribute keys, use subscript notation.

>>> ekey = G.add_edge(1, 2)
>>> G[1][2][0].update({0: 5})
>>> G.edges[1, 2, 0].update({0: 5})

networkx.MultiDiGraph.add_edges_from

MultiDiGraph.add_edges_from(ebunch_to_add, **attr)
Add all the edges in ebunch_to_add.

Parameters

- **ebunch_to_add** (container of edges) – Each edge given in the container will be added to the graph. The edges can be:
  - 2-tuples (u, v) or
  - 3-tuples (u, v, d) for an edge data dict d, or
  - 3-tuples (u, v, k) for not iterable key k, or
  - 4-tuples (u, v, k, d) for an edge with data and key k
- **attr** (keyword arguments, optional) – Edge data (or labels or objects) can be assigned using keyword arguments.

Returns

Return type A list of edge keys assigned to the edges in ebunch.

See also:

**add_edge()** add a single edge

**add_weighted_edges_from()** convenient way to add weighted edges

Notes

Adding the same edge twice has no effect but any edge data will be updated when each duplicate edge is added. Edge attributes specified in an ebunch take precedence over attributes specified via keyword arguments.

Default keys are generated using the method new_edge_key(). This method can be overridden by subclassing the base class and providing a custom new_edge_key() method.
Examples

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_edges_from([(0, 1), (1, 2)])  # using a list of edge tuples
>>> e = zip(range(0, 3), range(1, 4))
>>> G.add_edges_from(e)  # Add the path graph 0-1-2-3

Associate data to edges

```python
>>> G.add_edges_from([(1, 2), (2, 3)], weight=3)
>>> G.add_edges_from([(3, 4), (1, 4)], label='WN2898')
```

**networkx.MultiDiGraph.add_weighted_edges_from**

`MultiDiGraph.add_weighted_edges_from(ebunch_to_add, weight='weight', **attr)`

Add weighted edges in `ebunch_to_add` with specified weight `attr`.

**Parameters**

- `ebunch_to_add` *(container of edges)* – Each edge given in the list or container will be added to the graph. The edges must be given as 3-tuples `(u, v, w)` where `w` is a number.
- `weight` *(string, optional (default='weight'))* – The attribute name for the edge weights to be added.
- `attr` *(keyword arguments, optional (default= no attributes))* – Edge attributes to add/update for all edges.

**See also:**

*add_edge()* add a single edge

*add_edges_from()* add multiple edges

**Notes**

Adding the same edge twice for Graph/DiGraph simply updates the edge data. For MultiGraph/MultiDiGraph, duplicate edges are stored.

**Examples**

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_weighted_edges_from([(0, 1, 3.0), (1, 2, 7.5)])
```

**networkx.MultiDiGraph.new_edge_key**

`MultiDiGraph.new_edge_key(u, v)`

Return an unused key for edges between nodes `u` and `v`.

The nodes `u` and `v` do not need to be already in the graph.
Notes

In the standard MultiGraph class the new key is the number of existing edges between \( u \) and \( v \) (increased if necessary to ensure unused). The first edge will have key 0, then 1, etc. If an edge is removed further new_edge_keys may not be in this order.

Parameters \( u, v \) (nodes)

Returns key

Return type int

\[ \text{networkx.MultiDiGraph.remove_edge} \]

**MultiDiGraph.remove_edge** \((u, v, \text{key}=	ext{None})\)

Remove an edge between \( u \) and \( v \).

Parameters

- \( u, v \) (nodes) – Remove an edge between nodes \( u \) and \( v \).
- \( \text{key} \) (hashable identifier, optional (default=None)) – Used to distinguish multiple edges between a pair of nodes. If None remove a single (arbitrary) edge between \( u \) and \( v \).

Raises \text{NetworkXError} – If there is not an edge between \( u \) and \( v \), or if there is no edge with the specified key.

See also:

\text{remove_edges_from()} remove a collection of edges

Examples

```python
>>> G = nx.MultiDiGraph()
>>> nx.add_path(G, [0, 1, 2, 3])
>>> G.remove_edge(0, 1)
>>> e = (1, 2)
>>> G.remove_edge(*e)  # unpacks e from an edge tuple

For multiple edges

```python
>>> G = nx.MultiDiGraph()
>>> G.add_edges_from([(1, 2), (1, 2), (1, 2)])  # key_list returned
[0, 1, 2]
>>> G.remove_edge(1, 2)  # remove a single (arbitrary) edge

For edges with keys

```python
>>> G = nx.MultiDiGraph()
>>> G.add_edge(1, 2, key='first')
'first'
>>> G.add_edge(1, 2, key='second')
'second'
>>> G.remove_edge(1, 2, key='second')
```
networkx.MultiDiGraph.remove_edges_from

MultiDiGraph.remove_edges_from(ebunch)
Remove all edges specified in ebunch.

Parameters ebunch (list or container of edge tuples) – Each edge given in the list or container will be removed from the graph. The edges can be:

• 2-tuples (u, v) All edges between u and v are removed.
• 3-tuples (u, v, key) The edge identified by key is removed.
• 4-tuples (u, v, key, data) where data is ignored.

See also:

remove_edge() remove a single edge

Notes

Will fail silently if an edge in ebunch is not in the graph.

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> ebunch=[(1, 2), (2, 3)]
>>> G.remove_edges_from(ebunch)
```

Removing multiple copies of edges

```python
>>> G = nx.MultiGraph()
>>> keys = G.add_edges_from([(1, 2), (1, 2), (1, 2)])
>>> G.remove_edges_from([(1, 2), (1, 2)])
>>> list(G.edges())
[(1, 2)]
>>> G.remove_edges_from([(1, 2), (1, 2)])  # silently ignore extra copy
>>> list(G.edges)  # now empty graph
[]
```

networkx.MultiDiGraph.clear

MultiDiGraph.clear()
Remove all nodes and edges from the graph.
This also removes the name, and all graph, node, and edge attributes.

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.clear()
>>> list(G.nodes)
[]
```
Reporting nodes edges and neighbors

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networkx.MultiDiGraph.nodes

`MultiDiGraph.nodes`  
A NodeView of the Graph as G.nodes or G.nodes().

Can be used as G.nodes for data lookup and for set-like operations. Can also be used as G.nodes(data='color', default=None) to return a NodeDataView which reports specific node data but no set operations. It presents a dict-like interface as well with G.nodes.items() iterating over (node, nodedata) 2-tuples and G.nodes[3]['foo'] providing the value of the foo attribute for node 3. In addition, a view G.nodes.data('foo') provides a dict-like interface to the foo attribute of each node. G.nodes.data('foo', default=1) provides a default for nodes that do not have attribute foo.

Parameters

- **data** (string or bool, optional (default=False)) – The node attribute returned in 2-tuple (n, ddict[data]). If True, return entire node attribute dict as (n, ddict). If False, return just the nodes n.
- **default** (value, optional (default=None)) – Value used for nodes that don’t have the requested attribute. Only relevant if data is not True or False.
Allows set-like operations over the nodes as well as node attribute dict lookup and calling to get a NodeDataView. A NodeDataView iterates over \((n, \text{data})\) and has no set operations. A NodeView iterates over \(n\) and includes set operations.

When called, if data is False, an iterator over nodes. Otherwise an iterator of 2-tuples (node, attribute value) where the attribute is specified in \(\text{data}\). If data is True then the attribute becomes the entire data dictionary.

**Return type** NodeView

**Notes**

If your node data is not needed, it is simpler and equivalent to use the expression for \(n\) in \(G\), or \(\text{list}(G)\).

**Examples**

There are two simple ways of getting a list of all nodes in the graph:

```
>>> G = nx.path_graph(3)
>>> list(G.nodes)
[0, 1, 2]
>>> list(G)
[0, 1, 2]
```

To get the node data along with the nodes:

```
>>> G.add_node(1, time='5pm')
>>> G.nodes[0]['foo'] = 'bar'
>>> list(G.nodes(data=True))
[(0, {'foo': 'bar'}), (1, {'time': '5pm'}), (2, {})]
>>> list(G.nodes.data())
[(0, {'foo': 'bar'}), (1, {'time': '5pm'}), (2, {})]
```

```
>>> list(G.nodes(data='foo'))
[(0, 'bar'), (1, None), (2, None)]
>>> list(G.nodes.data('foo'))
[(0, 'bar'), (1, None), (2, None)]
```

```
>>> list(G.nodes(data='time'))
[(0, None), (1, '5pm'), (2, None)]
>>> list(G.nodes.data('time'))
[(0, None), (1, '5pm'), (2, None)]
```

```
>>> list(G.nodes(data='time', default='Not Available'))
[(0, 'Not Available'), (1, '5pm'), (2, 'Not Available')]
>>> list(G.nodes.data('time', default='Not Available'))
[(0, 'Not Available'), (1, '5pm'), (2, 'Not Available')]
```

If some of your nodes have an attribute and the rest are assumed to have a default attribute value you can create a dictionary from node/attribute pairs using the `default` keyword argument to guarantee the value is never None:

```
>>> G = nx.Graph()
>>> G.add_node(0)
```
NetworkX Reference, Release 2.2rc1.dev20180319181321

>>> G.add_node(1, weight=2)
>>> G.add_node(2, weight=3)
>>> dict(G.nodes(data='weight', default=1))
{0: 1, 1: 2, 2: 3}

networkx.MultiDiGraph.__iter__

MultiDiGraph.__iter__() Iterate over the nodes. Use: ‘for n in G’.

Returns niter – An iterator over all nodes in the graph.

Return type iterator

Examples

>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> [n for n in G]
[0, 1, 2, 3]
>>> list(G)
[0, 1, 2, 3]

networkx.MultiDiGraph.has_node

MultiDiGraph.has_node(n) Return True if the graph contains the node n.

Identical to n in G

Parameters n (node)

Examples

>>> G = nx.path_graph(3)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.has_node(0)
True

It is more readable and simpler to use

>>> 0 in G
True

networkx.MultiDiGraph.__contains__

MultiDiGraph.__contains__(n) Return True if n is a node, False otherwise. Use: ‘n in G’.
Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> 1 in G
True
```

`networkx.MultiDiGraph.edges`

`MultiDiGraph.edges`

An OutMultiEdgeView of the Graph as G.edges or G.edges().

def edges(self, nbunch=None, data=False, keys=False, default=None)

The OutMultiEdgeView provides set-like operations on the edge-tuples as well as edge attribute lookup. When called, it also provides an EdgeDataView object which allows control of access to edge attributes (but does not provide set-like operations). Hence, `G.edges[u, v]['color']` provides the value of the color attribute for edge `(u, v)` while `for (u, v, c) in G.edges(data='color', default='red'):` iterates through all the edges yielding the color attribute with default `'red'` if no color attribute exists.

Edges are returned as tuples with optional data and keys in the order (node, neighbor, key, data).

Parameters

- `nbunch` (single node, container, or all nodes (default=all nodes)) – The view will only report edges incident to these nodes.
- `data` (string or bool, optional (default=False)) – The edge attribute returned in 3-tuple (u, v, ddict[data]). If True, return edge attribute dict in 3-tuple (u, v, ddict). If False, return 2-tuple (u, v).
- `keys` (bool, optional (default=False)) – If True, return edge keys with each edge.
- `default` (value, optional (default=None)) – Value used for edges that don’t have the requested attribute. Only relevant if data is not True or False.

Returns edges – A view of edge attributes, usually it iterates over (u, v) (u, v, k) or (u, v, k, d) tuples of edges, but can also be used for attribute lookup as `edges[u, v, k]['foo']`.

Return type EdgeView

Notes

Nodes in `nbunch` that are not in the graph will be (quietly) ignored. For directed graphs this returns the out-edges.

Examples

```python
>>> G = nx.MultiDiGraph()
>>> nx.add_path(G, [0, 1, 2])
>>> key = G.add_edge(2, 3, weight=5)
>>> [e for e in G.edges()]
[(0, 1), (1, 2), (2, 3)]
>>> list(G.edges(data=True))  # default data is {} (empty dict)
[(0, 1, {}), (1, 2, {}), (2, 3, {'weight': 5})]
>>> list(G.edges(data='weight', default=1))
[(0, 1, 1), (1, 2, 1), (2, 3, 5)]
```

(continues on next page)
>>> list(G.edges(keys=True))  # default keys are integers
[(0, 1, 0), (1, 2, 0), (2, 3, 0)]
>>> list(G.edges(data=True, keys=True))
[(0, 1, 0, {}), (1, 2, 0, {}), (2, 3, 0, {'weight': 5})]
>>> list(G.edges(data='weight', default=1, keys=True))
[(0, 1, 1, {}), (1, 2, 0, {}), (2, 3, 0, 5)]
>>> list(G.edges([0, 2]))
[(0, 1), (2, 3)]
>>> list(G.edges(0))
[(0, 1)]
Examples

```python
>>> G = nx.MultiDiGraph()
>>> nx.add_path(G, [0, 1, 2])
>>> key = G.add_edge(2, 3, weight=5)
>>> [e for e in G.edges()]
[(0, 1), (1, 2), (2, 3)]
>>> list(G.edges(data=True)) # default data is {} (empty dict)
[(0, 1, {}), (1, 2, {}), (2, 3, {'weight': 5})]
>>> list(G.edges(data='weight', default=1))
[(0, 1, 1), (1, 2, 1), (2, 3, 5)]
>>> list(G.edges(keys=True)) # default keys are integers
[(0, 1, 0), (1, 2, 0), (2, 3, 0)]
>>> list(G.edges(data=True, keys=True))
[(0, 1, 0, {}), (1, 2, 0, {}), (2, 3, 0, {})]
>>> list(G.edges([0, 2]))
[(0, 1), (2, 3)]
>>> list(G.edges(0))
[(0, 1)]
```

See also:

in_edges, out_edges

`networkx.MultiDiGraph.in_edges`

`MultiDiGraph.in_edges`

An InMultiEdgeView of the Graph as G.in_edges or G.in_edges().

in_edges(self, nbunch=None, data=False, keys=False, default=None)

Parameters

- **nbunch** (single node, container, or all nodes (default= all nodes)) – The view will only report edges incident to these nodes.
- **data** (string or bool, optional (default=False)) – The edge attribute returned in 3-tuple (u, v, ddict[data]). If True, return edge attribute dict in 3-tuple (u, v, ddict). If False, return 2-tuple (u, v).
- **keys** (bool, optional (default=False)) – If True, return edge keys with each edge.
- **default** (value, optional (default=None)) – Value used for edges that don’t have the requested attribute. Only relevant if data is not True or False.

Returns **in_edges** – A view of edge attributes, usually it iterates over (u, v) or (u, v, k) or (u, v, k, d) tuples of edges, but can also be used for attribute lookup as edges[u, v, k]['foo'].

Return type InMultiEdgeView

See also:

edges

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networkx.MultiDiGraph.has_edge

**MultiDiGraph**. **has_edge** *(u, v, key=None)*

Return True if the graph has an edge between nodes u and v.

This is the same as `v in G[u]` or `key in G[u][v]` without KeyError exceptions.

**Parameters**

- **u, v (nodes)** – Nodes can be, for example, strings or numbers.
- **key** *(hashable identifier, optional (default=None))* – If specified return True only if the edge with key is found.

**Returns**

- **edge_ind** – True if edge is in the graph, False otherwise.
- **Return type** `bool`

**Examples**

Can be called either using two nodes `u, v`, an edge tuple `(u, v)`, or an edge tuple `(u, v, key)`.

```python
>>> G = nx.MultiGraph()  # or MultiDiGraph
>>> nx.add_path(G, [0, 1, 2, 3])
>>> G.has_edge(0, 1)  # using two nodes
True
>>> e = (0, 1)
>>> G.has_edge(*e)  # e is a 2-tuple (u, v)
True
>>> G.add_edge(0, 1, key='a')
'a'
>>> G.has_edge(0, 1, key='a')  # specify key
True
>>> e=(0, 1, 'a')
>>> G.has_edge(*e)  # e is a 3-tuple (u, v, 'a')
True
```

The following syntax are equivalent:

```python
>>> G.has_edge(0, 1)
True
>>> 1 in G[0]  # though this gives :exc:`KeyError` if 0 not in G
True
```

networkx.MultiDiGraph.get_edge_data

**MultiDiGraph**. **get_edge_data** *(u, v, key=None, default=None)*

Return the attribute dictionary associated with edge `(u, v)`.

This is identical to `G[u][v][key]` except the default is returned instead of an exception is the edge doesn’t exist.

**Parameters**

- **u, v (nodes)**
- **default** *(any Python object (default=None))* – Value to return if the edge `(u, v)` is not found.
• **key** *(hashable identifier, optional (default=None)) – Return data only for the edge with specified key.*

**Returns** edge_dict – The edge attribute dictionary.

**Return type** dictionary

**Examples**

```python
>>> G = nx.MultiGraph()  # or MultiDiGraph
>>> key = G.add_edge(0, 1, key='a', weight=7)
>>> G[0][1]["a"]  # key='a'
{"weight": 7}
>>> G.edges[0, 1, 'a']  # key='a'
{"weight": 7}
```

Warning: we protect the graph data structure by making `G.edges` and `G[1][2]` read-only dict-like structures. However, you can assign values to attributes in e.g. `G.edges[1, 2, 'a']` or `G[1][2]["a"]` using an additional bracket as shown next. You need to specify all edge info to assign to the edge data associated with an edge.

```python
>>> G[0][1]["a"]['weight'] = 10
>>> G.edges[0, 1, 'a']['weight'] = 10
>>> G[0][1]["a"]['weight']
10
>>> G.edges[1, 0, 'a']['weight']
10
```

```python
>>> G = nx.MultiGraph()  # or MultiDiGraph
>>> nx.add_path(G, [0, 1, 2, 3])
>>> G.get_edge_data(0, 1)
{0: {}}
>>> e = (0, 1)
>>> G.get_edge_data(*e)  # tuple form
{0: {}}
>>> G.get_edge_data('a', 'b', default=0)  # edge not in graph, return 0
0
```

**networkx.MultiDiGraph.neighbors**

**MultiDiGraph.neighbors(n)**

Return an iterator over successor nodes of n.

neighbors() and successors() are the same.

**networkx.MultiDiGraph.adj**

**MultiDiGraph.adj**

Graph adjacency object holding the neighbors of each node.

This object is a read-only dict-like structure with node keys and neighbor-dict values. The neighbor-dict is keyed by neighbor to the edgekey-dict. So `G.adj[3][2][0]['color'] = 'blue'` sets the color of the edge `(3, 2, 0)` to "blue".
Iterating over G.adj behaves like a dict. Useful idioms include for nbr, datadict in G.adj[n]. items().

The neighbor information is also provided by subscripting the graph. So for nbr, foovalue in G[node].data('foo', default=1): works.

For directed graphs, G.adj holds outgoing (successor) info.

```
>>> networkx.MultiDiGraph.__getitem__(n)
Parameters n (node) – A node in the graph.
Returns adj_dict – The adjacency dictionary for nodes connected to n.
Return type dictionary

Notes

G[n] is the same as G.adj[n] and similar to G.neighbors(n) (which is an iterator over G.adj[n])

Examples

>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G[0]
AtlasView({1: {}})
```

```
>>> networkx.MultiDiGraph.successors
MultiDiGraph.successors(n)
Return an iterator over successor nodes of n.
neighbors() and successors() are the same.
```

```
>>> networkx.MultiDiGraph.succ
MultiDiGraph.succ
Graph adjacency object holding the successors of each node.

This object is a read-only dict-like structure with node keys and neighbor-dict values. The neighbor-dict is keyed by neighbor to the edgekey-dict. So G.adj[3][2][0]['color'] = 'blue' sets the color of the edge (3, 2, 0) to "blue".

Iterating over G.adj behaves like a dict. Useful idioms include for nbr, datadict in G.adj[n]. items():

The neighbor information is also provided by subscripting the graph. So for nbr, foovalue in G[node].data('foo', default=1): works.

For directed graphs, G.succ is identical to G.adj.
```
networkx.MultiDiGraph.predecessors

**MultiDiGraph**. **predecessors** *(n)*

Return an iterator over predecessor nodes of *n*.

networkx.MultiDiGraph.adjacency

**MultiDiGraph**. **adjacency** *( )* 

Return an iterator over (node, adjacency dict) tuples for all nodes.

For directed graphs, only outgoing neighbors/adjacencies are included.

**Returns** adj_iter – An iterator over (node, adjacency dictionary) for all nodes in the graph.

**Return type** iterator

**Examples**

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> [(n, nbrdict) for n, nbrdict in G.adjacency()]
[(0, {1: {}}), (1, {0: {}, 2: {}}), (2, {1: {}, 3: {}}), (3, {2: {}})]
```

networkx.MultiDiGraph.nbunch_iter

**MultiDiGraph**. **nbunch_iter** *(nbunch=None)*

Return an iterator over nodes contained in *nbunch* that are also in the graph.

The nodes in *nbunch* are checked for membership in the graph and if not are silently ignored.

**Parameters**

*nbunch* *(single node, container, or all nodes (default= all nodes)) –* The view will only report edges incident to these nodes.

**Returns** niter – An iterator over nodes in *nbunch* that are also in the graph. If *nbunch* is None, iterate over all nodes in the graph.

**Return type** iterator

**Raises** NetworkXError – If *nbunch* is not a node or or sequence of nodes. If a node in *nbunch* is not hashable.

**See also:**

Graph. **__iter__**( )

**Notes**

When *nbunch* is an iterator, the returned iterator yields values directly from *nbunch*, becoming exhausted when *nbunch* is exhausted.

To test whether *nbunch* is a single node, one can use “if *nbunch* in self:”, even after processing with this routine. If *nbunch* is not a node or a (possibly empty) sequence/iterator or None, a NetworkXError is raised. Also, if any object in *nbunch* is not hashable, a NetworkXError is raised.
Counting nodes edges and neighbors

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<td>Return the number of nodes in the graph.</td>
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<tr>
<td><code>MultiDiGraph.number_of_nodes()</code></td>
<td>Return the number of nodes in the graph.</td>
</tr>
<tr>
<td><code>MultiDiGraph.__len__()</code></td>
<td>Return the number of nodes.</td>
</tr>
<tr>
<td><code>MultiDiGraph.degree</code></td>
<td>A DegreeView for the Graph as G.</td>
</tr>
<tr>
<td><code>MultiDiGraph.in_degree()</code></td>
<td>A DegreeView for (node, in_degree) or in_degree for single node.</td>
</tr>
<tr>
<td><code>MultiDiGraph.out_degree()</code></td>
<td>Return an iterator for (node, out-degree) or out-degree for single node.</td>
</tr>
<tr>
<td><code>MultiDiGraph.size([weight])</code></td>
<td>Return the number of edges or total of all edge weights.</td>
</tr>
<tr>
<td><code>MultiDiGraph.number_of_edges([u, v])</code></td>
<td>Return the number of edges between two nodes.</td>
</tr>
</tbody>
</table>

**networkx.MultiDiGraph.order**

`MultiDiGraph.order()`  
Return the number of nodes in the graph.  

**Returns**  
`nnodes` – The number of nodes in the graph.  

**Return type**  
`int`  

**See also:**  
`number_of_nodes()`, `__len__()`

**networkx.MultiDiGraph.number_of_nodes**

`MultiDiGraph.number_of_nodes()`  
Return the number of nodes in the graph.  

**Returns**  
`nnodes` – The number of nodes in the graph.  

**Return type**  
`int`  

**See also:**  
`order()`, `__len__()`

**Examples**

```python  
>>> G = nx.path_graph(3)  # or DiGraph, MultiGraph, MultiDiGraph, etc  
>>> len(G)  
3  
```

**networkx.MultiDiGraph.__len__**

`MultiDiGraph.__len__()`  
Return the number of nodes. Use: ‘len(G)’.  

**Returns**  
`nnodes` – The number of nodes in the graph.  

**Return type**  
`int`
Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> len(G)
4
```

networkx.MultiDiGraph.degree

A DegreeView for the Graph as G.degree or G.degree().

The node degree is the number of edges adjacent to the node. The weighted node degree is the sum of the edge weights for edges incident to that node.

This object provides an iterator for (node, degree) as well as lookup for the degree for a single node.

**Parameters**

- `nbunch` (single node, container, or all nodes (default=all nodes)) – The view will only report edges incident to these nodes.
- `weight` (string or None, optional (default=None)) – The name of an edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1. The degree is the sum of the edge weights adjacent to the node.

**Returns**

- If a single nodes is requested
  - `deg` (int) – Degree of the node
- OR if multiple nodes are requested
  - `nd_iter` (iterator) – The iterator returns two-tuples of (node, degree).

**See also:**

`out_degree`, `in_degree`

Examples

```python
>>> G = nx.MultiDiGraph()
>>> nx.add_path(G, [0, 1, 2, 3])
>>> G.degree(0) # node 0 with degree 1
1
>>> list(G.degree([0, 1, 2]))
[(0, 1), (1, 2), (2, 2)]
```

networkx.MultiDiGraph.in_degree

A DegreeView for (node, in_degree) or in_degree for single node.

The node in-degree is the number of edges pointing in to the node. The weighted node degree is the sum of the edge weights for edges incident to that node.

This object provides an iterator for (node, degree) as well as lookup for the degree for a single node.
Parameters

- **nbunch** *(single node, container, or all nodes (default=all nodes)) – The view will only report edges incident to these nodes.*

- **weight** *(string or None, optional (default=None)) – The edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1. The degree is the sum of the edge weights adjacent to the node.*

Returns

- **If a single node is requested**

- **deg** *(int) – Degree of the node*

- **OR if multiple nodes are requested**

- **nd_iter** *(iterator) – The iterator returns two-tuples of (node, in-degree).*

See also:

*degree, out_degree*

Examples

```python
>>> G = nx.MultiDiGraph()
>>> nx.add_path(G, [0, 1, 2, 3])
>>> G.in_degree(0)  # node 0 with degree 0
0
>>> list(G.in_degree([0, 1, 2]))
[(0, 0), (1, 1), (2, 1)]
```

networkx.MultiDiGraph.out_degree

`MultiDiGraph.out_degree`

Return an iterator for (node, out-degree) or out-degree for single node.

```python
out_degree(self, nbunch=None, weight=None)
```

The node out-degree is the number of edges pointing out of the node. This function returns the out-degree for a single node or an iterator for a bunch of nodes or if nothing is passed as argument.

Parameters

- **nbunch** *(single node, container, or all nodes (default=all nodes)) – The view will only report edges incident to these nodes.*

- **weight** *(string or None, optional (default=None)) – The edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1. The degree is the sum of the edge weights.*

Returns

- **If a single node is requested**

- **deg** *(int) – Degree of the node*

- **OR if multiple nodes are requested**

- **nd_iter** *(iterator) – The iterator returns two-tuples of (node, out-degree).*
See also:

degree, in_degree

Examples

```python
>>> G = nx.MultiDiGraph()
>>> nx.add_path(G, [0, 1, 2, 3])
>>> G.out_degree(0) # node 0 with degree 1
1
>>> list(G.out_degree([0, 1, 2]))
[(0, 1), (1, 1), (2, 1)]
```

**networkx.MultiDiGraph.size**

MultiDiGraph.size(weight=None)

Return the number of edges or total of all edge weights.

**Parameters**
weight (string or None, optional (default=None)) – The edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1.

**Returns**

size – The number of edges or (if weight keyword is provided) the total weight sum.

If weight is None, returns an int. Otherwise a float (or more general numeric if the weights are more general).

**Return type** numeric

See also:

degree, in_degree

Examples

```python
>>> G = nx.path_graph(4) # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.size()
3

>>> G = nx.Graph() # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_edge('a', 'b', weight=2)
>>> G.add_edge('b', 'c', weight=4)
>>> G.size()
2
>>> G.size(weight='weight')
6.0
```

**networkx.MultiDiGraph.number_of_edges**

MultiDiGraph.number_of_edges(u=None, v=None)

Return the number of edges between two nodes.
Parameters u, v (nodes, optional (Gefault=all edges)) – If u and v are specified, return the number of edges between u and v. Otherwise return the total number of all edges.

Returns nedges – The number of edges in the graph. If nodes u and v are specified return the number of edges between those nodes. If the graph is directed, this only returns the number of edges from u to v.

Return type int

See also:
size()

Examples

For undirected multigraphs, this method counts the total number of edges in the graph:

```python
>>> G = nx.MultiGraph()
>>> G.add_edges_from([(0, 1), (0, 1), (1, 2)])
[0, 1, 0]
>>> G.number_of_edges()
3
```

If you specify two nodes, this counts the total number of edges joining the two nodes:

```python
>>> G.number_of_edges(0, 1)
2
```

For directed multigraphs, this method can count the total number of directed edges from u to v:

```python
>>> G = nx.MultiDiGraph()
>>> G.add_edges_from([(0, 1), (0, 1), (1, 0)])
[0, 1, 0]
>>> G.number_of_edges(0, 1)
2
>>> G.number_of_edges(1, 0)
1
```

Making copies and subgraphs

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<td>as_view])</td>
<td></td>
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<tr>
<td>MultiDiGraph.to_directed([as_view])</td>
<td>Return a directed representation of the graph.</td>
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<td>MultiDiGraph.subgraph(nodes)</td>
<td>Return a SubGraph view of the subgraph induced on nodes in nodes.</td>
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<td>Returns the subgraph induced by the specified edges.</td>
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<td>Return the reverse of the graph.</td>
</tr>
<tr>
<td>MultiDiGraph.fresh_copy()</td>
<td>Return a fresh copy graph with the same data structure.</td>
</tr>
</tbody>
</table>
networkx.MultiDiGraph.copy

MultiDiGraph.copy(as_view=False)

Return a copy of the graph.

The copy method by default returns a shallow copy of the graph and attributes. That is, if an attribute is a container, that container is shared by the original an the copy. Use Python’s copy.deepcopy for new containers.

If as_view is True then a view is returned instead of a copy.

Notes

All copies reproduce the graph structure, but data attributes may be handled in different ways. There are four types of copies of a graph that people might want.

Deepcopy – The default behavior is a “deepcopy” where the graph structure as well as all data attributes and any objects they might contain are copied. The entire graph object is new so that changes in the copy do not affect the original object. (see Python’s copy.deepcopy)

Data Reference (Shallow) – For a shallow copy the graph structure is copied but the edge, node and graph attribute dicts are references to those in the original graph. This saves time and memory but could cause confusion if you change an attribute in one graph and it changes the attribute in the other. NetworkX does not provide this level of shallow copy.

Independent Shallow – This copy creates new independent attribute dicts and then does a shallow copy of the attributes. That is, any attributes that are containers are shared between the new graph and the original. This is exactly what dict.copy() provides. You can obtain this style copy using:

```python
>>> G = nx.path_graph(5)
>>> H = G.copy()
>>> H = G.copy(as_view=False)
>>> H = nx.Graph(G)
>>> H = G.fresh_copy().__class__(G)
```

Fresh Data – For fresh data, the graph structure is copied while new empty data attribute dicts are created. The resulting graph is independent of the original and it has no edge, node or graph attributes. Fresh copies are not enabled. Instead use:

```python
>>> H = G.fresh_copy()
>>> H.add_nodes_from(G)
>>> H.add_edges_from(G.edges)
```

View – Inspired by dict-views, graph-views act like read-only versions of the original graph, providing a copy of the original structure without requiring any memory for copying the information.

See the Python copy module for more information on shallow and deep copies, https://docs.python.org/2/library/copy.html.

Parameters

- **as_view** (bool, optional (default=False)) – If True, the returned graph-view provides a read-only view of the original graph without actually copying any data.

Returns

- **G** – A copy of the graph.

Return type

- **Graph**

See also:

- **to_directed()** return a directed copy of the graph.
Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> H = G.copy()
```

networkx.MultiDiGraph.to_undirected

**networkx.MultiDiGraph.to_undirected**(reciprocal=False, as_view=False)

Return an undirected representation of the digraph.

**Parameters**

- **reciprocal** (bool (optional)) – If True only keep edges that appear in both directions in the original digraph.
- **as_view** (bool (optional, default=False)) – If True return an undirected view of the original directed graph.

**Returns**

- **G** – An undirected graph with the same name and nodes and with edge (u, v, data) if either (u, v, data) or (v, u, data) is in the digraph. If both edges exist in digraph and their edge data is different, only one edge is created with an arbitrary choice of which edge data to use. You must check and correct for this manually if desired.

**Return type**

`MultiGraph`

**See also:**

`MultiGraph()`, `copy()`, `add_edge()`, `add_edges_from()`

**Notes**

This returns a “deepcopy” of the edge, node, and graph attributes which attempts to completely copy all of the data and references.

This is in contrast to the similar `D=MultiGraph(G)` which returns a shallow copy of the data.

See the Python copy module for more information on shallow and deep copies, [https://docs.python.org/2/library/copy.html](https://docs.python.org/2/library/copy.html).

Warning: If you have subclassed MultiDiGraph to use dict-like objects in the data structure, those changes do not transfer to the MultiGraph created by this method.

**Examples**

```python
>>> G = nx.path_graph(2)  # or MultiGraph, etc
>>> H = G.to_directed()
>>> list(H.edges)
[(0, 1), (1, 0)]
```

```python
>>> G2 = H.to_undirected()
>>> list(G2.edges)
[(0, 1)]
```
networkx.MultiDiGraph.to_directed

MultiDiGraph.to_directed(as_view=False)
Return a directed representation of the graph.

Returns G – A directed graph with the same name, same nodes, and with each edge (u, v, data)
replaced by two directed edges (u, v, data) and (v, u, data).

Return type MultiDiGraph

Notes

This returns a “deepcopy” of the edge, node, and graph attributes which attempts to completely copy all of the
data and references.

This is in contrast to the similar D=DiGraph(G) which returns a shallow copy of the data.

See the Python copy module for more information on shallow and deep copies, https://docs.python.org/2/library/
copy.html.

Warning: If you have subclassed MultiGraph to use dict-like objects in the data structure, those changes do not
transfer to the MultiDiGraph created by this method.

Examples

```python
>>> G = nx.Graph()  # or MultiGraph, etc
>>> G.add_edge(0, 1)
>>> H = G.to_directed()
>>> list(H.edges)
[(0, 1), (1, 0)]
```

If already directed, return a (deep) copy

```python
>>> G = nx.DiGraph()  # or MultiDiGraph, etc
>>> G.add_edge(0, 1)
>>> H = G.to_directed()
>>> list(H.edges)
[(0, 1)]
```

networkx.MultiDiGraph.subgraph

MultiDiGraph.subgraph(nodes)
Return a SubGraph view of the subgraph induced on nodes in nodes.

The induced subgraph of the graph contains the nodes in nodes and the edges between those nodes.

Parameters nodes (list, iterable) – A container of nodes which will be iterated through once.

Returns G – A subgraph view of the graph. The graph structure cannot be changed but node/edge
attributes can and are shared with the original graph.

Return type SubGraph View
Notes

The graph, edge and node attributes are shared with the original graph. Changes to the graph structure is ruled out by the view, but changes to attributes are reflected in the original graph.

To create a subgraph with its own copy of the edge/node attributes use: G.subgraph(nodes).copy()

For an inplace reduction of a graph to a subgraph you can remove nodes: G.remove_nodes_from([n for n in G if n not in set(nodes)])

Examples

```python
>>> G = nx.path_graph(4)  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> H = G.subgraph([0, 1, 2])
>>> list(H.edges)
[(0, 1), (1, 2)]
```

networkx.MultiDiGraph.edge_subgraph

MultiDiGraph.edge_subgraph(edges)

Returns the subgraph induced by the specified edges.

The induced subgraph contains each edge in edges and each node incident to any one of those edges.

Parameters

edges (iterable) – An iterable of edges in this graph.

Returns

G – An edge-induced subgraph of this graph with the same edge attributes.

Return type

Graph

Notes

The graph, edge, and node attributes in the returned subgraph view are references to the corresponding attributes in the original graph. The view is read-only.

To create a full graph version of the subgraph with its own copy of the edge or node attributes, use:

```python
>>> G.edge_subgraph(edges).copy()
```

Examples

```python
>>> G = nx.path_graph(5)
>>> H = G.edge_subgraph([(0, 1), (3, 4)])
>>> list(H.nodes)
[0, 1, 3, 4]
>>> list(H.edges)
[(0, 1), (3, 4)]
```
networkx.MultiDiGraph.reverse

MultiDiGraph.reverse(copy=True)
Return the reverse of the graph.

The reverse is a graph with the same nodes and edges but with the directions of the edges reversed.

Parameters copy (bool optional (default=True)) – If True, return a new DiGraph holding the reversed edges. If False, the reverse graph is created using a view of the original graph.

networkx.MultiDiGraph.fresh_copy

MultiDiGraph.fresh_copy()
Return a fresh copy graph with the same data structure.

A fresh copy has no nodes, edges or graph attributes. It is the same data structure as the current graph. This method is typically used to create an empty version of the graph.

Notes

If you subclass the base class you should overwrite this method to return your class of graph.

### 2.2.5 Ordered Graphs—Consistently ordered graphs

Consistently ordered variants of the default base classes.

The Ordered (Di/Multi/MultiDi) Graphs give a consistent order for reporting of nodes and edges. The order of node reporting agrees with node adding, but for edges, the order is not necessarily the order that the edges were added.

In general, you should use the default (i.e., unordered) graph classes. However, there are times (e.g., when testing) when you may need the order preserved.

class OrderedGraph(incoming_graph_data=None, **attr)
Consistently ordered variant of Graph.

class OrderedDiGraph(incoming_graph_data=None, **attr)
Consistently ordered variant of DiGraph.

class OrderedMultiGraph(incoming_graph_data=None, **attr)
Consistently ordered variant of MultiGraph.

class OrderedMultiDiGraph(incoming_graph_data=None, **attr)
Consistently ordered variant of MultiDiGraph.

Note: NetworkX uses dicts to store the nodes and neighbors in a graph. So the reporting of nodes and edges for the base graph classes will not necessarily be consistent across versions and platforms. If you need the order of nodes and edges to be consistent (e.g., when writing automated tests), please see OrderedGraph, OrderedDiGraph, OrderedMultiGraph, or OrderedMultiDiGraph, which behave like the base graph classes but give a consistent order for reporting of nodes and edges.
3.1 Approximations and Heuristics

Approximations of graph properties and Heuristic functions for optimization problems.

**Warning:** The approximation submodule is not imported in the top-level `networkx`.

These functions can be imported with `from networkx.algorithms import approximation`.

### 3.1.1 Connectivity

Fast approximation for node connectivity

```python
all_pairs_node_connectivity(G[, nbunch, cutoff])
```
Compute node connectivity between all pairs of nodes.

```python
local_node_connectivity(G, source, target[, . . .])
```
Compute node connectivity between source and target.

```python
node_connectivity(G[, s, t])
```
Returns an approximation for node connectivity for a graph or digraph G.

**networkx.algorithms.approximation.connectivity.all_pairs_node_connectivity**

The algorithm is a fast approximation that gives an strict lower bound on the actual number of node independent paths between two nodes. It works for both directed and undirected graphs.

**Parameters**

- **G** *(NetworkX graph)*

---

• **nbunch** (*container*) – Container of nodes. If provided node connectivity will be computed only over pairs of nodes in nbunch.

• **cutoff** (*integer*) – Maximum node connectivity to consider. If None, the minimum degree of source or target is used as a cutoff in each pair of nodes. Default value None.

**Returns** K – Dictionary, keyed by source and target, of pairwise node connectivity

**Return type** dictionary

**See also:**

`local_node_connectivity()`, `all_pairs_node_connectivity()`

**References**

`networkx.algorithms.approximation.connectivity.local_node_connectivity`

`local_node_connectivity(G, source, target, cutoff=None)`

Compute node connectivity between source and target.

Pairwise or local node connectivity between two distinct and nonadjacent nodes is the minimum number of nodes that must be removed (minimum separating cutset) to disconnect them. By Menger’s theorem, this is equal to the number of node independent paths (paths that share no nodes other than source and target). Which is what we compute in this function.

This algorithm is a fast approximation that gives an strict lower bound on the actual number of node independent paths between two nodes\(^1\). It works for both directed and undirected graphs.

**Parameters**

• **G** (*NetworkX graph*)

• **source** (*node*) – Starting node for node connectivity

• **target** (*node*) – Ending node for node connectivity

• **cutoff** (*integer*) – Maximum node connectivity to consider. If None, the minimum degree of source or target is used as a cutoff. Default value None.

**Returns** k – pairwise node connectivity

**Return type** integer

**Examples**

```python
>>> # Platonic octahedral graph has node connectivity 4
>>> # for each non adjacent node pair
>>> from networkx.algorithms import approximation as approx
>>> G = nx.octahedral_graph()
>>> approx.local_node_connectivity(G, 0, 5)
4
```

http://eclectic.ss.uci.edu/~drwhite/working.pdf
Notes

This algorithm\(^1\) finds node independents paths between two nodes by computing their shortest path using BFS, marking the nodes of the path found as ‘used’ and then searching other shortest paths excluding the nodes marked as used until no more paths exist. It is not exact because a shortest path could use nodes that, if the path were longer, may belong to two different node independent paths. Thus it only guarantees an strict lower bound on node connectivity.

Note that the authors propose a further refinement, losing accuracy and gaining speed, which is not implemented yet.

See also:

all_pairs_node_connectivity(), node_connectivity()

References

networkx.algorithms.approximation.connectivity.node_connectivity

node_connectivity \((G, s=None, t=None)\)

Returns an approximation for node connectivity for a graph or digraph \(G\).

Node connectivity is equal to the minimum number of nodes that must be removed to disconnect \(G\) or render it trivial. By Menger’s theorem, this is equal to the number of node independent paths (paths that share no nodes other than source and target).

If source and target nodes are provided, this function returns the local node connectivity: the minimum number of nodes that must be removed to break all paths from source to target in \(G\).

This algorithm is based on a fast approximation that gives an strict lower bound on the actual number of node independent paths between two nodes\(^1\). It works for both directed and undirected graphs.

Parameters

- \(G\) (NetworkX graph) – Undirected graph
- \(s\) (node) – Source node. Optional. Default value: None.
- \(t\) (node) – Target node. Optional. Default value: None.

Returns \(K\) – Node connectivity of \(G\), or local node connectivity if source and target are provided.

Return type integer

Examples

```python
>>> # Platonic octahedral graph is 4-node-connected
>>> from networkx.algorithms import approximation as approx
>>> G = nx.octahedral_graph()
>>> approx.node_connectivity(G)
4
```

http://eclectic.ss.uci.edu/~drwhite/working.pdf
Notes

This algorithm\(^1\) finds node independents paths between two nodes by computing their shortest path using BFS, marking the nodes of the path found as ‘used’ and then searching other shortest paths excluding the nodes marked as used until no more paths exist. It is not exact because a shortest path could use nodes that, if the path were longer, may belong to two different node independent paths. Thus it only guarantees an strict lower bound on node connectivity.

See also:

\[\text{all_pairs_node_connectivity()}, \text{local_node_connectivity()}\]

References

3.1.2 K-components

Fast approximation for k-component structure

\[
k\_components(G[, \text{min}\_\text{density}]) \quad \text{Returns the approximate k-component structure of a graph } G.
\]

\[
\text{networkx.algorithms.approximation.kcomponents.k\_components}
\]

\[
k\_components (G, \text{min}\_\text{density}=0.95)
\]

Returns the approximate k-component structure of a graph G.

A k-component is a maximal subgraph of a graph G that has, at least, node connectivity k: we need to remove at least k nodes to break it into more components. k-components have an inherent hierarchical structure because they are nested in terms of connectivity: a connected graph can contain several 2-components, each of which can contain one or more 3-components, and so forth.

This implementation is based on the fast heuristics to approximate the k-component structure of a graph\(^1\). Which, in turn, it is based on a fast approximation algorithm for finding good lower bounds of the number of node independent paths between two nodes\(^2\).

Parameters

- G (NetworkX graph) – Undirected graph
- min_density (Float) – Density relaxation threshold. Default value 0.95

Returns k_components – Dictionary with connectivity level k as key and a list of sets of nodes that form a k-component of level k as values.

Return type dict

Examples

```python
>>> # Petersen graph has 10 nodes and it is triconnected, thus all
>>> # nodes are in a single component on all three connectivity levels
>>> from networkx.algorithms import approximation as apxa
```

---


http://eclectic.ss.uci.edu/~drwhite/working.pdf
Notes

The logic of the approximation algorithm for computing the $k$-component structure is based on repeatedly applying simple and fast algorithms for $k$-cores and biconnected components in order to narrow down the number of pairs of nodes over which we have to compute White and Newman’s approximation algorithm for finding node independent paths. More formally, this algorithm is based on Whitney’s theorem, which states an inclusion relation among node connectivity, edge connectivity, and minimum degree for any graph $G$. This theorem implies that every $k$-component is nested inside a $k$-edge-component, which in turn, is contained in a $k$-core. Thus, this algorithm computes node independent paths among pairs of nodes in each biconnected part of each $k$-core, and repeats this procedure for each $k$ from 3 to the maximal core number of a node in the input graph.

Because, in practice, many nodes of the core of level $k$ inside a bicomponent actually are part of a component of level $k$, the auxiliary graph needed for the algorithm is likely to be very dense. Thus, we use a complement graph data structure (see AntiGraph) to save memory. AntiGraph only stores information of the edges that are not present in the actual auxiliary graph. When applying algorithms to this complement graph data structure, it behaves as if it were the dense version.

See also:

$k$-components()

References

3.1.3 Clique

Functions for computing large cliques.

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<td>Find the size of a large clique in a graph.</td>
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networkx.algorithms.approximation.clique.max_clique

max_clique(G)

Find the Maximum Clique

Finds the $O(|V|/(log|V|)^2)$ apx of maximum clique/independent set in the worst case.

Parameters

G (NetworkX graph) – Undirected graph

Returns

clique – The apx-maximum clique of the graph

Return type

set
Notes

A clique in an undirected graph $G = (V, E)$ is a subset of the vertex set $C \subseteq V$ such that for every two vertices in $C$ there exists an edge connecting the two. This is equivalent to saying that the subgraph induced by $C$ is complete (in some cases, the term clique may also refer to the subgraph).

A maximum clique is a clique of the largest possible size in a given graph. The clique number $\omega(G)$ of a graph $G$ is the number of vertices in a maximum clique in $G$. The intersection number of $G$ is the smallest number of cliques that together cover all edges of $G$.

https://en.wikipedia.org/wiki/Maximum_clique

References

networkx.algorithms.approximation.clique.clique_removal

clique_removal($G$)
Repeatedly remove cliques from the graph.

Results in a $O(|V|/\log |V|)^2$ approximation of maximum clique and independent set. Returns the largest independent set found, along with found maximal cliques.

Parameters $G$ (NetworkX graph) – Undirected graph

Returns max_ind_cliques – 2-tuple of Maximal Independent Set and list of maximal cliques (sets).

Return type (set, list) tuple

References

networkx.algorithms.approximation.clique.large_clique_size

large_clique_size($G$)
Find the size of a large clique in a graph.

A clique is a subset of nodes in which each pair of nodes is adjacent. This function is a heuristic for finding the size of a large clique in the graph.

Parameters $G$ (NetworkX graph)

Returns The size of a large clique in the graph.

Return type int

Notes

This implementation is from\(^1\). Its worst case time complexity is $O(nd^2)$, where $n$ is the number of nodes in the graph and $d$ is the maximum degree.

This function is a heuristic, which means it may work well in practice, but there is no rigorous mathematical guarantee on the ratio between the returned number and the actual largest clique size in the graph.

References

See also:

- `networkx.algorithms.approximation.clique.max_clique()` A function that returns an approximate maximum clique with a guarantee on the approximation ratio.
- `networkx.algorithms.clique` Functions for finding the exact maximum clique in a graph.

3.1.4 Clustering

`networkx.algorithms.approximation.clustering_coefficient.average_clustering`

`average_clustering(G[, trials])` Estimates the average clustering coefficient of G.

The local clustering of each node in G is the fraction of triangles that actually exist over all possible triangles in its neighborhood. The average clustering coefficient of a graph G is the mean of local clusterings.

This function finds an approximate average clustering coefficient for G by repeating n times (defined in trials) the following experiment: choose a node at random, choose two of its neighbors at random, and check if they are connected. The approximate coefficient is the fraction of triangles found over the number of trials.

Parameters

- G (NetworkX graph)
- trials (integer) – Number of trials to perform (default 1000).

Returns c – Approximated average clustering coefficient.

Return type float

References

3.1.5 Dominating Set

Functions for finding node and edge dominating sets.

A dominating set for an undirected graph G with vertex set V and edge set E is a subset D of V such that every vertex not in D is adjacent to at least one member of D. An edge dominating set is a subset F of E such that every edge not in F is incident to an endpoint of at least one edge in F.

`networkx.algorithms.approximation.dominating_set.min_weighted_dominating_set(G[, weight])` Returns a dominating set that approximates the minimum weight node dominating set.

`networkx.algorithms.approximation.dominating_set.min_edge_dominating_set(G)` Return minimum cardinality edge dominating set.

References


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networkx.algorithms.approximation.dominating_set.min_weighted_dominating_set

min_weighted_dominating_set(G, weight=None)

Returns a dominating set that approximates the minimum weight node dominating set.

Parameters

- G (NetworkX graph) – Undirected graph.
- weight (string) – The node attribute storing the weight of an edge. If provided, the node attribute with this key must be a number for each node. If not provided, each node is assumed to have weight one.

Returns

min_weight_dominating_set – A set of nodes, the sum of whose weights is no more than \((\log w(V)) w(V^*)\), where \(w(V)\) denotes the sum of the weights of each node in the graph and \(w(V^*)\) denotes the sum of the weights of each node in the minimum weight dominating set.

Return type

set

Notes

This algorithm computes an approximate minimum weighted dominating set for the graph \(G\). The returned solution has weight \((\log w(V)) w(V^*)\), where \(w(V)\) denotes the sum of the weights of each node in the graph and \(w(V^*)\) denotes the sum of the weights of each node in the minimum weight dominating set for the graph.

This implementation of the algorithm runs in \(O(m)\) time, where \(m\) is the number of edges in the graph.

References

networkx.algorithms.approximation.dominating_set.min_edge_dominating_set

min_edge_dominating_set(G)

Return minimum cardinality edge dominating set.

Parameters

- G (NetworkX graph) – Undirected graph

Returns

min_edge_dominating_set – Returns a set of dominating edges whose size is no more than 2 * OPT.

Return type

set

Notes

The algorithm computes an approximate solution to the edge dominating set problem. The result is no more than 2 * OPT in terms of size of the set. Runtime of the algorithm is \(O(|E|)\).

3.1.6 Independent Set

Independent Set

Independent set or stable set is a set of vertices in a graph, no two of which are adjacent. That is, it is a set \(I\) of vertices such that for every two vertices in \(I\), there is no edge connecting the two. Equivalently, each edge in the graph has at most one endpoint in \(I\). The size of an independent set is the number of vertices it contains.
A maximum independent set is a largest independent set for a given graph \( G \) and its size is denoted \( \alpha(G) \). The problem of finding such a set is called the maximum independent set problem and is an NP-hard optimization problem. As such, it is unlikely that there exists an efficient algorithm for finding a maximum independent set of a graph.

Wikipedia: Independent set

Independent set algorithm is based on the following paper:

\[ O(|V|/(\log |V|)^2) \] apx of maximum clique/independent set.


**maximum_independent_set**

maximum_independent_set \((G)\) Return an approximate maximum independent set.

- **Parameters** \( G \) (NetworkX graph) – Undirected graph
- **Returns** iset – The apx-maximum independent set
- **Return type** Set

**Notes**

Finds the \( O(|V|/(\log |V|)^2) \) apx of independent set in the worst case.

**References**

3.1.7 Matching

**Graph Matching**

Given a graph \( G = (V,E) \), a matching \( M \) in \( G \) is a set of pairwise non-adjacent edges; that is, no two edges share a common vertex.

Wikipedia: Matching

**min_maximal_matching**

min_maximal_matching \((G)\) Returns the minimum maximal matching of \( G \).

- **Parameters** \( G \) (NetworkX graph) – Undirected graph
- **Returns** min_maximal_matching – Returns a set of edges such that no two edges share a common endpoint and every edge not in the set shares some common endpoint in the set. Cardinality will be \( 2*OPT \) in the worst case.

3.1. Approximations and Heuristics
Return type set

Notes

The algorithm computes an approximate solution to the minimum maximal cardinality matching problem. The solution is no more than $2 \times \text{OPT}$ in size. Runtime is $O(|E|)$.

References

3.1.8 Ramsey

Ramsey numbers.

\[
\text{Ramsey number } R(2; s, t)
\]

networkx.algorithms.approximation.ramsey.ramsey_R2

\text{ramsey_R2}(G) \quad \text{Approximately computes the Ramsey number $R(2; s, t)$ for graph.}

Parameters G (NetworkX graph) – Undirected graph

Returns max_pair – Maximum clique, Maximum independent set.

Return type (set, set) tuple

3.1.9 Steiner Tree

networkx.algorithms.approximation.steiner_tree.metric_closure

\text{metric_closure}(G[, weight]) \quad \text{Return the metric closure of a graph.}

Parameters G (NetworkX graph) – Undirected graph

Returns Metric closure of the graph G.

Return type NetworkX graph

networkx.algorithms.approximation.steiner_tree.steiner_tree

\text{steiner_tree}(G, terminal_nodes[, weight]) \quad \text{Return an approximation to the minimum Steiner tree of a graph.}

Parameters G (NetworkX graph)

Returns Metric closure of the graph G.

Return type NetworkX graph
Parameters

• **G** *(NetworkX graph)*

• **terminal_nodes** *(list)* – A list of terminal nodes for which minimum steiner tree is to be found.

Returns Approximation to the minimum steiner tree of G induced by terminal_nodes.

Return type NetworkX graph

Notes

Steiner tree can be approximated by computing the minimum spanning tree of the subgraph of the metric closure of the graph induced by the terminal nodes, where the metric closure of G is the complete graph in which each edge is weighted by the shortest path distance between the nodes in G. This algorithm produces a tree whose weight is within a \((2 - (2 / t))\) factor of the weight of the optimal Steiner tree where \(t\) is number of terminal nodes.

### 3.1.10 Vertex Cover

Functions for computing an approximate minimum weight vertex cover.

A *vertex cover* is a subset of nodes such that each edge in the graph is incident to at least one node in the subset.

\[
\text{min_weighted_vertex_cover}(G[, \text{weight}]) \quad \text{Returns an approximate minimum weighted vertex cover.}
\]

networkx.algorithms.approximation.vertex_cover.min_weighted_vertex_cover

**min_weighted_vertex_cover** *(G, weight=None)*

Returns an approximate minimum weighted vertex cover.

The set of nodes returned by this function is guaranteed to be a vertex cover, and the total weight of the set is guaranteed to be at most twice the total weight of the minimum weight vertex cover. In other words,

\[
w(S) \leq 2 \times w(S^*)
\]

where \(S\) is the vertex cover returned by this function, \(S^*\) is the vertex cover of minimum weight out of all vertex covers of the graph, and \(w\) is the function that computes the sum of the weights of each node in that given set.

Parameters

• **G** *(NetworkX graph)*

• **weight** *(string, optional (default = None))* – If None, every node has weight 1. If a string, use this node attribute as the node weight. A node without this attribute is assumed to have weight 1.

Returns **min_weighted_cover** – Returns a set of nodes whose weight sum is no more than twice the weight sum of the minimum weight vertex cover.

Return type **set**
Notes

For a directed graph, a vertex cover has the same definition: a set of nodes such that each edge in the graph is incident to at least one node in the set. Whether the node is the head or tail of the directed edge is ignored.

This is the local-ratio algorithm for computing an approximate vertex cover. The algorithm greedily reduces the costs over edges, iteratively building a cover. The worst-case runtime of this implementation is $O(m \log n)$, where $n$ is the number of nodes and $m$ the number of edges in the graph.

References

3.2 Assortativity

3.2.1 Assortativity

```
degree_assortativity_coefficient(G[, x, y, weight])
attribute_assortativity_coefficient(G, attribute)
numeric_assortativity_coefficient(G, attribute)

degree_pearson_correlation_coefficient(G)
```

networkx.algorithms.assortativity.degree_assortativity_coefficient

degree_assortativity_coefficient (G, x='out', y='in', weight=None, nodes=None)

Compute degree assortativity of graph.

Assortativity measures the similarity of connections in the graph with respect to the node degree.

Parameters

- **G** (NetworkX graph)
- **x** (string (‘in’,’out’)) – The degree type for source node (directed graphs only).
- **y** (string (‘in’,’out’)) – The degree type for target node (directed graphs only).
- **weight** (string or None, optional (default=None)) – The edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1. The degree is the sum of the edge weights adjacent to the node.
- **nodes** (list or iterable (optional)) – Compute degree assortativity only for nodes in container. The default is all nodes.

Returns **r** – Assortativity of graph by degree.

Return type float
Examples

```python
>>> G=nx.path_graph(4)
>>> r=nx.degree_assortativity_coefficient(G)
>>> print("%3.1f"%r)
-0.5
```

See also:

- `attribute_assortativity_coefficient()`, `numeric_assortativity_coefficient()`, `neighbor_connectivity()`, `degree_mixing_dict()`, `degree_mixing_matrix()`

Notes

This computes Eq. (21) in Ref.¹, where $e$ is the joint probability distribution (mixing matrix) of the degrees. If $G$ is directed than the matrix $e$ is the joint probability of the user-specified degree type for the source and target.

References

networkx.algorithms.assortativity.attribute_assortativity_coefficient

attribute_assortativity_coefficient ($G$, attribute, nodes=None)

Compute assortativity for node attributes.

Assortativity measures the similarity of connections in the graph with respect to the given attribute.

Parameters

- $G$ (NetworkX graph)
- attribute (string) – Node attribute key
- nodes (list or iterable (optional)) – Compute attribute assortativity for nodes in container.
  The default is all nodes.

Returns r – Assortativity of graph for given attribute

Return type float

Examples

```python
>>> G=nx.Graph()
>>> G.add_nodes_from([0,1],color='red')
>>> G.add_nodes_from([2,3],color='blue')
>>> G.add_edges_from([(0,1),(2,3)])
>>> print(nx.attribute_assortativity_coefficient(G,'color'))
1.0
```


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Notes

This computes Eq. (2) in Ref.\(^1\), trace(M)−sum(M))/(1−sum(M), where M is the joint probability distribution (mixing matrix) of the specified attribute.

References

networkx.algorithms.assortativity.numeric_assortativity_coefficient

numeric_assortativity_coefficient \((G, \text{attribute}, \text{nodes}=\text{None})\)

Compute assortativity for numerical node attributes.

Assortativity measures the similarity of connections in the graph with respect to the given numeric attribute. The numeric attribute must be an integer.

Parameters

- **G** (NetworkX graph)
- **attribute** (string) – Node attribute key. The corresponding attribute value must be an integer.
- **nodes** (list or iterable (optional)) – Compute numeric assortativity only for attributes of nodes in container. The default is all nodes.

Returns **r** – Assortativity of graph for given attribute

Return type float

Examples

```python
>>> G=nx.Graph()
>>> G.add_nodes_from([0,1],size=2)
>>> G.add_nodes_from([2,3],size=3)
>>> G.add_edges_from([(0,1),(2,3)])
>>> print(nx.numeric_assortativity_coefficient(G,'size'))
1.0
```

Notes

This computes Eq. (21) in Ref.\(^1\), for the mixing matrix of of the specified attribute.

References

networkx.algorithms.assortativity.degree_pearson_correlation_coefficient

degree_pearson_correlation_coefficient \((G, x='out', y='in', weight=\text{None}, \text{nodes}=\text{None})\)

Compute degree assortativity of graph.

Assortativity measures the similarity of connections in the graph with respect to the node degree.

This is the same as degree_assortativity_coefficient but uses the potentially faster scipy.stats.pearsonr function.

Parameters

- **G** *(NetworkX graph)*
- **x** *(string ('in', 'out'))* – The degree type for source node (directed graphs only).
- **y** *(string ('in', 'out'))* – The degree type for target node (directed graphs only).
- **weight** *(string or None, optional (default=None))* – The edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1. The degree is the sum of the edge weights adjacent to the node.
- **nodes** *(list or iterable (optional))* – Compute pearson correlation of degrees only for specified nodes. The default is all nodes.

Returns **r** – Assortativity of graph by degree.

Return type **float**

Examples

```python
>>> G=nx.path_graph(4)
>>> r=nx.degree_pearson_correlation_coefficient(G)
>>> print("%.3f"%r)
-0.5
```

Notes

This calls scipy.stats.pearsonr.

References

3.2.2 Average neighbor degree

`average_neighbor_degree(G[, source, target, ...])` Returns the average degree of the neighborhood of each node.

networkx.algorithms.assortativity.average_neighbor_degree

`average_neighbor_degree(G, source='out', target='out', nodes=None, weight=None)` Returns the average degree of the neighborhood of each node.

The average neighborhood degree of a node \( i \) is

\[
k_{nn,i} = \frac{1}{|N(i)|} \sum_{j \in N(i)} k_j
\]

where \( N(i) \) are the neighbors of node \( i \) and \( k_j \) is the degree of node \( j \) which belongs to \( N(i) \). For weighted graphs, an analogous measure can be defined\(^1\),

\[
k_{nn,i}^w = \frac{1}{s_i} \sum_{j \in N(i)} w_{ij} k_j
\]


3.2. Assortativity
where \( s_i \) is the weighted degree of node \( i \), \( w_{ij} \) is the weight of the edge that links \( i \) and \( j \) and \( N(i) \) are the neighbors of node \( i \).

**Parameters**

- \( G \) (NetworkX graph)
- **source** (string ("in"|"out")) – Directed graphs only. Use “in”- or “out”-degree for source node.
- **target** (string ("in"|"out")) – Directed graphs only. Use “in”- or “out”-degree for target node.
- **nodes** (list or iterable, optional) – Compute neighbor degree for specified nodes. The default is all nodes in the graph.
- **weight** (string or None, optional (default=None)) – The edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1.

**Returns**

- \( d \) – A dictionary keyed by node with average neighbors degree value.

**Return type**

- dict

**Examples**

```python
>>> G=nx.path_graph(4)
>>> G.edges[0, 1]['weight'] = 5
>>> G.edges[2, 3]['weight'] = 3

>>> nx.average_neighbor_degree(G)
{0: 2.0, 1: 1.5, 2: 1.5, 3: 2.0}

>>> nx.average_neighbor_degree(G, weight='weight')
{0: 2.0, 1: 1.1666666666666667, 2: 1.25, 3: 2.0}

>>> G=nx.DiGraph()
>>> nx.add_path(G, [0, 1, 2, 3])

>>> nx.average_neighbor_degree(G, source='in', target='in')
{0: 1.0, 1: 1.0, 2: 1.0, 3: 0.0}

>>> nx.average_neighbor_degree(G, source='out', target='out')
{0: 1.0, 1: 1.0, 2: 0.0, 3: 0.0}
```

**Notes**

For directed graphs you can also specify in-degree or out-degree by passing keyword arguments.

**See also:**

- `average_degree_connectivity()`

**References**

**3.2.3 Average degree connectivity**
networkx.algorithms.assortativity.average_degree_connectivity

average_degree_connectivity \( (G, \text{source}='\text{in}+\text{out}', \text{target}='\text{in}+\text{out}', \text{nodes} = \text{None}, \text{weight} = \text{None}) \)

Compute the average degree connectivity of graph.

The average degree connectivity is the average nearest neighbor degree of nodes with degree \( k \). For weighted graphs, an analogous measure can be computed using the weighted average neighbors degree defined in \(^1\), for a node \( i \), as

\[
    k^{w}_{nn,i} = \frac{1}{s_i} \sum_{j \in N(i)} w_{ij} k_j
\]

where \( s_i \) is the weighted degree of node \( i \), \( w_{ij} \) is the weight of the edge that links \( i \) and \( j \), and \( N(i) \) are the neighbors of node \( i \).

Parameters

- \( G \) (NetworkX graph)
- \( \text{source} \) ("in"|"out"|"in+out" (default:"in+out")) – Directed graphs only. Use “in”- or “out”-degree for source node.
- \( \text{target} \) ("in"|"out"|"in+out" (default:"in+out")) – Directed graphs only. Use “in”- or “out”-degree for target node.
- \( \text{nodes} \) (list or iterable (optional)) – Compute neighbor connectivity for these nodes. The default is all nodes.
- \( \text{weight} \) (string or None, optional (default=None)) – The edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1.

Returns \( d \) – A dictionary keyed by degree \( k \) with the value of average connectivity.

Return type \( \text{dict} \)

Raises ValueError – If either \( \text{source} \) or \( \text{target} \) are not one of ‘in’, ‘out’, or ‘in+out’.

Examples

```python
>>> G=nx.path_graph(4)
>>> G.edges[1, 2]['weight'] = 3
>>> nx.k_nearest_neighbors(G)
{1: 2.0, 2: 1.5}
>>> nx.k_nearest_neighbors(G, weight='weight')
{1: 2.0, 2: 1.75}
```

See also:

neighbors_average_degree()

Notes

This algorithm is sometimes called “k nearest neighbors” and is also available as \texttt{k_nearest_neighbors}.

References

\texttt{networkx.algorithms.assortativity.k_nearest_neighbors}

\texttt{k_nearest_neighbors (G, source='in+out', target='in+out', nodes=None, weight=None)}

Compute the average degree connectivity of graph.

The average degree connectivity is the average nearest neighbor degree of nodes with degree \( k \). For weighted graphs, an analogous measure can be computed using the weighted average neighbors degree defined in\(^1\), for a node \( i \), as

\[
 k^{w}_{nn, i} = \frac{1}{s_i} \sum_{j \in N(i)} w_{ij} k_j
\]

where \( s_i \) is the weighted degree of node \( i \), \( w_{ij} \) is the weight of the edge that links \( i \) and \( j \), and \( N(i) \) are the neighbors of node \( i \).

Parameters

- **G** (*NetworkX graph*)
- **source** ("in"|"out"|"in+out" (default: "in+out")) – Directed graphs only. Use “in”- or “out”-degree for source node.
- **target** ("in"|"out"|"in+out" (default: "in+out")) – Directed graphs only. Use “in”- or “out”-degree for target node.
- **nodes** (*list or iterable (optional)*) – Compute neighbor connectivity for these nodes. The default is all nodes.
- **weight** (*string or None, optional (default=None)*) – The edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1.

Returns **d** – A dictionary keyed by degree \( k \) with the value of average connectivity.

Return type **dict**

Raises **ValueError** – If either **source** or **target** are not one of ‘in’, ‘out’, or ‘in+out’.

Examples

```
>>> G=nx.path_graph(4)
>>> G.edges[1, 2]['weight'] = 3
>>> nx.k_nearest_neighbors(G)
{1: 2.0, 2: 1.5}
>>> nx.k_nearest_neighbors(G, weight='weight')
{1: 2.0, 2: 1.75}
```

See also:

- \texttt{neighbors_average_degree()}\(^1\)

Notes

This algorithm is sometimes called “k nearest neighbors” and is also available as k_nearest_neighbors.

References

3.2.4 Mixing

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networkx.algorithms.assortativity.attribute_mixing_matrix

attribute_mixing_matrix (G, attribute[, nodes, ...])

Return mixing matrix for attribute.

Parameters

- G (graph) – NetworkX graph object.
- attribute (string) – Node attribute key.
- nodes (list or iterable (optional)) – Use only nodes in container to build the matrix. The default is all nodes.
- mapping (dictionary, optional) – Mapping from node attribute to integer index in matrix. If not specified, an arbitrary ordering will be used.
- normalized (bool (default=False)) – Return counts if False or probabilities if True.

Returns m – Counts or joint probability of occurrence of attribute pairs.

Return type numpy array

networkx.algorithms.assortativity.degree_mixing_matrix

degree_mixing_matrix (G, x=’out’, y=’in’, weight=None, nodes=None, normalized=True)

Return mixing matrix for attribute.

Parameters

- G (graph) – NetworkX graph object.
- x (string (‘in’,’out’)) – The degree type for source node (directed graphs only).
- y (string (‘in’,’out’)) – The degree type for target node (directed graphs only).
- nodes (list or iterable (optional)) – Build the matrix using only nodes in container. The default is all nodes.
- weight (string or None, optional (default=None)) – The edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1. The degree is the sum of the edge weights adjacent to the node.
**networkx.algorithms.assortativity.degree_mixing_dict**

**degree_mixing_dict** \( (G, x='out', y='in', weight=None, nodes=None, normalized=False) \)

Return dictionary representation of mixing matrix for degree.

**Parameters**

- \( G \) (graph) – NetworkX graph object.
- \( x \) (string) – The degree type for source node (directed graphs only).
- \( y \) (string) – The degree type for target node (directed graphs only).
- \( weight \) (string or None, optional (default=None)) – The edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1. The degree is the sum of the edge weights adjacent to the node.
- \( normalized \) (bool (default=False)) – Return counts if False or probabilities if True.

**Returns** \( d \) – Counts or joint probability of occurrence of degree pairs.

**Return type** dictionary

**networkx.algorithms.assortativity.attribute_mixing_dict**

**attribute_mixing_dict** \( (G, attribute, nodes=None, normalized=False) \)

Return dictionary representation of mixing matrix for attribute.

**Parameters**

- \( G \) (graph) – NetworkX graph object.
- \( attribute \) (string) – Node attribute key.
- \( nodes \) (list or iterable (optional)) – Unse nodes in container to build the dict. The default is all nodes.
- \( normalized \) (bool (default=False)) – Return counts if False or probabilities if True.

**Examples**

```python
>>> G=nx.Graph()
>>> G.add_nodes_from([0,1],color='red')
>>> G.add_nodes_from([2,3],color='blue')
>>> G.add_edge(1,3)
>>> d=nx.attribute_mixing_dict(G,'color')
>>> print(d['red']['blue'])
1
>>> print(d['blue']['red'])
1  # d symmetric for undirected graphs
```

**Returns** \( d \) – Counts or joint probability of occurrence of attribute pairs.

**Return type** dictionary

• **normalized** (bool (default=False)) – Return counts if False or probabilities if True.

**Returns** \( m \) – Counts, or joint probability, of occurrence of node degree.

**Return type** numpy array
3.3 Bipartite

This module provides functions and operations for bipartite graphs. Bipartite graphs \( B = (U, V, E) \) have two node sets \( U, V \) and edges in \( E \) that only connect nodes from opposite sets. It is common in the literature to use an spatial analogy referring to the two node sets as top and bottom nodes.

The bipartite algorithms are not imported into the networkx namespace at the top level so the easiest way to use them is with:

```python
>>> import networkx as nx
>>> from networkx.algorithms import bipartite
```

NetworkX does not have a custom bipartite graph class but the Graph() or DiGraph() classes can be used to represent bipartite graphs. However, you have to keep track of which set each node belongs to, and make sure that there is no edge between nodes of the same set. The convention used in NetworkX is to use a node attribute named `bipartite` with values 0 or 1 to identify the sets each node belongs to. This convention is not enforced in the source code of bipartite functions, it’s only a recommendation.

For example:

```python
>>> B = nx.Graph()
>>> # Add nodes with the node attribute "bipartite"
>>> B.add_nodes_from([1, 2, 3, 4], bipartite=0)
>>> B.add_nodes_from(['a', 'b', 'c'], bipartite=1)
>>> # Add edges only between nodes of opposite node sets
>>> B.add_edges_from([(1, 'a'), (1, 'b'), (2, 'b'), (2, 'c'), (3, 'c'), (4, 'a')])
```

Many algorithms of the bipartite module of NetworkX require, as an argument, a container with all the nodes that belong to one set, in addition to the bipartite graph \( B \). The functions in the bipartite package do not check that the node set is actually correct nor that the input graph is actually bipartite. If \( B \) is connected, you can find the two node sets using a two-coloring algorithm:

```python
>>> nx.is_connected(B)
True
>>> bottom_nodes, top_nodes = bipartite.sets(B)
```

However, if the input graph is not connected, there are more than one possible colorations. This is the reason why we require the user to pass a container with all nodes of one bipartite node set as an argument to most bipartite functions. In the face of ambiguity, we refuse the temptation to guess and raise an `AmbiguousSolution` Exception if the input graph for `bipartite.sets` is disconnected.

Using the `bipartite` node attribute, you can easily get the two node sets:

```python
>>> top_nodes = {n for n, d in B.nodes(data=True) if d['bipartite']==0}
>>> bottom_nodes = set(B) - top_nodes
```

So you can easily use the bipartite algorithms that require, as an argument, a container with all nodes that belong to one node set:

```python
>>> print(round(bipartite.density(B, bottom_nodes), 2))
0.5
>>> G = bipartite.projected_graph(B, top_nodes)
```

All bipartite graph generators in NetworkX build bipartite graphs with the `bipartite` node attribute. Thus, you can use the same approach:
```python
>>> RB = bipartite.random_graph(5, 7, 0.2)
>>> RB_top = {n for n, d in RB.nodes(data=True) if d['bipartite']==0}
>>> RB_bottom = set(RB) - RB_top
>>> list(RB_top)
[0, 1, 2, 3, 4]
>>> list(RB_bottom)
[5, 6, 7, 8, 9, 10, 11]
```

For other bipartite graph generators see `Generators`

### 3.3.1 Basic functions

**Bipartite Graph Algorithms**

<table>
<thead>
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<th>Function</th>
<th>Description</th>
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<td><code>is_bipartite(G)</code></td>
<td>Returns True if graph G is bipartite, False if not.</td>
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<tr>
<td><code>is_bipartite_node_set(G, nodes)</code></td>
<td>Returns True if nodes and G/nodes are a bipartition of G.</td>
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<tr>
<td><code>sets(G[, top_nodes])</code></td>
<td>Returns bipartite node sets of graph G.</td>
</tr>
<tr>
<td><code>color(G)</code></td>
<td>Returns a two-coloring of the graph.</td>
</tr>
<tr>
<td><code>density(B, nodes)</code></td>
<td>Return density of bipartite graph B.</td>
</tr>
<tr>
<td><code>degrees(B, nodes[, weight])</code></td>
<td>Return the degrees of the two node sets in the bipartite graph B.</td>
</tr>
</tbody>
</table>

**networkx.algorithms.bipartite.basic.is_bipartite**

`is_bipartite(G)`

Returns True if graph G is bipartite, False if not.

**Parameters**

- **G (NetworkX graph)**

**Examples**

```python
>>> from networkx.algorithms import bipartite
>>> G = nx.path_graph(4)
>>> print(bipartite.is_bipartite(G))
True
```

See also:

`color()`, `is_bipartite_node_set()`

**networkx.algorithms.bipartite.basic.is_bipartite_node_set**

`is_bipartite_node_set(G, nodes)`

Returns True if nodes and G/nodes are a bipartition of G.

**Parameters**

- **G (NetworkX graph)**
- **nodes (list or container)** – Check if nodes are one of a bipartite set.
Examples

```python
>>> from networkx.algorithms import bipartite
>>> G = nx.path_graph(4)
>>> X = set([1,3])
>>> bipartite.is_bipartite_node_set(G,X)
True
```

Notes

For connected graphs the bipartite sets are unique. This function handles disconnected graphs.

```
networkx.algorithms.bipartite.basic.sets

sets (G, top_nodes=None)
Returns bipartite node sets of graph G.
Raises an exception if the graph is not bipartite or if the input graph is disconnected and thus more than one valid solution exists. See bipartite documentation for further details on how bipartite graphs are handled in NetworkX.

Parameters
- G (NetworkX graph)
- top_nodes (container) – Container with all nodes in one bipartite node set. If not supplied it will be computed. But if more than one solution exists an exception will be raised.

Returns
- (X,Y) – One set of nodes for each part of the bipartite graph.

Return type
two-tuple of sets

Raises
- AmbiguousSolution : Exception – Raised if the input bipartite graph is disconnected and no container with all nodes in one bipartite set is provided. When determining the nodes in each bipartite set more than one valid solution is possible if the input graph is disconnected.
- NetworkXError: Exception – Raised if the input graph is not bipartite.
```

Examples

```python
>>> from networkx.algorithms import bipartite
>>> G = nx.path_graph(4)
>>> X, Y = bipartite.sets(G)
>>> list(X)
[0, 2]
>>> list(Y)
[1, 3]
```

See also:

color()
networkx.algorithms.bipartite.basic.color

**color** *(G)*

Returns a two-coloring of the graph.

Raises an exception if the graph is not bipartite.

**Parameters**

- **G** *(NetworkX graph)*

**Returns**

- **color** – A dictionary keyed by node with a 1 or 0 as data for each node color.

**Return type**

dictionary

**Raises**

- **exc:** NetworkXError if the graph is not two-colorable.

**Examples**

```python
>>> from networkx.algorithms import bipartite
>>> G = nx.path_graph(4)
>>> c = bipartite.color(G)
>>> print(c)
{0: 1, 1: 0, 2: 1, 3: 0}
```

You can use this to set a node attribute indicating the bipartite set:

```python
>>> nx.set_node_attributes(G, c, 'bipartite')
>>> print(G.nodes[0]['bipartite'])
1
>>> print(G.nodes[1]['bipartite'])
0
```

networkx.algorithms.bipartite.basic.density

**density** *(B, nodes)*

Return density of bipartite graph B.

**Parameters**

- **G** *(NetworkX graph)*
- **nodes** *(list or container)* – Nodes in one node set of the bipartite graph.

**Returns**

- **d** – The bipartite density

**Return type**

float

**Examples**

```python
>>> from networkx.algorithms import bipartite
>>> G = nx.complete_bipartite_graph(3,2)
>>> X=set([0,1,2])
>>> print(bipartite.density(G,X))
1.0
>>> Y=set([3,4])
>>> print(bipartite.density(G,Y))
1.0
```
The container of nodes passed as argument must contain all nodes in one of the two bipartite node sets to avoid ambiguity in the case of disconnected graphs. See bipartite documentation for further details on how bipartite graphs are handled in NetworkX.

See also:
color()
For example, to find a maximum matching in the complete bipartite graph with two vertices on the left and three vertices on the right:

```python
>>> import networkx as nx
>>> G = nx.complete_bipartite_graph(2, 3)
>>> left, right = nx.bipartite.sets(G)
>>> list(left)
[0, 1]
>>> list(right)
[2, 3, 4]
>>> nx.bipartite.maximum_matching(G)
{0: 2, 1: 3, 2: 0, 3: 1}
```

The dictionary returned by `maximum_matching()` includes a mapping for vertices in both the left and right vertex sets.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td><code>eppstein_matching(G[, top_nodes])</code></td>
<td>Returns the maximum cardinality matching of the bipartite graph G.</td>
</tr>
<tr>
<td><code>hopcroft_karp_matching(G[, top_nodes])</code></td>
<td>Returns the maximum cardinality matching of the bipartite graph G.</td>
</tr>
<tr>
<td><code>to_vertex_cover(G, matching[, top_nodes])</code></td>
<td>Returns the minimum vertex cover corresponding to the given maximum matching of the bipartite graph G.</td>
</tr>
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</table>

`networkx.algorithms.bipartite.matching.eppstein_matching`

**eppstein_matching** *(G, top_nodes=None)*

Returns the maximum cardinality matching of the bipartite graph G.

**Parameters**

- **G** *(NetworkX graph)* – Undirected bipartite graph
- **top_nodes** *(container)* – Container with all nodes in one bipartite node set. If not supplied it will be computed. But if more than one solution exists an exception will be raised.

**Returns** `matches` – The matching is returned as a dictionary, `matching`, such that `matching[v] == w` if node v is matched to node w. Unmatched nodes do not occur as a key in `mate`.

**Return type** `dictionary`

**Raises** *AmbiguousSolution: Exception* – Raised if the input bipartite graph is disconnected and no container with all nodes in one bipartite set is provided. When determining the nodes in each bipartite set more than one valid solution is possible if the input graph is disconnected.

**Notes**

This function is implemented with David Eppstein’s version of the algorithm Hopcroft–Karp algorithm (see `hopcroft_karp_matching()`), which originally appeared in the Python Algorithms and Data Structures library (PADS).

See *bipartite documentation* for further details on how bipartite graphs are handled in NetworkX.

See also:

`hopcroft_karp_matching()`
networkx.algorithms.bipartite.matching.hopcroft_karp_matching

hopcroft_karp_matching \( (G, \text{top_nodes}=\text{None}) \)

Returns the maximum cardinality matching of the bipartite graph \( G \).

Parameters

- \( G \) (NetworkX graph) – Undirected bipartite graph
- \( \text{top_nodes} \) (container) – Container with all nodes in one bipartite node set. If not supplied it will be computed. But if more than one solution exists an exception will be raised.

Returns \( \text{matches} \) – The matching is returned as a dictionary, \( \text{matches} \), such that \( \text{matches}[v]=w \) if node \( v \) is matched to node \( w \). Unmatched nodes do not occur as a key in \( \text{mate} \).

Return type dictionary

Raises AmbiguousSolution : Exception – Raised if the input bipartite graph is disconnected and no container with all nodes in one bipartite set is provided. When determining the nodes in each bipartite set more than one valid solution is possible if the input graph is disconnected.

Notes

This function is implemented with the Hopcroft–Karp matching algorithm for bipartite graphs.

See bipartite documentation for further details on how bipartite graphs are handled in NetworkX.

See also:

eppstein_matching()

References

networkx.algorithms.bipartite.matching.to_vertex_cover

to_vertex_cover \( (G, \text{matching}, \text{top_nodes}=\text{None}) \)

Returns the minimum vertex cover corresponding to the given maximum matching of the bipartite graph \( G \).

Parameters

- \( G \) (NetworkX graph) – Undirected bipartite graph
- \( \text{matching} \) (dictionary) – A dictionary whose keys are vertices in \( G \) and whose values are the distinct neighbors comprising the maximum matching for \( G \), as returned by, for example, maximum_matching(). The dictionary must represent the maximum matching.
- \( \text{top_nodes} \) (container) – Container with all nodes in one bipartite node set. If not supplied it will be computed. But if more than one solution exists an exception will be raised.

Returns \( \text{vertex_cover} \) – The minimum vertex cover in \( G \).

Return type set

Raises AmbiguousSolution : Exception – Raised if the input bipartite graph is disconnected and no container with all nodes in one bipartite set is provided. When determining the nodes in each bipartite set more than one valid solution is possible if the input graph is disconnected.
Notes

This function is implemented using the procedure guaranteed by Konig’s theorem, which proves an equivalence between a maximum matching and a minimum vertex cover in bipartite graphs.

Since a minimum vertex cover is the complement of a maximum independent set for any graph, one can compute the maximum independent set of a bipartite graph this way:

```python
>>> import networkx as nx

>>> G = nx.complete_bipartite_graph(2, 3)
>>> matching = nx.bipartite.maximum_matching(G)

>>> vertex_cover = nx.bipartite.to_vertex_cover(G, matching)

>>> independent_set = set(G) - vertex_cover

>>> print(list(independent_set))
[2, 3, 4]
```

See `bipartite documentation` for further details on how bipartite graphs are handled in NetworkX.

### 3.3.3 Matrix

Biadjacency matrices

**biadjacency_matrix**(G, row_order[, ...])  
Return the biadjacency matrix of the bipartite graph G.

**from_biadjacency_matrix**(A[, create_using, ...])  
Creates a new bipartite graph from a biadjacency matrix given as a SciPy sparse matrix.

networkx.algorithms.bipartite.matrix.biadjacency_matrix

**biadjacency_matrix**(G, row_order=None, column_order=None, dtype=None, weight='weight', format='csr')

Return the biadjacency matrix of the bipartite graph G.

Let $G = (U, V, E)$ be a bipartite graph with node sets $U = \{u_1, \ldots, u_r\}$ and $V = \{v_1, \ldots, v_s\}$. The biadjacency matrix $B$ is the $r \times s$ matrix in which $B_{i,j} = 1$ if, and only if, $(u_i, v_j) \in E$. If the parameter weight is not None and matches the name of an edge attribute, its value is used instead of 1.

**Parameters**

- **G** *(graph)* – A NetworkX graph
- **row_order** *(list of nodes)* – The rows of the matrix are ordered according to the list of nodes.
- **column_order** *(list, optional)* – The columns of the matrix are ordered according to the list of nodes. If column_order is None, then the ordering of columns is arbitrary.
- **dtype** *(NumPy data-type, optional)* – A valid NumPy dtype used to initialize the array. If None, then the NumPy default is used.
- **weight** *(string or None, optional (default='weight'))* – The edge data key used to provide each value in the matrix. If None, then each edge has weight 1.
- **format** *(str in {'bsr', 'csr', 'csc', 'coo', 'lil', 'dia', 'dok'})* – The type of the matrix to be returned (default `‘csr’`). For some algorithms different implementations of sparse matrices can perform better. See for details.

---

Returns M – Biadjacency matrix representation of the bipartite graph G.

Return type SciPy sparse matrix

Notes

No attempt is made to check that the input graph is bipartite.

For directed bipartite graphs only successors are considered as neighbors. To obtain an adjacency matrix with ones (or weight values) for both predecessors and successors you have to generate two biadjacency matrices where the rows of one of them are the columns of the other, and then add one to the transpose of the other.

See also:

adjacency_matrix(), from_biadjacency_matrix()

References

networkx.algorithms.bipartite.matrix.from_biadjacency_matrix

from_biadjacency_matrix(A, create_using=None, edge_attribute='weight')

Creates a new bipartite graph from a biadjacency matrix given as a SciPy sparse matrix.

Parameters

• A (scipy sparse matrix) – A biadjacency matrix representation of a graph
• create_using (NetworkX graph) – Use specified graph for result. The default is Graph()
• edge_attribute (string) – Name of edge attribute to store matrix numeric value. The data will have the same type as the matrix entry (int, float, (real,imag)).

Notes

The nodes are labeled with the attribute bipartite set to an integer 0 or 1 representing membership in part 0 or part 1 of the bipartite graph.

If create_using is an instance of networkx.MultiGraph or networkx.MultiDiGraph and the entries of A are of type int, then this function returns a multigraph (of the same type as create_using) with parallel edges. In this case, edge_attribute will be ignored.

See also:

biadjacency_matrix(), from_numpy_matrix()

References


3.3.4 Projections

One-mode (unipartite) projections of bipartite graphs.
networkx.algorithms.bipartite.projection.projected_graph

projected_graph (B, nodes, multigraph=False)
Returns the projection of B onto one of its node sets.

Parameters
- B (NetworkX graph) – The input graph should be bipartite.
- nodes (list or iterable) – Nodes to project onto (the “bottom” nodes).
- multigraph (bool (default=False)) – If True return a multigraph where the multiple edges represent multiple shared neighbors. They edge key in the multigraph is assigned to the label of the neighbor.

Returns
Graph – A graph that is the projection onto the given nodes.

Return type
NetworkX graph or multigraph

Examples

```python
>>> from networkx.algorithms import bipartite
>>> B = nx.path_graph(4)
>>> G = bipartite.projected_graph(B, [1, 3])
>>> list(G)
[1, 3]
>>> list(G.edges())
[(1, 3)]
```

If nodes a, and b are connected through both nodes 1 and 2 then building a multigraph results in two edges in the projection onto [a, b]:

```python
>>> B = nx.Graph()
>>> B.add_edges_from([('a', 1), ('b', 1), ('a', 2), ('b', 2)])
>>> G = bipartite.projected_graph(B, ['a', 'b'], multigraph=True)
>>> print(sorted((u, v) for u, v in G.edges()))
[['a', 'b'], ['a', 'b']]
```
Notes

No attempt is made to verify that the input graph B is bipartite. Returns a simple graph that is the projection of the bipartite graph B onto the set of nodes given in list nodes. If multigraph=True then a multigraph is returned with an edge for every shared neighbor.

Directed graphs are allowed as input. The output will also then be a directed graph with edges if there is a directed path between the nodes.

The graph and node properties are (shallow) copied to the projected graph.

See bipartite documentation for further details on how bipartite graphs are handled in NetworkX.

See also:

- is_bipartite()
- is_bipartite_node_set()
- sets()
- weighted_projected_graph()
- collaboration_weighted_projected_graph()
- overlap_weighted_projected_graph()
- generic_weighted_projected_graph()

networkx.algorithms.bipartite.projection.weighted_projected_graph

weighted_projected_graph (B, nodes, ratio=False)

Returns a weighted projection of B onto one of its node sets.

The weighted projected graph is the projection of the bipartite network B onto the specified nodes with weights representing the number of shared neighbors or the ratio between actual shared neighbors and possible shared neighbors if ratio is True\(^1\). The nodes retain their attributes and are connected in the resulting graph if they have an edge to a common node in the original graph.

Parameters

- \(B\) (NetworkX graph) – The input graph should be bipartite.
- \(nodes\) (list or iterable) – Nodes to project onto (the “bottom” nodes).
- \(ratio\) (Bool (default=False)) – If True, edge weight is the ratio between actual shared neighbors and possible shared neighbors. If False, edges weight is the number of shared neighbors.

Returns Graph – A graph that is the projection onto the given nodes.

Return type NetworkX graph

Examples

```python
>>> from networkx.algorithms import bipartite
>>> B = nx.path_graph(4)
>>> G = bipartite.weighted_projected_graph(B, [1, 3])
>>> list(G)
[1, 3]
>>> list(G.edges(data=True))
[(1, 3, {'weight': 1})]
>>> G = bipartite.weighted_projected_graph(B, [1, 3], ratio=True)
>>> list(G.edges(data=True))
[(1, 3, {'weight': 0.5})]
```

Notes

No attempt is made to verify that the input graph B is bipartite. The graph and node properties are (shallow) copied to the projected graph.

See bipartite documentation for further details on how bipartite graphs are handled in NetworkX.

See also:

is_bipartite(), is_bipartite_node_set(), sets(), collaboration_weighted_projected_graph(),
overlap_weighted_projected_graph(), generic_weighted_projected_graph(),
projected_graph()

References

networkx.algorithms.bipartite.projection.collaboration_weighted_projected_graph

collaboration_weighted_projected_graph(B, nodes)

Newman’s weighted projection of B onto one of its node sets.

The collaboration weighted projection is the projection of the bipartite network B onto the specified nodes with weights assigned using Newman’s collaboration model:\n
\[ w_{u,v} = \sum_{k} \delta_{u}^{k} \delta_{v}^{k} \frac{d_{k}}{d_{k} - 1} \]

where \( u \) and \( v \) are nodes from the bottom bipartite node set, and \( k \) is a node of the top node set. The value \( d_{k} \) is the degree of node \( k \) in the bipartite network and \( \delta_{u}^{k} \) is 1 if node \( u \) is linked to node \( k \) in the original bipartite graph or 0 otherwise.

The nodes retain their attributes and are connected in the resulting graph if have an edge to a common node in the original bipartite graph.

Parameters

- \( B \) (NetworkX graph) – The input graph should be bipartite.
- \( nodes \) (list or iterable) – Nodes to project onto (the “bottom” nodes).

Returns

Graph – A graph that is the projection onto the given nodes.

Return type

NetworkX graph

Examples

```python
>>> from networkx.algorithms import bipartite
>>> B = nx.path_graph(5)
>>> B.add_edge(1, 5)
>>> G = bipartite.collaboration_weighted_projected_graph(B, [0, 2, 4, 5])
>>> list(G)
[0, 2, 4, 5]
>>> for edge in G.edges(data=True): print(edge)
...
(0, 2, {'weight': 0.5})
(0, 5, {'weight': 0.5})
```

Notes

No attempt is made to verify that the input graph B is bipartite. The graph and node properties are (shallow) copied to the projected graph.

See bipartite documentation for further details on how bipartite graphs are handled in NetworkX.

See also:

\texttt{is\_bipartite()}, \texttt{is\_bipartite\_node\_set()}, \texttt{sets()}, \texttt{weighted\_projected\_graph()}, \texttt{overlap\_weighted\_projected\_graph()}, \texttt{generic\_weighted\_projected\_graph()}, \texttt{projected\_graph()}

References

\texttt{networkx.algorithms.bipartite.projection.overlap\_weighted\_projected\_graph}

\texttt{overlap\_weighted\_projected\_graph}(B, nodes, jaccard=True)

Overlap weighted projection of B onto one of its node sets.

The overlap weighted projection is the projection of the bipartite network B onto the specified nodes with weights representing the Jaccard index between the neighborhoods of the two nodes in the original bipartite network$^1$:

$$w_{v,u} = \frac{|N(u) \cap N(v)|}{|N(u) \cup N(v)|}$$

or if the parameter ‘jaccard’ is False, the fraction of common neighbors by minimum of both nodes degree in the original bipartite graph$^1$:

$$w_{v,u} = \frac{|N(u) \cap N(v)|}{\min(|N(u)|, |N(v)|)}$$

The nodes retain their attributes and are connected in the resulting graph if have an edge to a common node in the original bipartite graph.

Parameters

- B (\texttt{NetworkX graph}) – The input graph should be bipartite.
- nodes (\texttt{list or iterable}) – Nodes to project onto (the “bottom” nodes).
- jaccard (\texttt{Bool (default=True)})

Returns Graph – A graph that is the projection onto the given nodes.

Return type NetworkX graph

---

Examples

```python
>>> from networkx.algorithms import bipartite
>>> B = nx.path_graph(5)
>>> nodes = [0, 2, 4]
>>> G = bipartite.overlap_weighted_projected_graph(B, nodes)
>>> list(G)
[0, 2, 4]
>>> list(G.edges(data=True))
[(0, 2, {'weight': 0.5}), (2, 4, {'weight': 0.5})]
>>> G = bipartite.overlap_weighted_projected_graph(B, nodes, jaccard=False)
>>> list(G.edges(data=True))
[(0, 2, {'weight': 1.0}), (2, 4, {'weight': 1.0})]
```

Notes

No attempt is made to verify that the input graph B is bipartite. The graph and node properties are (shallow) copied to the projected graph.

See `bipartite documentation` for further details on how bipartite graphs are handled in NetworkX.

See also:

- `is_bipartite()`, `is_bipartite_node_set()`, `sets()`, `weighted_projected_graph()`, `collaboration_weighted_projected_graph()`, `generic_weighted_projected_graph()`, `projected_graph()`

References

`networkx.algorithms.bipartite.projection.generic_weighted_projected_graph`

`generic_weighted_projected_graph(B, nodes, weight_function=None)`

Weighted projection of B with a user-specified weight function.

The bipartite network B is projected on to the specified nodes with weights computed by a user-specified function. This function must accept as a parameter the neighborhood sets of two nodes and return an integer or a float.

The nodes retain their attributes and are connected in the resulting graph if they have an edge to a common node in the original graph.

Parameters

- **B** (*NetworkX graph*) – The input graph should be bipartite.
- **nodes** (*list or iterable*) – Nodes to project onto (the “bottom” nodes).
- **weight_function** (*function*) – This function must accept as parameters the same input graph that this function, and two nodes; and return an integer or a float. The default function computes the number of shared neighbors.

Returns **Graph** – A graph that is the projection onto the given nodes.

Return type `NetworkX graph`
Examples

```python
>>> from networkx.algorithms import bipartite
>>> # Define some custom weight functions
>>> def jaccard(G, u, v):
...     unbrs = set(G[u])
...     vnbrs = set(G[v])
...     return float(len(unbrs & vnbrs)) / len(unbrs | vnbrs)
...
>>> def my_weight(G, u, v, weight='weight'):
...     w = 0
...     for nbr in set(G[u]) & set(G[v]):
...         w += G[u][nbr].get(weight, 1) + G[v][nbr].get(weight, 1)
...     return w
...
>>> # A complete bipartite graph with 4 nodes and 4 edges
>>> B = nx.complete_bipartite_graph(2, 2)
>>> # Add some arbitrary weight to the edges
>>> for i, (u, v) in enumerate(B.edges):
...     B.edges[u, v]['weight'] = i + 1
>>> for edge in B.edges(data=True):
...     print(edge)
...     (0, 2, {'weight': 1})
...     (0, 3, {'weight': 2})
...     (1, 2, {'weight': 3})
...     (1, 3, {'weight': 4})
>>> # By default, the weight is the number of shared neighbors
>>> G = bipartite.generic_weighted_projected_graph(B, [0, 1])
>>> print(list(G.edges(data=True)))
... [(0, 1, {'weight': 2})]
>>> # To specify a custom weight function use the weight_function parameter
>>> G = bipartite.generic_weighted_projected_graph(B, [0, 1], weight_function=jaccard)
>>> print(list(G.edges(data=True)))
... [(0, 1, {'weight': 1.0})]
>>> G = bipartite.generic_weighted_projected_graph(B, [0, 1], weight_function=my_weight)
>>> print(list(G.edges(data=True)))
... [(0, 1, {'weight': 10})]
```

Notes

No attempt is made to verify that the input graph B is bipartite. The graph and node properties are (shallow) copied to the projected graph.

See `bipartite documentation` for further details on how bipartite graphs are handled in NetworkX.

See also:

- `is_bipartite()`, `is_bipartite_node_set()`, `sets()`, `weighted_projected_graph()`, `collaboration_weighted_projected_graph()`, `overlap_weighted_projected_graph()`, `projected_graph()`
3.3.5 Spectral

Spectral bipartivity measure.

\[ \text{spectral_bipartivity}(G[, \text{nodes}, \text{weight}]) \]

Returns the spectral bipartivity.

```
from networkx.algorithms import bipartite
G = nx.path_graph(4)
bipartite.spectral_bipartivity(G)
>>> 1.0
```

Notes

This implementation uses Numpy (dense) matrices which are not efficient for storing large sparse graphs.

See also:

color()

References

3.3.6 Clustering

```
clustering(G[, nodes, mode])
```

Compute a bipartite clustering coefficient for nodes.

```
average_clustering(G[, nodes, mode])
```

Compute the average bipartite clustering coefficient.

```
latapy_clustering(G[, nodes, mode])
```

Compute a bipartite clustering coefficient for nodes.

```
robins_alexander_clustering(G)
```

Compute the bipartite clustering of G.
networkx.algorithms.bipartite.cluster.clustering

clustering(G, nodes=None, mode='dot')

Compute a bipartite clustering coefficient for nodes.

The bipartite clustering coefficient is a measure of local density of connections defined as:

\[ c_u = \frac{\sum_{v \in N(N(u))} c_{uv}}{|N(N(u))|} \]

where \( N(N(u)) \) are the second order neighbors of \( u \) in \( G \) excluding \( u \), and \( c_{uv} \) is the pairwise clustering coefficient between nodes \( u \) and \( v \).

The mode selects the function for \( c_{uv} \) which can be:

- **dot**:
  \[ c_{uv} = \frac{|N(u) \cap N(v)|}{|N(u) \cup N(v)|} \]

- **min**:
  \[ c_{uv} = \frac{|N(u) \cap N(v)|}{\min(|N(u)|, |N(v)|)} \]

- **max**:
  \[ c_{uv} = \frac{|N(u) \cap N(v)|}{\max(|N(u)|, |N(v)|)} \]

**Parameters**

- **G (graph)** – A bipartite graph
- **nodes (list or iterable (optional))** – Compute bipartite clustering for these nodes. The default is all nodes in \( G \).
- **mode (string)** – The pairwise bipartite clustering method to be used in the computation. It must be “dot”, “max”, or “min”.

**Returns** clustering – A dictionary keyed by node with the clustering coefficient value.

**Return type** dictionary

**Examples**

```python
>>> from networkx.algorithms import bipartite
>>> G = nx.path_graph(4)  # path graphs are bipartite
>>> c = bipartite.clustering(G)
>>> c[0]
0.5
>>> c = bipartite.clustering(G, mode='min')
>>> c[0]
1.0
```

**See also:**
- `robins_alexander_clustering()`, `square_clustering()`, `average_clustering()`

---

networkx.algorithms.bipartite.cluster.average_clustering

average_clustering (G, nodes=None, mode='dot')
Compute the average bipartite clustering coefficient.

A clustering coefficient for the whole graph is the average,

\[ C = \frac{1}{n} \sum_{v \in G} c_v, \]

where \( n \) is the number of nodes in \( G \).

Similar measures for the two bipartite sets can be defined

\[ C_X = \frac{1}{|X|} \sum_{v \in X} c_v, \]

where \( X \) is a bipartite set of \( G \).

Parameters
• G (graph) – a bipartite graph
• nodes (list or iterable, optional) – A container of nodes to use in computing the average. The nodes should be either the entire graph (the default) or one of the bipartite sets.
• mode (string) – The pairwise bipartite clustering method. It must be “dot”, “max”, or “min”

Returns clustering – The average bipartite clustering for the given set of nodes or the entire graph if no nodes are specified.

Return type float

Examples

```python
>>> from networkx.algorithms import bipartite
>>> G=nx.star_graph(3)  # star graphs are bipartite
>>> bipartite.average_clustering(G)
0.75
>>> X,Y=bipartite.sets(G)
>>> bipartite.average_clustering(G,X)
0.0
>>> bipartite.average_clustering(G,Y)
1.0
```

See also:
clustering()

Notes

The container of nodes passed to this function must contain all of the nodes in one of the bipartite sets ("top" or "bottom") in order to compute the correct average bipartite clustering coefficients. See bipartite documentation for further details on how bipartite graphs are handled in NetworkX.

References

networkx.algorithms.bipartite.cluster.latapy_clustering

latapy_clustering \((G, \text{nodes=\text{None, mode='dot'}})\)

Compute a bipartite clustering coefficient for nodes.

The bipartite clustering coefficient is a measure of local density of connections defined as\(^1\):

\[
\phi_u = \frac{\sum_{v \in N(N(u))} c_{uv}}{|N(N(u))|}
\]

where \(N(N(u))\) are the second order neighbors of \(u\) in \(G\) excluding \(u\), and \(c_{uv}\) is the pairwise clustering coefficient between nodes \(u\) and \(v\).

The mode selects the function for \(c_{uv}\) which can be:
- **dot**: \(c_{uv} = \frac{|N(u) \cap N(v)|}{|N(u) \cup N(v)|}\)
- **min**: \(c_{uv} = \frac{|N(u) \cap N(v)|}{\min(|N(u)|, |N(v)|)}\)
- **max**: \(c_{uv} = \frac{|N(u) \cap N(v)|}{\max(|N(u)|, |N(v)|)}\)

**Parameters**
- **\(G\) (graph)** – A bipartite graph
- **\(\text{nodes (list or iterable (optional))}\)** – Compute bipartite clustering for these nodes. The default is all nodes in \(G\).
- **\(\text{mode (string)}\)** – The pairwise bipartite clustering method to be used in the computation. It must be “dot”, “max”, or “min”.

**Returns** clustering – A dictionary keyed by node with the clustering coefficient value.

**Return type** dictionary

**Examples**

```python
>>> from networkx.algorithms import bipartite
>>> G = nx.path_graph(4)  # path graphs are bipartite
>>> c = bipartite.clustering(G)
>>> c[0]
0.5
>>> c = bipartite.clustering(G, mode='min')
>>> c[0]
1.0
```

**See also:**

- `robins_alexander_clustering()`, `square_clustering()`, `average_clustering()`

References

networkx.algorithms.bipartite.cluster.robins_alexander_clustering

robins_alexander_clustering(G)
Compute the bipartite clustering of G.

Robins and Alexander\(^1\) defined bipartite clustering coefficient as four times the number of four cycles \(C_4\) divided by the number of three paths \(L_3\) in a bipartite graph:

\[
CC_4 = \frac{4 \cdot C_4}{L_3}
\]

Parameters  
G (graph) – a bipartite graph  

Returns  
clustering – The Robins and Alexander bipartite clustering for the input graph.  

Return type  
float

Examples

```python
>>> from networkx.algorithms import bipartite
>>> G = nx.davis_southern_women_graph()
>>> print(round(bipartite.robins_alexander_clustering(G), 3))
0.468
```

See also:

latapy_clustering(), square_clustering()

References

3.3.7 Redundancy

Node redundancy for bipartite graphs.

\[
\text{node_redundancy}(G[, \text{nodes}])
\]
Computes the node redundancy coefficients for the nodes in the bipartite graph \(G\).

networkx.algorithms.bipartite.redundancy.node_redundancy

node_redundancy (G, nodes=None)
Computes the node redundancy coefficients for the nodes in the bipartite graph \(G\).

The redundancy coefficient of a node \(v\) is the fraction of pairs of neighbors of \(v\) that are both linked to other nodes. In a one-mode projection these nodes would be linked together even if \(v\) were not there.

More formally, for any vertex \(v\), the redundancy coefficient of ‘\(v\)’ is defined by

\[
rc(v) = \frac{|\{(u, w) \subseteq N(v), \exists v' \neq v, (v', u) \in E \text{ and } (v', w) \in E\}|}{|N(v)||N(v)|-1}.
\]

where \( N(v) \) is the set of neighbors of \( v \) in \( G \).

**Parameters**

- \( G \) (graph) – A bipartite graph
- \( \text{nodes} \) (list or iterable (optional)) – Compute redundancy for these nodes. The default is all nodes in \( G \).

**Returns** redundancy – A dictionary keyed by node with the node redundancy value.

**Return type** dictionary

**Examples**

Compute the redundancy coefficient of each node in a graph:

```python
>>> import networkx as nx
>>> from networkx.algorithms import bipartite
>>> G = nx.cycle_graph(4)
>>> rc = bipartite.node_redundancy(G)
>>> rc[0]
1.0
```

Compute the average redundancy for the graph:

```python
>>> import networkx as nx
>>> from networkx.algorithms import bipartite
>>> G = nx.cycle_graph(4)
>>> rc = bipartite.node_redundancy(G)
>>> sum(rc.values()) / len(G)
1.0
```

Compute the average redundancy for a set of nodes:

```python
>>> import networkx as nx
>>> from networkx.algorithms import bipartite
>>> G = nx.cycle_graph(4)
>>> rc = bipartite.node_redundancy(G)
>>> nodes = [0, 2]
>>> sum(rc[n] for n in nodes) / len(nodes)
1.0
```

**Raises** NetworkXError – If any of the nodes in the graph (or in \( \text{nodes} \), if specified) has (out-)degree less than two (which would result in division by zero, according to the definition of the redundancy coefficient).

**References**

3.3.8 Centrality

| closeness_centrality \((G, \text{nodes}, \text{normalized})\) | Compute the closeness centrality for nodes in a bipartite network. |

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<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>degree_centrality(G, nodes)</code></td>
<td>Compute the degree centrality for nodes in a bipartite network.</td>
</tr>
<tr>
<td><code>betweenness_centrality(G, nodes)</code></td>
<td>Compute betweenness centrality for nodes in a bipartite network.</td>
</tr>
</tbody>
</table>

**networkx.algorithms.bipartite.centrality.closeness_centrality**

**closeness_centrality** \((G, nodes, normalized=True)\)

Compute the closeness centrality for nodes in a bipartite network.

The closeness of a node is the distance to all other nodes in the graph or in the case that the graph is not connected to all other nodes in the connected component containing that node.

**Parameters**

- **G (graph)** – A bipartite network
- **nodes (list or container)** – Container with all nodes in one bipartite node set.
- **normalized (bool, optional)** – If True (default) normalize by connected component size.

**Returns**

- **closeness** – Dictionary keyed by node with bipartite closeness centrality as the value.

**Return type**

- **dictionary**

**See also:**

- `betweenness_centrality()`, `degree_centrality()`, `sets()`, `is_bipartite()`

**Notes**

The nodes input parameter must contain all nodes in one bipartite node set, but the dictionary returned contains all nodes from both node sets. See bipartite documentation for further details on how bipartite graphs are handled in NetworkX.

Closeness centrality is normalized by the minimum distance possible. In the bipartite case the minimum distance for a node in one bipartite node set is 1 from all nodes in the other node set and 2 from all other nodes in its own set\(^1\). Thus the closeness centrality for node \(v\) in the two bipartite sets \(U\) with \(n\) nodes and \(V\) with \(m\) nodes is

\[
c_v = \frac{m + 2(n - 1)}{d}, \text{for } v \in U,
\]

\[
c_v = \frac{n + 2(m - 1)}{d}, \text{for } v \in V,
\]

where \(d\) is the sum of the distances from \(v\) to all other nodes.

Higher values of closeness indicate higher centrality.

As in the unipartite case, setting normalized=True causes the values to normalized further to \(n-1 / \text{size}(G)-1\) where \(n\) is the number of nodes in the connected part of graph containing the node. If the graph is not completely connected, this algorithm computes the closeness centrality for each connected part separately.

---

References

networkx.algorithms.bipartite.centrality.degree_centrality

degree_centrality \((G, \text{nodes})\)
Compute the degree centrality for nodes in a bipartite network.

The degree centrality for a node \(v\) is the fraction of nodes connected to it.

Parameters

- **G (graph)** – A bipartite network
- **nodes (list or container)** – Container with all nodes in one bipartite node set.

Returns **centrality** – Dictionary keyed by node with bipartite degree centrality as the value.

Return type *dictionary*

See also:

*betweenness_centrality(), closeness_centrality(), sets(), is_bipartite()*

Notes

The nodes input parameter must contain all nodes in one bipartite node set, but the dictionary returned contains all nodes from both bipartite node sets. See bipartite documentation for further details on how bipartite graphs are handled in NetworkX.

For unipartite networks, the degree centrality values are normalized by dividing by the maximum possible degree (which is \(n-1\) where \(n\) is the number of nodes in \(G\)).

In the bipartite case, the maximum possible degree of a node in a bipartite node set is the number of nodes in the opposite node set\(^1\). The degree centrality for a node \(v\) in the bipartite sets \(U\) with \(n\) nodes and \(V\) with \(m\) nodes is

\[
    d_v = \frac{\deg(v)}{m}, \text{for } v \in U, \\
    d_v = \frac{\deg(v)}{n}, \text{for } v \in V,
\]

where \(\deg(v)\) is the degree of node \(v\).

References

networkx.algorithms.bipartite.centrality.betweenness_centrality

betweenness_centrality \((G, \text{nodes})\)
Compute betweenness centrality for nodes in a bipartite network.

Betweenness centrality of a node \(v\) is the sum of the fraction of all-pairs shortest paths that pass through \(v\).

Values of betweenness are normalized by the maximum possible value which for bipartite graphs is limited by the relative size of the two node sets\(^1\).


Let $n$ be the number of nodes in the node set $U$ and $m$ be the number of nodes in the node set $V$, then nodes in $U$ are normalized by dividing by

$$\frac{1}{2} \left[ m^2(s + 1)^2 + m(s + 1)(2t - s - 1) - t(2s - t + 3) \right],$$

where

$$s = (n - 1) \div m, \quad t = (n - 1) \mod m,$$

and nodes in $V$ are normalized by dividing by

$$\frac{1}{2} \left[ n^2(p + 1)^2 + n(p + 1)(2r - p - 1) - r(2p - r + 3) \right],$$

where,

$$p = (m - 1) \div n, \quad r = (m - 1) \mod n.$$

**Parameters**

- $G$ (graph) – A bipartite graph
- $nodes$ (list or container) – Container with all nodes in one bipartite node set.

**Returns**

- betweenness – Dictionary keyed by node with bipartite betweenness centrality as the value.

**Return type**

dictionary

**See also:**

degree_centrality(), closeness_centrality(), sets(), is_bipartite()

**Notes**

The nodes input parameter must contain all nodes in one bipartite node set, but the dictionary returned contains all nodes from both node sets. See bipartite documentation for further details on how bipartite graphs are handled in NetworkX.

**References**

### 3.3.9 Generators

Generators and functions for bipartite graphs.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>complete_bipartite_graph(n1, n2[, create_using])</td>
<td>Return the complete bipartite graph $K_{n_1,n_2}$.</td>
</tr>
<tr>
<td>configuration_model(aseq, bseq[, ...])</td>
<td>Return a random bipartite graph from two given degree sequences.</td>
</tr>
<tr>
<td>havel_hakimi_graph(aseq, bseq[, create_using])</td>
<td>Return a bipartite graph from two given degree sequences using a Havel-Hakimi style construction.</td>
</tr>
<tr>
<td>reverse_havel_hakimi_graph(aseq, bseq[, ...])</td>
<td>Return a bipartite graph from two given degree sequences using a Havel-Hakimi style construction.</td>
</tr>
<tr>
<td>alternating_havel_hakimi_graph(aseq, bseq[, ...])</td>
<td>Return a bipartite graph from two given degree sequences using an alternating Havel-Hakimi style construction.</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>preferential_attachment_graph(aseq, p[, ...])</td>
<td>Create a bipartite graph with a preferential attachment model from a given single degree sequence.</td>
</tr>
<tr>
<td>random_graph(n, m, p[, seed, directed])</td>
<td>Return a bipartite random graph.</td>
</tr>
<tr>
<td>gnmk_random_graph(n, m, k[, seed, directed])</td>
<td>Return a random bipartite graph $G_{n,m,k}$.</td>
</tr>
</tbody>
</table>

**networkx.algorithms.bipartite.generators.complete_bipartite_graph**

`complete_bipartite_graph(n1, n2, create_using=None)`

Return the complete bipartite graph $K_{n_1,n_2}$.

Composed of two partitions with $n_1$ nodes in the first and $n_2$ nodes in the second. Each node in the first is connected to each node in the second.

**Parameters**

- `n1` (integer) – Number of nodes for node set A.
- `n2` (integer) – Number of nodes for node set B.
- `create_using` (NetworkX graph instance, optional) – Return graph of this type.

**Notes**

Node labels are the integers 0 to $n_1 + n_2 - 1$.

The nodes are assigned the attribute ‘bipartite’ with the value 0 or 1 to indicate which bipartite set the node belongs to.

**networkx.algorithms.bipartite.generators.configuration_model**

`configuration_model(aseq, bseq, create_using=None, seed=None)`

Return a random bipartite graph from two given degree sequences.

**Parameters**

- `aseq` (list) – Degree sequence for node set A.
- `bseq` (list) – Degree sequence for node set B.
- `create_using` (NetworkX graph instance, optional) – Return graph of this type.
- `seed` (integer, optional) – Seed for random number generator.

- Nodes from the set A are connected to nodes in the set B by
  - choosing randomly from the possible free stubs, one in A and one in B.

**Notes**

The sum of the two sequences must be equal: $\text{sum}(aseq)=\text{sum}(bseq)$ If no graph type is specified use MultiGraph with parallel edges. If you want a graph with no parallel edges use create_using=Graph() but then the resulting degree sequences might not be exact.

The nodes are assigned the attribute ‘bipartite’ with the value 0 or 1 to indicate which bipartite set the node belongs to.

3.3. Bipartite
This function is not imported in the main namespace. To use it you have to explicitly import the bipartite package.

**networkx.algorithms.bipartite.generators.havel_hakimi_graph**

**havel_hakimi_graph** *(aseq, bseq, create_using=None)*

Return a bipartite graph from two given degree sequences using a Havel-Hakimi style construction.

Nodes from the set A are connected to nodes in the set B by connecting the highest degree nodes in set A to the highest degree nodes in set B until all stubs are connected.

**Parameters**

- `aseq` *(list)* – Degree sequence for node set A.
- `bseq` *(list)* – Degree sequence for node set B.
- `create_using` *(NetworkX graph instance, optional)* – Return graph of this type.

**Notes**

This function is not imported in the main namespace. To use it you have to explicitly import the bipartite package.

The sum of the two sequences must be equal: \(\text{sum}(\text{aseq}) = \text{sum}(\text{bseq})\) If no graph type is specified use MultiGraph with parallel edges. If you want a graph with no parallel edges use `create_using=Graph()` but then the resulting degree sequences might not be exact.

The nodes are assigned the attribute ‘bipartite’ with the value 0 or 1 to indicate which bipartite set the node belongs to.

**networkx.algorithms.bipartite.generators.reverse_havel_hakimi_graph**

**reverse_havel_hakimi_graph** *(aseq, bseq, create_using=None)*

Return a bipartite graph from two given degree sequences using a Havel-Hakimi style construction.

Nodes from set A are connected to nodes in the set B by connecting the highest degree nodes in set A to the lowest degree nodes in set B until all stubs are connected.

**Parameters**

- `aseq` *(list)* – Degree sequence for node set A.
- `bseq` *(list)* – Degree sequence for node set B.
- `create_using` *(NetworkX graph instance, optional)* – Return graph of this type.

**Notes**

This function is not imported in the main namespace. To use it you have to explicitly import the bipartite package.

The sum of the two sequences must be equal: \(\text{sum}(\text{aseq}) = \text{sum}(\text{bseq})\) If no graph type is specified use MultiGraph with parallel edges. If you want a graph with no parallel edges use `create_using=Graph()` but then the resulting degree sequences might not be exact.

The nodes are assigned the attribute ‘bipartite’ with the value 0 or 1 to indicate which bipartite set the node belongs to.
networkx.algorithms.bipartite.generators.alternating_havel_hakimi_graph

alternating_havel_hakimi_graph (aseq, bseq, create_using=None)

Return a bipartite graph from two given degree sequences using an alternating Havel-Hakimi style construction.

Nodes from the set A are connected to nodes in the set B by connecting the highest degree nodes in set A to
alternatively the highest and the lowest degree nodes in set B until all stubs are connected.

Parameters

• aseq (list) – Degree sequence for node set A.
• bseq (list) – Degree sequence for node set B.
• create_using (NetworkX graph instance, optional) – Return graph of this type.

Notes

This function is not imported in the main namespace. To use it you have to explicitly import the bipartite
package.

The sum of the two sequences must be equal: sum(aseq)=sum(bseq) If no graph type is specified use MultiGraph
with parallel edges. If you want a graph with no parallel edges use create_using=Graph() but then the resulting
degree sequences might not be exact.

The nodes are assigned the attribute ‘bipartite’ with the value 0 or 1 to indicate which bipartite set the node
belongs to.

networkx.algorithms.bipartite.generators.preferential_attachment_graph

preferential_attachment_graph (aseq, p, create_using=None, seed=None)

Create a bipartite graph with a preferential attachment model from a given single degree sequence.

Parameters

• aseq (list) – Degree sequence for node set A.
• p (float) – Probability that a new bottom node is added.
• create_using (NetworkX graph instance, optional) – Return graph of this type.
• seed (integer, optional) – Seed for random number generator.

References

Notes

This function is not imported in the main namespace. To use it you have to explicitly import the bipartite
package.

networkx.algorithms.bipartite.generators.random_graph

random_graph (n, m, p, seed=None, directed=False)

Return a bipartite random graph.

This is a bipartite version of the binomial (Erdős-Rényi) graph.
Parameters

- **n** (*int*) – The number of nodes in the first bipartite set.
- **m** (*int*) – The number of nodes in the second bipartite set.
- **p** (*float*) – Probability for edge creation.
- **seed** (*int, optional*) – Seed for random number generator (default=None).
- **directed** (*bool, optional (default=False*)) – If True return a directed graph

Notes

This function is not imported in the main namespace. To use it you have to explicitly import the bipartite package.

The bipartite random graph algorithm chooses each of the n*m (undirected) or 2*nm (directed) possible edges with probability p.

This algorithm is \(O(n + m)\) where \(m\) is the expected number of edges.

The nodes are assigned the attribute ‘bipartite’ with the value 0 or 1 to indicate which bipartite set the node belongs to.

See also:

- `gnp_random_graph()`, `configuration_model()`

References

`networkx.algorithms.bipartite.generators.gnmk_random_graph`

`gnmk_random_graph(n, m, k, seed=None, directed=False)`

Return a random bipartite graph \(G_{n,m,k}\).

Produces a bipartite graph chosen randomly out of the set of all graphs with n top nodes, m bottom nodes, and k edges.

Parameters

- **n** (*int*) – The number of nodes in the first bipartite set.
- **m** (*int*) – The number of nodes in the second bipartite set.
- **k** (*int*) – The number of edges
- **seed** (*int, optional*) – Seed for random number generator (default=None).
- **directed** (*bool, optional (default=False*)) – If True return a directed graph

Examples

```python
from networkx.algorithms import bipartite
G = bipartite.gnmk_random_graph(10, 20, 50)
```

See also:

- `gnm_random_graph()`
Notes

This function is not imported in the main namespace. To use it you have to explicitly import the bipartite package.

If \( k > m \times n \) then a complete bipartite graph is returned.

This graph is a bipartite version of the \( G_{nm} \) random graph model.

### 3.3.10 Covering

Functions related to graph covers.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
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<tbody>
<tr>
<td><code>min_edge_cover(G[, matching_algorithm])</code></td>
<td>Returns a set of edges which constitutes the minimum edge cover of the graph.</td>
</tr>
</tbody>
</table>

#### `networkx.algorithms.bipartite.covering.min_edge_cover`

`min_edge_cover(G, matching_algorithm=None)`

Returns a set of edges which constitutes the minimum edge cover of the graph.

The smallest edge cover can be found in polynomial time by finding a maximum matching and extending it greedily so that all nodes are covered.

**Parameters**

- `G (NetworkX graph)` – An undirected bipartite graph.
- `matching_algorithm (function)` – A function that returns a maximum cardinality matching in a given bipartite graph. The function must take one input, the graph \( G \), and return a dictionary mapping each node to its mate. If not specified, `hopcroft_karp_matching()` will be used. Other possibilities include `eppstein_matching()`.

**Returns**

A set of the edges in a minimum edge cover of the graph, given as pairs of nodes. It contains both the edges \((u, v)\) and \((v, u)\) for given nodes \( u \) and \( v \) among the edges of minimum edge cover.

**Return type**

`set`

#### Notes

An edge cover of a graph is a set of edges such that every node of the graph is incident to at least one edge of the set. A minimum edge cover is an edge covering of smallest cardinality.

Due to its implementation, the worst-case running time of this algorithm is bounded by the worst-case running time of the function `matching_algorithm`.

### 3.4 Boundary

Routines to find the boundary of a set of nodes.

An edge boundary is a set of edges, each of which has exactly one endpoint in a given set of nodes (or, in the case of directed graphs, the set of edges whose source node is in the set).
A node boundary of a set $S$ of nodes is the set of (out-)neighbors of nodes in $S$ that are outside $S$.

+-----------------+------------------------------------------------------------------------------------------------------------------+
<table>
<thead>
<tr>
<th>Syntax</th>
<th>Returns the edge boundary of <code>nbunch1</code>.*</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>edge_boundary</code></td>
<td><code>edge_boundary(G, nbunch1[, nbunch2, data, ...])</code></td>
</tr>
<tr>
<td><code>node_boundary</code></td>
<td><code>node_boundary(G, nbunch1[, nbunch2])</code></td>
</tr>
<tr>
<td>-----------------</td>
<td>------------------------------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>

### 3.4.1 `networkx.algorithms.boundary.edge_boundary`

**edge_boundary** *(G, nbunch1, nbunch2=None, data=False, keys=False, default=None)*

Returns the edge boundary of `nbunch1`.

The edge boundary of a set $S$ with respect to a set $T$ is the set of edges $(u, v)$ such that $u$ is in $S$ and $v$ is in $T$. If $T$ is not specified, it is assumed to be the set of all nodes not in $S$.

**Parameters**

- **G** *(NetworkX graph)*
- **nbunch1** *(iterable)* — Iterable of nodes in the graph representing the set of nodes whose edge boundary will be returned. (This is the set $S$ from the definition above.)
- **nbunch2** *(iterable)* — Iterable of nodes representing the target (or “exterior”) set of nodes. (This is the set $T$ from the definition above.) If not specified, this is assumed to be the set of all nodes in $G$ not in `nbunch1`.
- **keys** *(bool)* — This parameter has the same meaning as in `MultiGraph.edges()`.
- **data** *(bool or object)* — This parameter has the same meaning as in `MultiGraph.edges()`.
- **default** *(object)* — This parameter has the same meaning as in `MultiGraph.edges()`.

**Returns** An iterator over the edges in the boundary of `nbunch1` with respect to `nbunch2`. If `keys`, `data`, or `default` are specified and $G$ is a multigraph, then edges are returned with keys and/or data, as in `MultiGraph.edges()`.

**Return type** iterator

**Notes**

Any element of `nbunch` that is not in the graph $G$ will be ignored.

`nbunch1` and `nbunch2` are usually meant to be disjoint, but in the interest of speed and generality, that is not required here.

### 3.4.2 `networkx.algorithms.boundary.node_boundary`

**node_boundary** *(G, nbunch1, nbunch2=None)*

Returns the node boundary of `nbunch1`.

The node boundary of a set $S$ with respect to a set $T$ is the set of nodes $v$ in $T$ such that for some $u$ in $S$, there is an edge joining $u$ to $v$. If $T$ is not specified, it is assumed to be the set of all nodes not in $S$.

**Parameters**

- **G** *(NetworkX graph)*
- **nbunch1** *(iterable)* — Iterable of nodes in the graph representing the set of nodes whose node boundary will be returned. (This is the set $S$ from the definition above.)
• **nbunch2 (iterable)** – Iterable of nodes representing the target (or “exterior”) set of nodes. (This is the set \( T \) from the definition above.) If not specified, this is assumed to be the set of all nodes in \( G \) not in \( \text{nbunch1} \).

**Returns** The node boundary of \( \text{nbunch1} \) with respect to \( \text{nbunch2} \).

**Return type** set

**Notes**

Any element of \( \text{nbunch} \) that is not in the graph \( G \) will be ignored.

\( \text{nbunch1} \) and \( \text{nbunch2} \) are usually meant to be disjoint, but in the interest of speed and generality, that is not required here.

### 3.5 Bridges

Bridge-finding algorithms.

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#### 3.5.1 networkx.algorithms.bridges.bridges

**bridges** \((G, \text{root}=\text{None})\)

Generate all bridges in a graph.

A bridge in a graph is an edge whose removal causes the number of connected components of the graph to increase. Equivalently, a bridge is an edge that does not belong to any cycle.

**Parameters**

- **\( G \) (undirected graph)**
- **\( \text{root} \) (node (optional))** – A node in the graph \( G \). If specified, only the bridges in the connected component containing this node will be returned.

**Yields** \( e \) (edge) – An edge in the graph whose removal disconnects the graph (or causes the number of connected components to increase).

**Raises** NodeNotFound – If \( \text{root} \) is not in the graph \( G \).

**Examples**

The barbell graph with parameter zero has a single bridge:

```python
>>> G = nx.barbell_graph(10, 0)
>>> list(nx.bridges(G))
[(9, 10)]
```
Notes

This is an implementation of the algorithm described in [1]. An edge is a bridge if and only if it is not contained in any chain. Chains are found using the `networkx.chain_decomposition()` function.

Ignoring polylogarithmic factors, the worst-case time complexity is the same as the `networkx.chain_decomposition()` function, $O(m + n)$, where $n$ is the number of nodes in the graph and $m$ is the number of edges.

References

3.5.2 networkx.algorithms.bridges.has_bridges

`has_bridges(G, root=None)`

Decide whether a graph has any bridges.

A bridge in a graph is an edge whose removal causes the number of connected components of the graph to increase.

Parameters

- `G` *(undirected graph)*
- `root` *(node (optional)) – A node in the graph G. If specified, only the bridges in the connected component containing this node will be considered.*

Returns Whether the graph (or the connected component containing `root`) has any bridges.

Return type bool

Raises NodeNotFound – If `root` is not in the graph `G`.

Examples

The barbell graph with parameter zero has a single bridge:

```python
>>> G = nx.barbell_graph(10, 0)
>>> nx.has_bridges(G)
True
```

On the other hand, the cycle graph has no bridges:

```python
>>> G = nx.cycle_graph(5)
>>> nx.has_bridges(G)
False
```

Notes

This implementation uses the `networkx.bridges()` function, so it shares its worst-case time complexity, $O(m + n)$, ignoring polylogarithmic factors, where $n$ is the number of nodes in the graph and $m$ is the number of edges.
3.6 Centrality

3.6.1 Degree

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**networkx.algorithms.centrality.degree_centrality**

**degree_centrality** *(G)*

Compute the degree centrality for nodes.

The degree centrality for a node v is the fraction of nodes it is connected to.

- **Parameters** *G* *(graph)* – A networkx graph
- **Returns** *nodes* – Dictionary of nodes with degree centrality as the value.
- **Return type** dictionary

**Notes**

The degree centrality values are normalized by dividing by the maximum possible degree in a simple graph n-1 where n is the number of nodes in G.

For multigraphs or graphs with self loops the maximum degree might be higher than n-1 and values of degree centrality greater than 1 are possible.

**networkx.algorithms.centrality.in_degree_centrality**

**in_degree_centrality** *(G)*

Compute the in-degree centrality for nodes.

The in-degree centrality for a node v is the fraction of nodes its incoming edges are connected to.

- **Parameters** *G* *(graph)* – A NetworkX graph
- **Returns** *nodes* – Dictionary of nodes with in-degree centrality as values.
- **Return type** dictionary

**Raises** NetworkXNotImplemented: – If G is undirected.

**See also:**

`degree_centrality()`, `out_degree_centrality()`

**Notes**

The degree centrality values are normalized by dividing by the maximum possible degree in a simple graph n-1 where n is the number of nodes in G.
For multigraphs or graphs with self loops the maximum degree might be higher than n-1 and values of degree centrality greater than 1 are possible.

**networkx.algorithms.centrality.out_degree_centrality**

out_degree_centrality \((G)\)

Compute the out-degree centrality for nodes.

The out-degree centrality for a node \(v\) is the fraction of nodes its outgoing edges are connected to.

**Parameters**

- \(G\) (graph) – A NetworkX graph

**Returns**

- nodes – Dictionary of nodes with out-degree centrality as values.

**Return type**
dictionary

**Raises**

- NetworkXNotImplemented: – If \(G\) is undirected.

**See also:**

degree_centrality(), in_degree_centrality()

**Notes**

The degree centrality values are normalized by dividing by the maximum possible degree in a simple graph \(n-1\) where \(n\) is the number of nodes in \(G\).

For multigraphs or graphs with self loops the maximum degree might be higher than \(n-1\) and values of degree centrality greater than 1 are possible.

### 3.6.2 Eigenvector

**eigenvector_centrality**(G[, max_iter, tol, ...]) Compute the eigenvector centrality for the graph \(G\).

Eigenvector centrality computes the centrality for a node based on the centrality of its neighbors. The eigenvector centrality for node \(i\) is

\[ Ax = \lambda x \]

where \(A\) is the adjacency matrix of the graph \(G\) with eigenvalue \(\lambda\). By virtue of the Perron–Frobenius theorem, there is a unique and positive solution if \(\lambda\) is the largest eigenvalue associated with the eigenvector of the adjacency matrix \(A\) (\(^2\)).

**Parameters**

- \(G\) (graph) – A networkx graph

---

• **max_iter** (*integer, optional (default=100)*) – Maximum number of iterations in power method.

• **tol** (*float, optional (default=1.0e-6)*) – Error tolerance used to check convergence in power method iteration.

• **nstart** (*dictionary, optional (default=None)*) – Starting value of eigenvector iteration for each node.

• **weight** (*None or string, optional (default=None)*) – If None, all edge weights are considered equal. Otherwise holds the name of the edge attribute used as weight.

**Returns**

- **nodes** – Dictionary of nodes with eigenvector centrality as the value.

**Return type** dictionary

**Examples**

```python
>>> G = nx.path_graph(4)
>>> centrality = nx.eigenvector_centrality(G)
>>> sorted((v, '{:0.2f}'.format(c)) for v, c in centrality.items())
[(0, '0.37'), (1, '0.60'), (2, '0.60'), (3, '0.37')]
```

**Raises**

- **NetworkXPointlessConcept** – If the graph G is the null graph.

- **NetworkXError** – If each value in nstart is zero.

- **PowerIterationFailedConvergence** – If the algorithm fails to converge to the specified tolerance within the specified number of iterations of the power iteration method.

**See also:**

`eigenvector_centrality_numpy()`, `pagerank()`, `hits()`

**Notes**

The measure was introduced by\(^1\) and is discussed in\(^2\).

The power iteration method is used to compute the eigenvector and convergence is not guaranteed. Our method stops after `max_iter` iterations or when the change in the computed vector between two iterations is smaller than an error tolerance of `G.number_of_nodes() * tol`. This implementation uses \((A + I)\) rather than the adjacency matrix \(A\) because it shifts the spectrum to enable discerning the correct eigenvector even for networks with multiple dominant eigenvalues.

For directed graphs this is “left” eigenvector centrality which corresponds to the in-edges in the graph. For out-edges eigenvector centrality first reverse the graph with `G.reverse()`.


---

3.6. Centrality 175
References
	networkx.algorithms.centrality.eigenvector_centrality_numpy

eigenvector_centrality_numpy \((G, \text{weight}=\text{None}, \text{max_iter}=50, \text{tol}=0)\)

Compute the eigenvector centrality for the graph \(G\).

Eigenvector centrality computes the centrality for a node based on the centrality of its neighbors. The eigenvector centrality for node \(i\) is

\[Ax = \lambda x\]

where \(A\) is the adjacency matrix of the graph \(G\) with eigenvalue \(\lambda\). By virtue of the Perron–Frobenius theorem, there is a unique and positive solution if \(\lambda\) is the largest eigenvalue associated with the eigenvector of the adjacency matrix \(A\)\(^2\).

Parameters

- \(G\) (graph) – A networkx graph
- \text{weight} (\text{None or string, optional (default=\text{None})}) – The name of the edge attribute used as weight. If None, all edge weights are considered equal.
- \text{max_iter} (\text{integer, optional (default=100)}) – Maximum number of iterations in power method.
- \text{tol} (\text{float, optional (default=1.0e-6)}) – Relative accuracy for eigenvalues (stopping criterion). The default value of 0 implies machine precision.

Returns

- \text{nodes} – Dictionary of nodes with eigenvector centrality as the value.
- \text{Return type} dictionary

Examples

```python
>>> G = nx.path_graph(4)
>>> centrality = nx.eigenvector_centrality_numpy(G)
>>> print([''.format(node, centrality[\node]) for node in centrality])
['0 0.37', '1 0.60', '2 0.60', '3 0.37']
```

See also:
eigenvector_centrality(), pagerank(), hits()

Notes

The measure was introduced by\(^1\).

This algorithm uses the SciPy sparse eigenvalue solver (ARPACK) to find the largest eigenvalue/eigenvector pair.

For directed graphs this is “left” eigenvector centrality which corresponds to the in-edges in the graph. For out-edges eigenvector centrality first reverse the graph with \(G.reverse()\).


**References**

networkx.algorithms.centrality.katz_centrality

**katz_centrality** *(G, alpha=0.1, beta=1.0, max_iter=1000, tol=1e-06, nstart=None, normalized=True, weight=None)*

Compute the Katz centrality for the nodes of the graph G.

Katz centrality computes the centrality for a node based on the centrality of its neighbors. It is a generalization of the eigenvector centrality. The Katz centrality for node \( i \) is

\[
x_i = \alpha \sum_j A_{ij} x_j + \beta,
\]

where \( A \) is the adjacency matrix of graph G with eigenvalues \( \lambda \).

The parameter \( \beta \) controls the initial centrality and

\[
\alpha < \frac{1}{\lambda_{\text{max}}}.
\]

Katz centrality computes the relative influence of a node within a network by measuring the number of the immediate neighbors (first degree nodes) and also all other nodes in the network that connect to the node under consideration through these immediate neighbors.

Extra weight can be provided to immediate neighbors through the parameter \( \beta \). Connections made with distant neighbors are, however, penalized by an attenuation factor \( \alpha \) which should be strictly less than the inverse largest eigenvalue of the adjacency matrix in order for the Katz centrality to be computed correctly. More information is provided in\(^1\).

**Parameters**

- **G** *(graph)* – A NetworkX graph.
- **alpha** *(float)* – Attenuation factor
- **beta** *(scalar or dictionary, optional (default=1.0))* – Weight attributed to the immediate neighborhood. If not a scalar, the dictionary must have an value for every node.
- **max_iter** *(integer, optional (default=1000))* – Maximum number of iterations in power method.
- **tol** *(float, optional (default=1.0e-6))* – Error tolerance used to check convergence in power method iteration.
- **nstart** *(dictionary, optional)* – Starting value of Katz iteration for each node.
- **normalized** *(bool, optional (default=True))* – If True normalize the resulting values.
- **weight** *(None or string, optional (default=None))* – If None, all edge weights are considered equal. Otherwise holds the name of the edge attribute used as weight.

**Returns**  
**nodes** – Dictionary of nodes with Katz centrality as the value.

**Return type**  
dictionary

**Raises**

- **NetworkXError** – If the parameter beta is not a scalar but lacks a value for at least one node
- **PowerIterationFailedConvergence** – If the algorithm fails to converge to the specified tolerance within the specified number of iterations of the power iteration method.

---

Examples

```
>>> import math
>>> G = nx.path_graph(4)
>>> phi = (1 + math.sqrt(5)) / 2.0  # largest eigenvalue of adj matrix
>>> centrality = nx.katz_centrality(G, 1/phi - 0.01)
>>> for n, c in sorted(centrality.items()):...
...   print("%d %0.2f" % (n, c))
0 0.37
1 0.60
2 0.60
3 0.37
```

See also:

`katz_centrality_numpy()`, `eigenvector_centrality()`, `eigenvector_centrality_numpy()`, `pagerank()`, `hits()`

Notes

Katz centrality was introduced by\(^2\).

This algorithm it uses the power method to find the eigenvector corresponding to the largest eigenvalue of the adjacency matrix of G. The parameter \(\alpha\) should be strictly less than the inverse of largest eigenvalue of the adjacency matrix for the algorithm to converge. You can use \(\max(nx.adjacency_spectrum(G))\) to get \(\lambda_{\text{max}}\) the largest eigenvalue of the adjacency matrix. The iteration will stop after \(\text{max}_\text{iter}\) iterations or an error tolerance of \(\text{number}_\text{of}_\text{nodes}(G) \times \text{tol}\) has been reached.

When \(\alpha = 1/\lambda_{\text{max}}\) and \(\beta = 0\), Katz centrality is the same as eigenvector centrality.

For directed graphs this finds “left” eigenvectors which corresponds to the in-edges in the graph. For out-edges Katz centrality first reverse the graph with \(G\text{.reverse()}\).

References

`networkx.algorithms.centrality.katz_centrality_numpy`

`katz_centrality_numpy(G, alpha=0.1, beta=1.0, normalized=True, weight=None)`

Compute the Katz centrality for the graph G.

Katz centrality computes the centrality for a node based on the centrality of its neighbors. It is a generalization of the eigenvector centrality. The Katz centrality for node \(i\) is

\[
x_i = \alpha \sum_j A_{ij} x_j + \beta,
\]

where \(A\) is the adjacency matrix of graph G with eigenvalues \(\lambda\).

The parameter \(\beta\) controls the initial centrality and

\[
\alpha < \frac{1}{\lambda_{\text{max}}}.
\]

Katz centrality computes the relative influence of a node within a network by measuring the number of the immediate neighbors (first degree nodes) and also all other nodes in the network that connect to the node under consideration through these immediate neighbors.

Extra weight can be provided to immediate neighbors through the parameter $\beta$. Connections made with distant neighbors are, however, penalized by an attenuation factor $\alpha$ which should be strictly less than the inverse largest eigenvalue of the adjacency matrix in order for the Katz centrality to be computed correctly. More information is provided in\(^1\).

**Parameters**

- **G** *(graph)* – A NetworkX graph
- **alpha** *(float)* – Attenuation factor
- **beta** *(scalar or dictionary, optional (default=1.0))* – Weight attributed to the immediate neighborhood. If not a scalar the dictionary must have an value for every node.
- **normalized** *(bool)* – If True normalize the resulting values.
- **weight** *(None or string, optional)* – If None, all edge weights are considered equal. Otherwise holds the name of the edge attribute used as weight.

**Returns**

- **nodes** – Dictionary of nodes with Katz centrality as the value.

**Return type**

- **dictionary**

**Raises**

- **NetworkXError** – If the parameter beta is not a scalar but lacks a value for at least one node

**Examples**

```python
>>> import math
>>> G = nx.path_graph(4)
>>> phi = (1 + math.sqrt(5)) / 2.0  # largest eigenvalue of adj matrix
>>> centrality = nx.katz_centrality_numpy(G, 1/phi)
>>> for n, c in sorted(centrality.items()):
...    print("%d %0.2f" % (n, c))
0 0.37
1 0.60
2 0.60
3 0.37
```

**See also:**

- `katz_centrality()`, `eigenvector_centrality_numpy()`, `eigenvector_centrality()`, `pagerank()`, `hits()`

**Notes**

Katz centrality was introduced by\(^2\).

This algorithm uses a direct linear solver to solve the above equation. The parameter alpha should be strictly less than the inverse of largest eigenvalue of the adjacency matrix for there to be a solution. You can use `max(nx.adjacency_spectrum(G))` to get $\lambda_{\text{max}}$ the largest eigenvalue of the adjacency matrix.

---


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### 3.6. Centrality
When $\alpha = 1/\lambda_{\text{max}}$ and $\beta = 0$, Katz centrality is the same as eigenvector centrality.

For directed graphs this finds “left” eigenvectors which corresponds to the in-edges in the graph. For out-edges
Katz centrality first reverse the graph with $G\text{.reverse()}$.

References

3.6.3 Closeness

closeness_centrality($G$, $u$, $distance$, ...) Compute closeness centrality for nodes.

networkx.algorithms.centrality.closeness_centrality
closeness_centrality($G$, $u=None$, $distance=None$, $wf\text{\_improved=True}$, $reverse=False$)
Compute closeness centrality for nodes.

Closeness centrality\(^1\) of a node $u$ is the reciprocal of the average shortest path distance to $u$ over all $n-1$
reachable nodes.

\[
C(u) = \frac{n - 1}{\sum_{v=1}^{n-1} d(v, u)},
\]

where $d(v, u)$ is the shortest-path distance between $v$ and $u$, and $n$ is the number of nodes that can reach $u$.

Notice that higher values of closeness indicate higher centrality.

Wasserman and Faust propose an improved formula for graphs with more than one connected component. The
result is “a ratio of the fraction of actors in the group who are reachable, to the average distance” from the
reachable actors\(^2\). You might think this scale factor is inverted but it is not. As is, nodes from small components
receive a smaller closeness value. Letting $N$ denote the number of nodes in the graph,

\[
C_{WF}(u) = \frac{n - 1}{N - 1} \frac{n - 1}{\sum_{v=1}^{n-1} d(v, u)},
\]

Parameters

- $G$ (graph) – A NetworkX graph
- $u$ (node, optional) – Return only the value for node $u$
- $distance$ (edge attribute key, optional (default=None)) – Use the specified edge attribute as
  the edge distance in shortest path calculations
- $wf\text{\_improved}$ (bool, optional (default=True)) – If True, scale by the fraction of nodes reachable. This gives the
  Wasserman and Faust improved formula. For single component graphs
  it is the same as the original formula.
- $reverse$ (bool, optional (default=False)) – If True and $G$ is a digraph, reverse the edges of
  $G$, using successors instead of predecessors.

Returns

nodes – Dictionary of nodes with closeness centrality as the value.

Return type dictionary

See also:

betweenness_centrality(), load_centrality(), eigenvector_centrality(),
degree_centrality()

socialnetworks/papers/freeman79-centrality.pdf

Notes

The closeness centrality is normalized to \((n-1) / (|G|-1)\) where \(n\) is the number of nodes in the connected part of graph containing the node. If the graph is not completely connected, this algorithm computes the closeness centrality for each connected part separately scaled by that part’s size.

If the ‘distance’ keyword is set to an edge attribute key then the shortest-path length will be computed using Dijkstra’s algorithm with that edge attribute as the edge weight.

References

3.6.4 Current Flow Closeness

current_flow_closeness_centrality(G[, weight=None, dtype=<type 'float'>, solver='lu'])

Compute current-flow closeness centrality for nodes.

Current-flow closeness centrality is variant of closeness centrality based on effective resistance between nodes in a network. This metric is also known as information centrality.

Parameters

- G (graph) – A NetworkX graph.
- weight (None or string, optional (default=None)) – If None, all edge weights are considered equal. Otherwise holds the name of the edge attribute used as weight.
- dtype (data type (default=float)) – Default data type for internal matrices. Set to np.float32 for lower memory consumption.
- solver (string (default='lu')) – Type of linear solver to use for computing the flow matrix.
  Options are “full” (uses most memory), “lu” (recommended), and “cg” (uses least memory).

Returns nodes – Dictionary of nodes with current flow closeness centrality as the value.

Return type dictionary

See also:
closeness_centrality()
References

3.6.5 (Shortest Path) Betweenness

\textit{betweenness\_centrality}(G[, k, normalized, ...]) Compute the shortest-path betweenness centrality for nodes.

\textit{edge\_betweenness\_centrality}(G[, k, ...]) Compute betweenness centrality for edges.

\textit{betweenness\_centrality\_subset}(G, sources, ...) Compute betweenness centrality for a subset of nodes.

\textit{edge\_betweenness\_centrality\_subset}(G, ..., [...]) Compute betweenness centrality for edges for a subset of nodes.

networkx.algorithms.centrality.betweenness\_centrality

\textit{betweenness\_centrality}(G, k=None, normalized=True, weight=None, endpoints=False, seed=None) Compute the shortest-path betweenness centrality for nodes.

Betweenness centrality of a node \( v \) is the sum of the fraction of all-pairs shortest paths that pass through \( v \)

\[
    c_B(v) = \sum_{s,t \in V} \frac{\sigma(s,t|v)}{\sigma(s,t)}
\]

where \( V \) is the set of nodes, \( \sigma(s,t) \) is the number of shortest \( (s,t) \)-paths, and \( \sigma(s,t|v) \) is the number of those paths passing through some node \( v \) other than \( s, t \). If \( s = t \), \( \sigma(s,t) = 1 \), and if \( v \in s, t \), \( \sigma(s,t|v) = 0 \).²

Parameters

\begin{itemize}
    \item \texttt{G (graph)} – A NetworkX graph.
    \item \texttt{k (int, optional (default=None))} – If \( k \) is not None use \( k \) node samples to estimate betweenness. The value of \( k \leq n \) where \( n \) is the number of nodes in the graph. Higher values give better approximation.
    \item \texttt{normalized (bool, optional)} – If True the betweenness values are normalized by \( 2/n(n-1) \) for graphs, and \( 1/(n(n-1)(n-2)) \) for directed graphs where \( n \) is the number of nodes in \( G \).
    \item \texttt{weight (None or string, optional (default=None))} – If None, all edge weights are considered equal. Otherwise holds the name of the edge attribute used as weight.
    \item \texttt{endpoints (bool, optional)} – If True include the endpoints in the shortest path counts.
\end{itemize}

Returns \texttt{nodes} – Dictionary of nodes with betweenness centrality as the value.

Return type \texttt{dictionary}

See also:

\textit{edge\_betweenness\_centrality()}, \textit{load\_centrality()}

Notes

The algorithm is from Ulrik Brandes. See for the original first published version and for details on algorithms for variations and related metrics.

For approximate betweenness calculations set k=#samples to use k nodes (“pivots”) to estimate the betweenness values. For an estimate of the number of pivots needed see.

For weighted graphs the edge weights must be greater than zero. Zero edge weights can produce an infinite number of equal length paths between pairs of nodes.

References

networkx.algorithms.centrality.edge_betweenness_centrality

`edge_betweenness_centrality(G, k=None, normalized=True, weight=None, seed=None)`

Compute betweenness centrality for edges.

Betweenness centrality of an edge e is the sum of the fraction of all-pairs shortest paths that pass through e

\[ c_B(e) = \sum_{s,t \in V} \frac{\sigma(s, t|e)}{\sigma(s, t)} \]

where \( V \) is the set of nodes, \( \sigma(s, t) \) is the number of shortest \((s, t)\)-paths, and \( \sigma(s, t|e) \) is the number of those paths passing through edge \( e \).

Parameters

- G (graph) – A NetworkX graph.
- k (int, optional (default=None)) – If k is not None use k node samples to estimate betweenness. The value of k <= n where n is the number of nodes in the graph. Higher values give better approximation.
- normalized (bool, optional) – If True the betweenness values are normalized by \( 2/(n(n-1)) \) for graphs, and \( 1/(n(n-1)) \) for directed graphs where \( n \) is the number of nodes in G.
- weight (None or string, optional (default=None)) – If None, all edge weights are considered equal. Otherwise holds the name of the edge attribute used as weight.

Returns edges – Dictionary of edges with betweenness centrality as the value.

Return type dictionary

See also:

`betweenness_centrality()`, `edge_load()`
For weighted graphs the edge weights must be greater than zero. Zero edge weights can produce an infinite number of equal length paths between pairs of nodes.

References

networkx.algorithms.centrality.betweenness_centrality_subset

betweenness_centrality_subset (G, sources, targets, normalized=False, weight=None)

Compute betweenness centrality for a subset of nodes.

\[ c_B(v) = \sum_{s \in S, t \in T} \frac{\sigma(s, t|v)}{\sigma(s, t)} \]

where \( S \) is the set of sources, \( T \) is the set of targets, \( \sigma(s, t) \) is the number of shortest \((s, t)\)-paths, and \( \sigma(s, t|v) \) is the number of those paths passing through some node \( v \) other than \( s, t \). If \( s = t \), \( \sigma(s, t) = 1 \), and if \( v \in s, t \), \( \sigma(s, t|v) = 0^2 \).

Parameters

- **G** (graph) – A NetworkX graph.
- **sources** (list of nodes) – Nodes to use as sources for shortest paths in betweenness
- **targets** (list of nodes) – Nodes to use as targets for shortest paths in betweenness
- **normalized** (bool, optional) – If True the betweenness values are normalized by \( \frac{2}{(n-1)(n-2)} \) for graphs, and \( \frac{1}{(n-1)(n-2)} \) for directed graphs where \( n \) is the number of nodes in \( G \).
- **weight** (None or string, optional (default=None)) – If None, all edge weights are considered equal. Otherwise holds the name of the edge attribute used as weight.

Returns **nodes** – Dictionary of nodes with betweenness centrality as the value.

Return type **dictionary**

See also:

edge_betweenness_centrality(), load_centrality()

Notes

The basic algorithm is from\(^1\).

For weighted graphs the edge weights must be greater than zero. Zero edge weights can produce an infinite number of equal length paths between pairs of nodes.

The normalization might seem a little strange but it is the same as in betweenness_centrality() and is designed to make betweenness_centrality(G) be the same as betweenness_centrality_subset(G,sources=G.nodes(),targets=G.nodes()).


References

networkx.algorithms.centrality.edge_betweenness_centrality_subset

decision_of_betweenness_centrality_subset \( G, \text{sources}, \text{targets}, \text{normalized}=\text{False}, \text{weight}=\text{None} \)

Compute betweenness centrality for edges for a subset of nodes.

\[
c_B(v) = \sum_{s \in S, t \in T} \frac{\sigma(s, t|e)}{\sigma(s, t)}
\]

where \( S \) is the set of sources, \( T \) is the set of targets, \( \sigma(s, t) \) is the number of shortest \((s, t)\)-paths, and \( \sigma(s, t|e) \) is the number of those paths passing through edge \( e \).

Parameters

- \( G \) (graph) – A networkx graph.
- \( \text{sources} \) (list of nodes) – Nodes to use as sources for shortest paths in betweenness.
- \( \text{targets} \) (list of nodes) – Nodes to use as targets for shortest paths in betweenness.
- \( \text{normalized} \) (bool, optional) – If True the betweenness values are normalized by \( 2/(n(n-1)) \) for graphs, and \( 1/(n(n-1)) \) for directed graphs where \( n \) is the number of nodes in \( G \).
- \( \text{weight} \) (None or string, optional (default=None)) – If None, all edge weights are considered equal. Otherwise holds the name of the edge attribute used as weight.

Returns edges – Dictionary of edges with Betweenness centrality as the value.

Return type dictionary

See also:

\( \text{betweenness_centrality()}, \text{edge_load()} \)

Notes

The basic algorithm is from\(^1\).

For weighted graphs the edge weights must be greater than zero. Zero edge weights can produce an infinite number of equal length paths between pairs of nodes.

The normalization might seem a little strange but it is the same as in \( \text{edge_betweenness_centrality()} \) and is designed to make \( \text{edge_betweenness_centrality}(G) \) be the same as \( \text{edge_betweenness_centrality_subset}(G, \text{sources}=G.\text{nodes()}, \text{targets}=G.\text{nodes}()) \).

References

3.6.6 Current Flow Betweenness


current_flow_betweenness_centrality(G, ...)

edge_current_flow_betweenness_centrality(G)

approximate_current_flow_betweenness_centrality(G, ...)

current_flow_betweenness_centrality_subset(G, ...)

edge_current_flow_betweenness_centrality_subset(G, ...)

networkx.algorithms.centrality.current_flow_betweenness_centrality

current_flow_betweenness_centrality(G, normalized=True, weight=None, dtype=float, solver='full')

Compute current-flow betweenness centrality for nodes.
Current-flow betweenness centrality uses an electrical current model for information spreading in contrast to betweenness centrality which uses shortest paths.

Current-flow betweenness centrality is also known as random-walk betweenness centrality\(^2\).

Parameters

- **G** (graph) – A NetworkX graph
- **normalized** (bool, optional (default=True)) – If True the betweenness values are normalized by \(2/((n-1)(n-2))\) where \(n\) is the number of nodes in \(G\).
- **weight** (string or None, optional (default=None)) – Key for edge data used as the edge weight. If None, then use 1 as each edge weight.
- **dtype** (data type (float)) – Default data type for internal matrices. Set to np.float32 for lower memory consumption.
- **solver** (string (default= 'lu')) – Type of linear solver to use for computing the flow matrix. Options are “full” (uses most memory), “lu” (recommended), and “cg” (uses least memory).

Returns **nodes** – Dictionary of nodes with betweenness centrality as the value.

Return type **dictionary**

See also:

approximate_current_flow_betweenness_centrality(), betweenness_centrality(), edge_betweenness_centrality(), edge_current_flow_betweenness_centrality()

Notes

Current-flow betweenness can be computed in \(O(I(n - 1) + mn \log n)\) time\(^1\), where \(I(n - 1)\) is the time needed to compute the inverse Laplacian. For a full matrix this is \(O(n^3)\) but using sparse methods you can achieve \(O(mn \sqrt{k})\) where \(k\) is the Laplacian matrix condition number.

The space required is \(O(nw)\) where \(w\) is the width of the sparse Laplacian matrix. Worse case is \(w = n\) for \(O(n^2)\).


If the edges have a ‘weight’ attribute they will be used as weights in this algorithm. Unspecified weights are set to 1.

References

networkx.algorithms.centrality.edge_current_flow_betweenness_centrality

edge_current_flow_betweenness_centrality(G, normalized=True, weight=None, dtype=float, solver='full')

Compute current-flow betweenness centrality for edges.

Current-flow betweenness centrality uses an electrical current model for information spreading in contrast to betweenness centrality which uses shortest paths.

Current-flow betweenness centrality is also known as random-walk betweenness centrality.

Parameters

- G (graph) – A NetworkX graph
- normalized (bool, optional (default=True)) – If True the betweenness values are normalized by \(2/((n-1)(n-2))\) where \(n\) is the number of nodes in \(G\).
- weight (string or None, optional (default=None)) – Key for edge data used as the edge weight. If None, then use 1 as each edge weight.
- dtype (data type (default=float)) – Default data type for internal matrices. Set to np.float32 for lower memory consumption.
- solver (string (default='lu')) – Type of linear solver to use for computing the flow matrix. Options are “full” (uses most memory), “lu” (recommended), and “cg” (uses least memory).

Returns

nodes – Dictionary of edge tuples with betweenness centrality as the value.

Return type

dictionary

Raises

NetworkXError – The algorithm does not support DiGraphs. If the input graph is an instance of DiGraph class, NetworkXError is raised.

See also:

betweenness_centrality(), edge_betweenness_centrality(), current_flow_betweenness_centrality()

Notes

Current-flow betweenness can be computed in \(O(I(n - 1) + mn \log n)\) time\(^1\), where \(I(n - 1)\) is the time needed to compute the inverse Laplacian. For a full matrix this is \(O(n^3)\) but using sparse methods you can achieve \(O(mn \sqrt{k})\) where \(k\) is the Laplacian matrix condition number.

The space required is \(O(nw)\) where \(w\) is the width of the sparse Laplacian matrix. Worse case is \(w = n\) for \(O(n^2)\).

If the edges have a ‘weight’ attribute they will be used as weights in this algorithm. Unspecified weights are set to 1.

---


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approximate_current_flow_betweenness_centrality \((G, \ normalized=True, \ weight=None, \\
\text{dtype}=\text{<type 'float'>}, \ solver='full', \\
\text{epsilon}=0.5, \ kmax=10000)\)

Compute the approximate current-flow betweenness centrality for nodes.

Approximates the current-flow betweenness centrality within absolute error of epsilon with high probability\(^1\).

**Parameters**

- \(G\) (graph) – A NetworkX graph
- \(\text{normalized}\) (bool, optional (default=True)) – If True the betweenness values are normalized by \(2/(n-1)(n-2)\) where \(n\) is the number of nodes in \(G\).
- \(\text{weight}\) (string or None, optional (default=None)) – Key for edge data used as the edge weight. If None, then use 1 as each edge weight.
- \(\text{dtype}\) (data type (float)) – Default data type for internal matrices. Set to np.float32 for lower memory consumption.
- \(\text{solver}\) (string (default='lu')) – Type of linear solver to use for computing the flow matrix. Options are “full” (uses most memory), “lu” (recommended), and “cg” (uses least memory).
- \(\text{epsilon}\) (float) – Absolute error tolerance.
- \(\text{kmax}\) (int) – Maximum number of sample node pairs to use for approximation.

**Returns** nodes – Dictionary of nodes with betweenness centrality as the value.

**Return type** dictionary

**See also:**

`current_flow_betweenness_centrality()`

**Notes**

The running time is \(O((1/e^2)m\sqrt{k}\log n)\) and the space required is \(O(m)\) for \(n\) nodes and \(m\) edges.

If the edges have a ‘weight’ attribute they will be used as weights in this algorithm. Unspecified weights are set to 1.

**References**

networkx.algorithms.centrality.current_flow_betweenness_centrality_subset

current_flow_betweenness_centrality_subset \((G, \ sources, \ targets, \ normalized=True, \\
\text{weight}=\text{None}, \ \text{dtype}=\text{<type 'float'>}, \\
\text{solver}='lu')\)

Compute current-flow betweenness centrality for subsets of nodes.

Current-flow betweenness centrality uses an electrical current model for information spreading in contrast to betweenness centrality which uses shortest paths.

Current-flow betweenness centrality is also known as random-walk betweenness centrality\(^2\).

**Parameters**

- \(G\) (graph) – A NetworkX graph
- **sources** (list of nodes) – Nodes to use as sources for current
- **targets** (list of nodes) – Nodes to use as sinks for current
- **normalized** (bool, optional (default=True)) – If True the betweenness values are normalized by \(b=b/(n-1)(n-2)\) where \(n\) is the number of nodes in \(G\).
- **weight** (string or None, optional (default=None)) – Key for edge data used as the edge weight. If None, then use 1 as each edge weight.
- **dtype** (data type (float)) – Default data type for internal matrices. Set to np.float32 for lower memory consumption.
- **solver** (string (default='lu')) – Type of linear solver to use for computing the flow matrix. Options are “full” (uses most memory), “lu” (recommended), and “cg” (uses least memory).

**Returns** nodes – Dictionary of nodes with betweenness centrality as the value.

**Return type** dictionary

**See also:**

approximate_current_flow_betweenness_centrality(), betweenness_centrality(), edge_betweenness_centrality(), edge_current_flow_betweenness_centrality()

**Notes**

Current-flow betweenness can be computed in \(O(I(n-1) + mn \log n)\) time\(^1\), where \(I(n-1)\) is the time needed to compute the inverse Laplacian. For a full matrix this is \(O(n^3)\) but using sparse methods you can achieve \(O(nm\sqrt{k})\) where \(k\) is the Laplacian matrix condition number.

The space required is \(O(nw)\) where \(w\) is the width of the sparse Laplacian matrix. Worse case is \(w = n\) for \(O(n^2)\).

If the edges have a ‘weight’ attribute they will be used as weights in this algorithm. Unspecified weights are set to 1.

**References**

networkx.algorithms.centrality.edge_current_flow_betweenness_centrality_subset

**edge_current_flow_betweenness_centrality_subset** (\(G\), **sources**, **targets**, **normalized**=True, **weight**=None, **dtype**=<type 'float'>, **solver**='lu')

Compute current-flow betweenness centrality for edges using subsets of nodes.

Current-flow betweenness centrality uses an electrical current model for information spreading in contrast to betweenness centrality which uses shortest paths.

Current-flow betweenness centrality is also known as random-walk betweenness centrality\(^2\).

---


Parameters

- **G** *(graph)* – A NetworkX graph
- **sources** *(list of nodes)* – Nodes to use as sources for current
- **targets** *(list of nodes)* – Nodes to use as sinks for current
- **normalized** *(bool, optional (default=True))* – If True the betweenness values are normalized by \(b=b/(n-1)(n-2)\) where \(n\) is the number of nodes in \(G\).
- **weight** *(string or None, optional (default=None))* – Key for edge data used as the edge weight. If None, then use 1 as each edge weight.
- **dtype** *(data type (float))* – Default data type for internal matrices. Set to np.float32 for lower memory consumption.
- **solver** *(string (default='lu'))* – Type of linear solver to use for computing the flow matrix. Options are “full” (uses most memory), “lu” (recommended), and “cg” (uses least memory).

Returns **nodes** – Dictionary of edge tuples with betweenness centrality as the value.

Return type **dict**

See also:

- `betweenness_centrality()`, `edge_betweenness_centrality()`, `current_flow_betweenness_centrality()`

Notes

Current-flow betweenness can be computed in \(O(I(n-1) + mn \log n)\) time\(^1\), where \(I(n-1)\) is the time needed to compute the inverse Laplacian. For a full matrix this is \(O(n^3)\) but using sparse methods you can achieve \(O(nm\sqrt{k})\) where \(k\) is the Laplacian matrix condition number.

The space required is \(O(nw)\) where \(w\) is the width of the sparse Laplacian matrix. Worse case is \(w = n\) for \(O(n^2)\).

If the edges have a ‘weight’ attribute they will be used as weights in this algorithm. Unspecified weights are set to 1.

References

3.6.7 Communicability Betweenness

\[ communicability_betweenness_centrality(G[, normalized=True]) \]

networkx.algorithms.centrality.communicability_betweenness_centrality

Communicability betweenness measure makes use of the number of walks connecting every pair of nodes as the basis of a betweenness centrality measure.

Parameters `G (graph)`

Returns `nodes` – Dictionary of nodes with communicability betweenness as the value.

Return type `dictionary`

Raises `NetworkXError` – If the graph is not undirected and simple.

Notes

Let $G=(V,E)$ be a simple undirected graph with $n$ nodes and $m$ edges, and $A$ denote the adjacency matrix of $G$.

Let $G(r)=(V,E(r))$ be the graph resulting from removing all edges connected to node $r$ but not the node itself.

The adjacency matrix for $G(r)$ is $A+E(r)$, where $E(r)$ has nonzeros only in row and column $r$.

The subraph betweenness of a node $r$ is

$$\omega_r = \frac{1}{C} \sum_p \sum_q G_{pq}^{prq}, p \neq q, q \neq r,$$

where $G_{pq}^{prq}=(e^{A}_{pq} - (e^{A+E(r)})_{pq})$ is the number of walks involving node $r$, $G_{pq}=(e^{A})_{pq}$ is the number of closed walks starting at node $p$ and ending at node $q$, and $C=(n-1)^2-(n-1)$ is a normalization factor equal to the number of terms in the sum.

The resulting $\omega_r$ takes values between zero and one. The lower bound cannot be attained for a connected graph, and the upper bound is attained in the star graph.

References

Examples

```python
>>> G = nx.Graph([(0,1),(1,2),(1,5),(5,4),(2,4),(2,3),(4,3),(3,6)])
>>> cbc = nx.communicability_betweenness_centrality(G)
```

3.6.8 Load

**load_centrality***(G[, v, cutoff, normalized,...])** Compute load centrality for nodes.

**edge_load_centrality***(G[, cutoff])** Compute edge load.

networkx.algorithms.centrality.load_centrality

**load_centrality***(G, v=None, cutoff=None, normalized=True, weight=None)**

Compute load centrality for nodes.

The load centrality of a node is the fraction of all shortest paths that pass through that node.

Parameters

- **G (graph)** – A networkx graph.

---

• **normalized** (bool, optional (default=True)) – If True the betweenness values are normalized by b=b/(n-1)(n-2) where n is the number of nodes in G.

• **weight** (None or string, optional (default=None)) – If None, edge weights are ignored. Otherwise holds the name of the edge attribute used as weight.

• **cutoff** (bool, optional (default=None)) – If specified, only consider paths of length <= cutoff.

**Returns**

nodes – Dictionary of nodes with centrality as the value.

**Return type**

dictionary

**See also:**

`betweenness_centrality()`

**Notes**

Load centrality is slightly different than betweenness. It was originally introduced by\(^2\). For this load algorithm see\(^1\).

**References**

`networkx.algorithms.centrality.edge_load_centrality`

`edge_load_centrality(G, cutoff=False)`

Compute edge load.

**WARNING:** This concept of edge load has not been analysed or discussed outside of NetworkX that we know of. It is based loosely on load_centrality in the sense that it counts the number of shortest paths which cross each edge. This function is for demonstration and testing purposes.

**Parameters**

• G (graph) – A networkx graph

• cutoff (bool, optional (default=False)) – If specified, only consider paths of length <= cutoff.

**Returns**

• A dict keyed by edge 2-tuple to the number of shortest paths

• which use that edge. Where more than one path is shortest

• the count is divided equally among paths.

### 3.6.9 Subgraph

| **subgraph_centrality(G)** | Return subgraph centrality for each node in G. |
| **subgraph_centrality_exp(G)** | Return the subgraph centrality for each node of G. |
| **estrada_index(G)** | Return the Estrada index of a the graph G. |

---


subgraph_centrality \( (G) \)

Return subgraph centrality for each node in \( G \).

Subgraph centrality of a node \( n \) is the sum of weighted closed walks of all lengths starting and ending at node \( n \). The weights decrease with path length. Each closed walk is associated with a connected subgraph \(^1\).

**Parameters**  
\( G \) (graph)

**Returns**  
nodes – Dictionary of nodes with subgraph centrality as the value.

**Return type**  
dictionary

**Raises**  
NetworkXError – If the graph is not undirected and simple.

See also:

subgraph_centrality_exp()  
Alternative algorithm of the subgraph centrality for each node of \( G \).

**Notes**

This version of the algorithm computes eigenvalues and eigenvectors of the adjacency matrix.

Subgraph centrality of a node \( u \) in \( G \) can be found using a spectral decomposition of the adjacency matrix \(^1\),

\[
SC(u) = \sum_{j=1}^{N} (v_j^u)^2 e^{\lambda_j},
\]

where \( v_j \) is an eigenvector of the adjacency matrix \( A \) of \( G \) corresponding to the eigenvalue \( \lambda_j \).

**Examples**

(Example from\(^1\))

```python
>>> G = nx.Graph([(1,2),(1,5),(1,8),(2,3),(2,8),(3,4),(3,6),(4,5),(4,7),(5,6),(6,7),(7,8)])
>>> sc = nx.subgraph_centrality(G)
```

```python
>>> print(['%s %0.2f'%(node,sc[node]) for node in sorted(sc)])
['1 3.90', '2 3.90', '3 3.64', '4 3.71', '5 3.64', '6 3.71', '7 3.64', '8 3.90']
```

**References**

networkx.algorithms.centrality.subgraph_centrality_exp

subgraph_centrality_exp \( (G) \)

Return the subgraph centrality for each node of \( G \).

Subgraph centrality of a node \( n \) is the sum of weighted closed walks of all lengths starting and ending at node \( n \). The weights decrease with path length. Each closed walk is associated with a connected subgraph \(^1\).

**Parameters**  
\( G \) (graph)

**Returns**  
nodes – Dictionary of nodes with subgraph centrality as the value.

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https://arxiv.org/abs/cond-mat/0504730

https://arxiv.org/abs/cond-mat/0504730

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Return type  dictionary

Raises  NetworkXError – If the graph is not undirected and simple.

See also:

*subgraph_centrality()**  Alternative algorithm of the subgraph centrality for each node of G.

Notes

This version of the algorithm exponentiates the adjacency matrix.

The subgraph centrality of a node \( u \) in G can be found using the matrix exponential of the adjacency matrix of G,

\[
SC(u) = (e^A)_{uu}.
\]

References

Examples

(Example from\(^1\))

```python
>>> G = nx.Graph([(1,2),(1,5),(1,8),(2,3),(2,8),(3,4),(3,6),(4,5),(4,7),(5,6),(6,7),(7,8)])
>>> sc = nx.subgraph_centrality_exp(G)
>>> print(['%s %0.2f'%(node,sc[node]) for node in sorted(sc)])
['1 3.90', '2 3.90', '3 3.64', '4 3.71', '5 3.64', '6 3.71', '7 3.64', '8 3.90']
```

**networkx.algorithms.centrality.estrada_index**

*estrada_index* \((G)\)

Return the Estrada index of a the graph G.

The Estrada Index is a topological index of folding or 3D “compactness” \(^1\).

Parameters  \( G \) (graph)

Returns  estrada index

Return type  float

Raises  NetworkXError – If the graph is not undirected and simple.

Notes

Let \( G=(V,E) \) be a simple undirected graph with \( n \) nodes and let \( \lambda_1 \leq \lambda_2 \leq \cdots \lambda_n \) be a non-increasing ordering of the eigenvalues of its adjacency matrix \( A \). The Estrada index is \(^{1,2}\)

\[
EE(G) = \sum_{j=1}^{n} e^{\lambda_j}.
\]

---

3.6.10 Harmonic Centrality

`harmonic_centrality(G[, nbunch, distance])`  
Compute harmonic centrality for nodes.

Harmonic centrality\(^1\) of a node \(u\) is the sum of the reciprocal of the shortest path distances from all other nodes to \(u\)

\[
C(u) = \sum_{v \neq u} \frac{1}{d(v, u)}
\]

where \(d(v, u)\) is the shortest-path distance between \(v\) and \(u\).

Notice that higher values indicate higher centrality.

**Parameters**

- `G (graph)` – A NetworkX graph
- `nbunch (container)` – Container of nodes. If provided harmonic centrality will be computed only over the nodes in `nbunch`.
- `distance (edge attribute key, optional (default=None))` – Use the specified edge attribute as the edge distance in shortest path calculations. If `None`, then each edge will have distance equal to 1.

**Returns**

- `nodes` – Dictionary of nodes with harmonic centrality as the value.

**Return type**

- `dictionary`

**See also:**

- `betweenness_centrality()`, `load_centrality()`, `eigenvector_centrality()`, `degree_centrality()`, `closeness_centrality()`

**Notes**

If the ‘distance’ keyword is set to an edge attribute key then the shortest-path length will be computed using Dijkstra’s algorithm with that edge attribute as the edge weight.

References

3.6.11 Reaching

local_reaching_centrality(G, v[, paths, ...])  Returns the local reaching centrality of a node in a directed graph.

global_reaching_centrality(G[, weight, ...])  Returns the global reaching centrality of a directed graph.

networkx.algorithms.centrality.local_reaching_centrality

local_reaching_centrality (G, v, paths=None, weight=None, normalized=True)

Returns the local reaching centrality of a node in a directed graph.

The local reaching centrality of a node in a directed graph is the proportion of other nodes reachable from that node.

Parameters

- G (DiGraph) – A NetworkX DiGraph.
- v (node) – A node in the directed graph G.
- paths (dictionary (default=None)) – If this is not None it must be a dictionary rep-
 resentation of single-source shortest paths, as computed by, for example, networkx.  
  shortest_path() with source node v. Use this keyword argument if you intend to 
  invoke this function many times but don’t want the paths to be recomputed each time.
- weight (None or string, optional (default=None)) – Attribute to use for edge weights. If 
  None, each edge weight is assumed to be one. A higher weight implies a stronger connec-
  tion between nodes and a shorter path length.
- normalized (bool, optional (default=True)) – Whether to normalize the edge weights by 
  the total sum of edge weights.

Returns h – The local reaching centrality of the node v in the graph G.

Return type float

Examples

>>> import networkx as nx
>>> G = nx.DiGraph()
>>> G.add_edges_from([(1, 2), (1, 3)])
>>> nx.local_reaching_centrality(G, 3)
0.0
>>> G.add_edge(3, 2)
>>> nx.local_reaching_centrality(G, 3)
0.5

See also:

global_reaching_centrality()

networkx.algorithms.centrality.global_reaching_centrality

**global_reaching_centrality** *(G, weight=None, normalized=True)*

Returns the global reaching centrality of a directed graph.

The *global reaching centrality* of a weighted directed graph is the average over all nodes of the difference between the local reaching centrality of the node and the greatest local reaching centrality of any node in the graph\(^1\). For more information on the local reaching centrality, see `local_reaching_centrality()`.

Informally, the local reaching centrality is the proportion of the graph that is reachable from the neighbors of the node.

**Parameters**

- **G** *(DiGraph)* – A networkx DiGraph.
- **weight** *(None or string, optional (default=None))* – Attribute to use for edge weights. If None, each edge weight is assumed to be one. A higher weight implies a stronger connection between nodes and a shorter path length.
- **normalized** *(bool, optional (default=True))* – Whether to normalize the edge weights by the total sum of edge weights.

**Returns** **h** – The global reaching centrality of the graph.

**Return type** float

**Examples**

```python
>>> import networkx as nx
>>> G = nx.DiGraph()
>>> G.add_edge(1, 2)
>>> G.add_edge(1, 3)
>>> nx.global_reaching_centrality(G)
1.0
>>> G.add_edge(3, 2)
>>> nx.global_reaching_centrality(G)
0.75
```

**See also:**

- `local_reaching_centrality()`

**References**

3.7 Chains

Functions for finding chains in a graph.

```plaintext
chain_decomposition(G[, root])
```

Return the chain decomposition of a graph.

3.7.1 networkx.algorithms.chains.chain_decomposition

chain_decomposition \((G, \text{root}=\text{None})\)

Return the chain decomposition of a graph.

The chain decomposition of a graph with respect a depth-first search tree is a set of cycles or paths derived from
the set of fundamental cycles of the tree in the following manner. Consider each fundamental cycle with respect
to the given tree, represented as a list of edges beginning with the nontree edge oriented away from the root of
the tree. For each fundamental cycle, if it overlaps with any previous fundamental cycle, just take the initial
non-overlapping segment, which is a path instead of a cycle. Each cycle or path is called a chain. For more
information, see\(^1\).

Parameters

- \(G\) (undirected graph)
- \(\text{root}\) (node (optional)) – A node in the graph \(G\). If specified, only the chain decomposition
  for the connected component containing this node will be returned. This node indicates the
  root of the depth-first search tree.

Yields chain (list) – A list of edges representing a chain. There is no guarantee on the orientation
of the edges in each chain (for example, if a chain includes the edge joining nodes 1 and 2, the
chain may include either \((1, 2)\) or \((2, 1)\)).

Raises NodeNotFound – If \(\text{root}\) is not in the graph \(G\).

Notes

The worst-case running time of this implementation is linear in the number of nodes and number of edges\(^1\).

References

3.8 Chordal

Algorithms for chordal graphs.

A graph is chordal if every cycle of length at least 4 has a chord (an edge joining two nodes not adjacent in the cycle).

https://en.wikipedia.org/wiki/Chordal_graph

<table>
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<tr>
<th>Function</th>
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<tbody>
<tr>
<td>is_chordal(G)</td>
<td>Checks whether (G) is a chordal graph.</td>
</tr>
<tr>
<td>chordal_graph Cliques(G)</td>
<td>Returns the set of maximal cliques of a chordal graph.</td>
</tr>
<tr>
<td>chordal_graph_treewidth(G)</td>
<td>Returns the treewidth of the chordal graph (G).</td>
</tr>
<tr>
<td>find_induced_nodes(G, s, t[, treewidth_bound])</td>
<td>Returns the set of induced nodes in the path from (s) to (t).</td>
</tr>
</tbody>
</table>

3.8.1 networkx.algorithms.chordal.is_chordal

is_chordal \((G)\)

Checks whether \(G\) is a chordal graph.

A graph is chordal if every cycle of length at least 4 has a chord (an edge joining two nodes not adjacent in the
cycle).

Parameters $G$ (graph) – A NetworkX graph.

Returns chordal – True if $G$ is a chordal graph and False otherwise.

Return type bool

Raises NetworkXError – The algorithm does not support DiGraph, MultiGraph and MultiDiGraph. If the input graph is an instance of one of these classes, a NetworkXError is raised.

Examples

```python
>>> import networkx as nx
>>> e=[(1,2), (1,3), (2,3), (2,4), (3,4), (3,5), (3,6), (4,5), (4,6), (5,6)]
>>> G=nx.Graph(e)
>>> nx.is_chordal(G)
True
```

Notes

The routine tries to go through every node following maximum cardinality search. It returns False when it finds that the separator for any node is not a clique. Based on the algorithms in\(^1\).

References

3.8.2 networkx.algorithms.chordal.chordal_graph_cliques

chordal_graph_cliques ($G$)

Returns the set of maximal cliques of a chordal graph.

The algorithm breaks the graph in connected components and performs a maximum cardinality search in each component to get the cliques.

Parameters $G$ (graph) – A NetworkX graph

Returns cliques

Return type A set containing the maximal cliques in $G$.

Raises NetworkXError – The algorithm does not support DiGraph, MultiGraph and MultiDiGraph. If the input graph is an instance of one of these classes, a NetworkXError is raised. The algorithm can only be applied to chordal graphs. If the input graph is found to be non-chordal, a NetworkXError is raised.

Examples

```python
>>> import networkx as nx
>>> e= [(1,2), (1,3), (2,3), (2,4), (3,4), (3,5), (3,6), (4,5), (4,6), (5,6), (7,8)]
>>> G = nx.Graph(e)
>>> G.add_node(9)
>>> setlist = nx.chordal_graph_cliques(G)
```

3.8.3 networkx.algorithms.chordal.chordal_graph_treewidth

chordal_graph_treewidth(G)

Returns the treewidth of the chordal graph G.

**Parameters**
G (graph) – A NetworkX graph

**Returns**
treewidth – The size of the largest clique in the graph minus one.

**Return type**
int

**Raises**
NetworkXError – The algorithm does not support DiGraph, MultiGraph and MultiDiGraph. If the input graph is an instance of one of these classes, a NetworkXError is raised. The algorithm can only be applied to chordal graphs. If the input graph is found to be non-chordal, a NetworkXError is raised.

**Examples**

```python
>>> import networkx as nx
>>> e = [(1,2), (1,3), (2,3), (2,4), (3,4), (3,5), (3,6), (4,5), (4,6), (5,6), (7,8)]
>>> G = nx.Graph(e)
>>> G.add_node(9)
>>> nx.chordal_graph_treewidth(G)
3
```

**References**

3.8.4 networkx.algorithms.chordal.find_induced_nodes

find_induced_nodes(G, s, t, treewidth_bound=9223372036854775807)

Returns the set of induced nodes in the path from s to t.

**Parameters**
- G (graph) – A chordal NetworkX graph
- s (node) – Source node to look for induced nodes
- t (node) – Destination node to look for induced nodes
- treewidth_bound (float) – Maximum treewidth acceptable for the graph H. The search for induced nodes will end as soon as the treewidth_bound is exceeded.

**Returns**
I – The set of induced nodes in the path from s to t in G

**Return type**
Set of nodes

** Raises**
NetworkXError – The algorithm does not support DiGraph, MultiGraph and MultiDiGraph. If the input graph is an instance of one of these classes, a NetworkXError is raised. The algorithm can only be applied to chordal graphs. If the input graph is found to be non-chordal, a NetworkXError is raised.

**Examples**
>>> import networkx as nx
>>> G=nx.Graph()
>>> G = nx.generators.classic.path_graph(10)
>>> I = nx.find_induced_nodes(G,1,9,2)
>>> list(I)
[1, 2, 3, 4, 5, 6, 7, 8, 9]

Notes

G must be a chordal graph and (s,t) an edge that is not in G.

If a treewidth_bound is provided, the search for induced nodes will end as soon as the treewidth_bound is exceeded.

The algorithm is inspired by Algorithm 4 in\(^1\). A formal definition of induced node can also be found on that reference.

References

3.9 Clique

Functions for finding and manipulating cliques.

Finding the largest clique in a graph is NP-complete problem, so most of these algorithms have an exponential running time; for more information, see the Wikipedia article on the clique problem\(^1\).

<table>
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<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>enumerate_all_cliques(G)</td>
<td>Returns all cliques in an undirected graph.</td>
</tr>
<tr>
<td>find_cliques(G)</td>
<td>Returns all maximal cliques in an undirected graph.</td>
</tr>
<tr>
<td>make_max_clique_graph(G[, create_using])</td>
<td>Returns the maximal clique graph of the given graph.</td>
</tr>
<tr>
<td>make_clique_bipartite(G[, fpos, ...])</td>
<td>Returns the bipartite clique graph corresponding to G.</td>
</tr>
<tr>
<td>graph_clique_number(G[, cliques])</td>
<td>Returns the clique number of the graph.</td>
</tr>
<tr>
<td>graph_number_of_cliques(G[, cliques])</td>
<td>Returns the number of maximal cliques in the graph.</td>
</tr>
<tr>
<td>node_clique_number(G[, nodes, cliques])</td>
<td>Returns the size of the largest maximal clique containing each given node.</td>
</tr>
<tr>
<td>number_of_cliques(G[, nodes, cliques])</td>
<td>Returns the number of maximal cliques for each node.</td>
</tr>
<tr>
<td>cliques_containing_node(G[, nodes, cliques])</td>
<td>Returns a list of cliques containing the given node.</td>
</tr>
</tbody>
</table>

3.9.1 networkx.algorithms.clique.enumerate_all_cliques

enumerate_all_cliques(G)

Returns all cliques in an undirected graph.

This function returns an iterator over cliques, each of which is a list of nodes. The iteration is ordered by cardinality of the cliques: first all cliques of size one, then all cliques of size two, etc.

Parameters G (NetworkX graph) – An undirected graph.

Returns An iterator over cliques, each of which is a list of nodes in G. The cliques are ordered according to size.


Return type  iterator

Notes

To obtain a list of all cliques, use `list(enumerate_all_cliques(G))`. However, be aware that in the worst-case, the length of this list can be exponential in the number of nodes in the graph (for example, when the graph is the complete graph). This function avoids storing all cliques in memory by only keeping current candidate node lists in memory during its search.

The implementation is adapted from the algorithm by Zhang, et al. (2005)\(^1\) to output all cliques discovered.

This algorithm ignores self-loops and parallel edges, since cliques are not conventionally defined with such edges.

References

3.9.2 networkx.algorithms.clique.find_cliques

**find_cliques**\((G)\)

Returns all maximal cliques in an undirected graph.

For each node \(v\), a *maximal clique for* \(v\) is a largest complete subgraph containing \(v\). The largest maximal clique is sometimes called the *maximum clique*.

This function returns an iterator over cliques, each of which is a list of nodes. It is an iterative implementation, so should not suffer from recursion depth issues.

**Parameters**  
\(G\) (NetworkX graph) – An undirected graph.

**Returns**  
An iterator over maximal cliques, each of which is a list of nodes in \(G\). The order of cliques is arbitrary.

**Return type**  
iterator

See also:

**find_cliques_recursive**()  
A recursive version of the same algorithm.

Notes

To obtain a list of all maximal cliques, use `list(find_cliques(G))`. However, be aware that in the worst-case, the length of this list can be exponential in the number of nodes in the graph (for example, when the graph is the complete graph). This function avoids storing all cliques in memory by only keeping current candidate node lists in memory during its search.

This implementation is based on the algorithm published by Bron and Kerbosch (1973)\(^1\), as adapted by Tomita, Tanaka and Takahashi (2006)\(^2\) and discussed in Cazals and Karande (2008)\(^3\). It essentially unrolls the re-

---


cursion used in the references to avoid issues of recursion stack depth (for a recursive implementation, see `find_cliques_recursive()`).

This algorithm ignores self-loops and parallel edges, since cliques are not conventionally defined with such edges.

References

3.9.3 networkx.algorithms.clique.make_max_clique_graph

`make_max_clique_graph(G, create_using=None)`

Returns the maximal clique graph of the given graph.

The nodes of the maximal clique graph of $G$ are the cliques of $G$ and an edge joins two cliques if the cliques are not disjoint.

**Parameters**

- $G$ (*NetworkX* graph)
- `create_using` (*NetworkX* graph) – If provided, this graph will be cleared and the nodes and edges of the maximal clique graph will be added to this graph.

**Returns** A graph whose nodes are the cliques of $G$ and whose edges join two cliques if they are not disjoint.

**Return type** *NetworkX* graph

**Notes**

This function behaves like the following code:

```python
import networkx as nx
G = nx.make_clique_bipartite(G)
cliques = {v for v in G.nodes() if G.nodes[v]['bipartite'] == 0}
G = nx.bipartite.project(G, cliques)
G = nx.relabel_nodes(G, {-v: v - 1 for v in G})
```

It should be faster, though, since it skips all the intermediate steps.

3.9.4 networkx.algorithms.clique.make_clique_bipartite

`make_clique_bipartite(G, fpos=None, create_using=None, name=None)`

Returns the bipartite clique graph corresponding to $G$.

In the returned bipartite graph, the “bottom” nodes are the nodes of $G$ and the “top” nodes represent the maximal cliques of $G$. There is an edge from node $v$ to clique $C$ in the returned graph if and only if $v$ is an element of $C$.

**Parameters**

- $G$ (*NetworkX* graph) – An undirected graph.
- `fpos` (*bool*) – If True or not None, the returned graph will have an additional attribute, `pos`, a dictionary mapping node to position in the Euclidean plane.
- `create_using` (*NetworkX* graph) – If provided, this graph will be cleared and the nodes and edges of the bipartite graph will be added to this graph.
Returns

A bipartite graph whose “bottom” set is the nodes of the graph $G$, whose “top” set is the cliques of $G$, and whose edges join nodes of $G$ to the cliques that contain them.

The nodes of the graph $G$ have the node attribute ‘bipartite’ set to 1 and the nodes representing cliques have the node attribute ‘bipartite’ set to 0, as is the convention for bipartite graphs in NetworkX.

Return type  NetworkX graph

3.9.5 networkx.algorithms.clique.graph_clique_number

graph_clique_number $(G, \text{cliques}=\text{None})$

Returns the clique number of the graph.

The clique number of a graph is the size of the largest clique in the graph.

Parameters

- $G$ (NetworkX graph) – An undirected graph.
- cliques (list) – A list of cliques, each of which is itself a list of nodes. If not specified, the list of all cliques will be computed, as by find_cliques().

Returns  The size of the largest clique in $G$.

Return type  int

Notes

You should provide cliques if you have already computed the list of maximal cliques, in order to avoid an exponential time search for maximal cliques.

3.9.6 networkx.algorithms.clique.graph_number_of_cliques

graph_number_of_cliques $(G, \text{cliques}=\text{None})$

Returns the number of maximal cliques in the graph.

Parameters

- $G$ (NetworkX graph) – An undirected graph.
- cliques (list) – A list of cliques, each of which is itself a list of nodes. If not specified, the list of all cliques will be computed, as by find_cliques().

Returns  The number of maximal cliques in $G$.

Return type  int

Notes

You should provide cliques if you have already computed the list of maximal cliques, in order to avoid an exponential time search for maximal cliques.
3.9.7 networkx.algorithms.clique.node_clique_number

node_clique_number \((G, nodes=None, cliques=None)\)

Returns the size of the largest maximal clique containing each given node.

Returns a single or list depending on input nodes. Optional list of cliques can be input if already computed.

3.9.8 networkx.algorithms.clique.number_of_cliques

number_of_cliques \((G, nodes=None, cliques=None)\)

Returns the number of maximal cliques for each node.

Returns a single or list depending on input nodes. Optional list of cliques can be input if already computed.

3.9.9 networkx.algorithms.clique.cliques_containing_node

cliques_containing_node \((G, nodes=None, cliques=None)\)

Returns a list of cliques containing the given node.

Returns a single list or list of lists depending on input nodes. Optional list of cliques can be input if already computed.

3.10 Clustering

Algorithms to characterize the number of triangles in a graph.

<table>
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<tr>
<th>Function</th>
<th>Description</th>
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<tr>
<td>triangles ((G[, nodes]))</td>
<td>Compute the number of triangles.</td>
</tr>
<tr>
<td>transitivity ((G))</td>
<td>Compute graph transitivity, the fraction of all possible triangles present in (G).</td>
</tr>
<tr>
<td>clustering ((G[, nodes, weight]))</td>
<td>Compute the clustering coefficient for nodes.</td>
</tr>
<tr>
<td>average_clustering ((G[, nodes, weight, ...]))</td>
<td>Compute the average clustering coefficient for the graph (G).</td>
</tr>
<tr>
<td>square_clustering ((G[, nodes]))</td>
<td>Compute the squares clustering coefficient for nodes.</td>
</tr>
<tr>
<td>generalized_degree ((G[, nodes]))</td>
<td>Compute the generalized degree for nodes.</td>
</tr>
</tbody>
</table>

3.10.1 networkx.algorithms.cluster.triangles

triangles \((G, nodes=None)\)

Compute the number of triangles.

Finds the number of triangles that include a node as one vertex.

Parameters

- \(G\) (graph) – A networkx graph
- \(nodes\) (container of nodes, optional (default= all nodes in \(G\))) – Compute triangles for nodes in this container.

Returns out – Number of triangles keyed by node label.

Return type dictionary
Examples

```python
>>> G = nx.complete_graph(5)
>>> print(nx.triangles(G, 0))
6
>>> print(nx.triangles(G))
{0: 6, 1: 6, 2: 6, 3: 6, 4: 6}
>>> print(list(nx.triangles(G, (0, 1)).values()))
[6, 6]
```

Notes

When computing triangles for the entire graph each triangle is counted three times, once at each node. Self loops are ignored.

3.10.2 networkx.algorithms.cluster.transitivity

`transitivity(G)`

Compute graph transitivity, the fraction of all possible triangles present in G.

Possible triangles are identified by the number of “triads” (two edges with a shared vertex).

The transitivity is

\[
T = \frac{3 \text{#triangles}}{\text{#triads}}.
\]

Parameters

- `G` (graph)

Returns

- `out` – Transitivity

Return type

float

Examples

```python
>>> G = nx.complete_graph(5)
>>> print(nx.transitivity(G))
1.0
```

3.10.3 networkx.algorithms.cluster.clustering

`clustering(G, nodes=None, weight=None)`

Compute the clustering coefficient for nodes.

For unweighted graphs, the clustering of a node \( u \) is the fraction of possible triangles through that node that exist,

\[
c_u = \frac{2T(u)}{\text{deg}(u)(\text{deg}(u) - 1)},
\]

where \( T(u) \) is the number of triangles through node \( u \) and \( \text{deg}(u) \) is the degree of \( u \).
For weighted graphs, the clustering is defined as the geometric average of the subgraph edge weights\(^1\),

\[
c_u = \frac{1}{\text{deg}(u)(\text{deg}(u) - 1)} \sum_{uv} (\hat{w}_{uv}\hat{w}_{uw}\hat{w}_{vw})^{1/3}.
\]

The edge weights \(\hat{w}_{uv}\) are normalized by the maximum weight in the network \(\hat{w}_{uv} = w_{uv}/\max(w)\).

The value of \(c_u\) is assigned to 0 if \(\text{deg}(u) < 2\).

**Parameters**

- \(G\) (graph)
- \(\text{nodes}\) (container of nodes, optional (default=all nodes in \(G\))) – Compute clustering for nodes in this container.
- \(\text{weight}\) (string or None, optional (default=None)) – The edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1.

**Returns**

- \(out\) – Clustering coefficient at specified nodes

**Return type**

- float, or dictionary

**Examples**

```python
>>> G=nx.complete_graph(5)
>>> print(nx.clustering(G,0))
1.0
>>> print(nx.clustering(G))
{0: 1.0, 1: 1.0, 2: 1.0, 3: 1.0, 4: 1.0}
```

**Notes**

Self loops are ignored.

**References**

3.10.4 networkx.algorithms.cluster.average_clustering

`average_clustering(G, nodes=None, weight=None, count_zeros=True)`

Compute the average clustering coefficient for the graph \(G\).

The clustering coefficient for the graph is the average,

\[
C = \frac{1}{n} \sum_{v \in G} c_v,
\]

where \(n\) is the number of nodes in \(G\).

**Parameters**

- \(G\) (graph)

• **nodes** *(container of nodes, optional (default=all nodes in G)) – Compute average clustering for nodes in this container.*

• **weight** *(string or None, optional (default=None)) – The edge attribute that holds the numerical value used as a weight. If None, then each edge has weight 1.*

• **count_zeros** *(bool)* – If False include only the nodes with nonzero clustering in the average.

Returns **avg** – Average clustering

Return type **float**

**Examples**

```python
>>> G=nx.complete_graph(5)
>>> print(nx.average_clustering(G))
1.0
```

**Notes**

This is a space saving routine; it might be faster to use the clustering function to get a list and then take the average.

Self loops are ignored.

**References**

**3.10.5 networkx.algorithms.cluster.square_clustering**

**square_clustering**(G, nodes=None)

Compute the squares clustering coefficient for nodes.

For each node return the fraction of possible squares that exist at the node

\[ C_4(v) = \frac{\sum_{u=1}^{k_v} \sum_{w=1}^{k_u} q_v(u,w)}{\sum_{u=1}^{k_v} \sum_{w=1}^{k_u} [a_v(u,w) + q_v(u,w)]} \]

where \( q_v(u,w) \) are the number of common neighbors of \( u \) and \( w \) other than \( v \) (ie squares), and \( a_v(u, w) = (k_u - (1+q_v(u,w)+\theta_{uv}))(k_w - (1+q_v(u,w)+\theta_{uw})) \), where \( \theta_{uw} = 1 \) if \( u \) and \( w \) are connected and 0 otherwise.

**Parameters**

• **G** *(graph)*

• **nodes** *(container of nodes, optional (default=all nodes in G)) – Compute clustering for nodes in this container.*

Returns **c4** – A dictionary keyed by node with the square clustering coefficient value.

Return type **dictionary**

---

Examples

```python
>>> G=nx.complete_graph(5)
>>> print(nx.square_clustering(G,0))
1.0
>>> print(nx.square_clustering(G))
{0: 1.0, 1: 1.0, 2: 1.0, 3: 1.0, 4: 1.0}
```

Notes

While \( C_3(v) \) (triangle clustering) gives the probability that two neighbors of node \( v \) are connected with each other, \( C_4(v) \) is the probability that two neighbors of node \( v \) share a common neighbor different from \( v \). This algorithm can be applied to both bipartite and unipartite networks.

References

3.10.6 networkx.algorithms.cluster.generalized_degree

generalized_degree \((G, \text{nodes}=\text{None})\)

Compute the generalized degree for nodes.

For each node, the generalized degree shows how many edges of given triangle multiplicity the node is connected to. The triangle multiplicity of an edge is the number of triangles an edge participates in. The generalized degree of node \( i \) can be written as a vector \( \mathbf{k}_i=(k_i^{(0)}, \ldots, k_i^{(N-2)}) \) where \( k_i^{(j)} \) is the number of edges attached to node \( i \) that participate in \( j \) triangles.

Parameters

- \( G \) (graph)
- \( \text{nodes} \) (container of nodes, optional (default=all nodes in \( G \)) – Compute the generalized degree for nodes in this container.

Returns out – Generalized degree of specified nodes. The Counter is keyed by edge triangle multiplicity.

Return type Counter, or dictionary of Counters

Examples

```python
>>> G=nx.complete_graph(5)
>>> print(nx.generalized_degree(G,0))
Counter({3: 4})
>>> print(nx.generalized_degree(G))
{0: Counter({3: 4}), 1: Counter({3: 4}), 2: Counter({3: 4}), 3: Counter({3: 4}), 4: Counter({3: 4})}
```

To recover the number of triangles attached to a node:

```python
>>> k1 = nx.generalized_degree(G,0)
>>> sum([k*v for k,v in k1.items()])/2 == nx.triangles(G,0)
True
```
Notes

In a network of \(N\) nodes, the highest triangle multiplicity an edge can have is \(N-2\).

The return value does not include a zero entry if no edges of a particular triangle multiplicity are present.

The number of triangles node \(i\) is attached to can be recovered from the generalized degree \(\mathbf{k}_i=(k_i^{(0)}, \ldots, k_i^{(N-2)})\) by \((k_i^{(1)}+2k_i^{(2)}+\ldots+(N-2)k_i^{(N-2)})/2\).

References

3.11 Coloring

\texttt{greedy\_color}(G[, strategy, interchange])  \color{gray}{\text{Color a graph using various strategies of greedy graph coloring.}}

3.11.1 networkx.algorithms.coloring.greedy\_color

\texttt{greedy\_color}(G, strategy='largest\_first', interchange=False)

Color a graph using various strategies of greedy graph coloring.

Attempts to color a graph using as few colors as possible, where no neighbours of a node can have same color as the node itself. The given strategy determines the order in which nodes are colored.

The strategies are described in\(^1\), and smallest-last is based on\(^2\).

Parameters

- \(G\) (\textit{NetworkX} graph)
- \texttt{strategy} (\textit{string or function}(\(G\), \texttt{colors})) – A function (or a string representing a function) that provides the coloring strategy, by returning nodes in the ordering they should be colored. \(G\) is the graph, and \texttt{colors} is a dictionary of the currently assigned colors, keyed by nodes.

The function must return an iterable over all the nodes in \(G\).

If the strategy function is an iterator generator (that is, a function with \texttt{yield} statements), keep in mind that the \texttt{colors} dictionary will be updated after each \texttt{yield}, since this function chooses colors greedily.

If \texttt{strategy} is a string, it must be one of the following, each of which represents one of the built-in strategy functions.

- 'largest\_first'
- 'random\_sequential'
- 'smallest\_last'
- 'independent\_set'
- 'connected\_sequential\_bfs'
- 'connected\_sequential\_dfs'


The 'connected_sequential' strategy is an alias for the previous strategy. 'strategy_saturation_largest_first' and 'DSATUR' are also aliases for the previous strategy. The 'strategy_saturation_largest_first' strategy iterates over all the nodes of G in “saturation order” (also known as “DSATUR”). The 'strategy_smallest_last' strategy returns a deque of the nodes of G, “smallest” last.

interchange (bool) – Will use the color interchange algorithm described by^3 if set to True. Note that 'strategy_saturation_largest_first' and 'strategy_independent_set' do not work with interchange. Furthermore, if you use interchange with your own strategy function, you cannot rely on the values in the colors argument.

Returns
• A dictionary with keys representing nodes and values representing corresponding coloring.

Examples

```python
>>> G = nx.cycle_graph(4)
>>> d = nx.coloring.greedy_color(G, strategy='largest_first')
>>> d in [{0: 0, 1: 1, 2: 0, 3: 1}, {0: 1, 1: 0, 2: 1, 3: 0}]
True
```

Raises
NetworkXPointlessConcept – If strategy is 'strategy_saturation_largest_first' or 'strategy_independent_set' and interchange is True.

References

Some node ordering strategies are provided for use with `greedy_color()`:

<table>
<thead>
<tr>
<th>Strategy Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>strategy_connected_sequential(G, colors[, ...])</td>
<td>Returns an iterable over nodes in G in the order given by a breadth-first or depth-first traversal.</td>
</tr>
<tr>
<td>strategy_connected_sequential_dfs(G, colors)</td>
<td>Returns an iterable over nodes in G in the order given by a depth-first traversal.</td>
</tr>
<tr>
<td>strategy_connected_sequential_bfs(G, colors)</td>
<td>Returns an iterable over nodes in G in the order given by a breadth-first traversal.</td>
</tr>
<tr>
<td>strategy_independent_set(G, colors)</td>
<td>Uses a greedy independent set removal strategy to determine the colors.</td>
</tr>
<tr>
<td>strategy_largest_first(G, colors)</td>
<td>Returns a list of the nodes of G in decreasing order by degree.</td>
</tr>
<tr>
<td>strategy_random_sequential(G, colors)</td>
<td>Returns a random permutation of the nodes of G as a list.</td>
</tr>
<tr>
<td>strategy_saturation_largest_first(G, colors)</td>
<td>Iterates over all the nodes of G in “saturation order” (also known as “DSATUR”).</td>
</tr>
<tr>
<td>strategy_smallest_last(G, colors)</td>
<td>Returns a deque of the nodes of G, “smallest” last.</td>
</tr>
</tbody>
</table>

3.11.2 networkx.algorithms.coloring.strategy_connected_sequential

strategy_connected_sequential \((G, \text{colors}, \text{traversal}='\text{dfs}')\)

Returns an iterable over nodes in \(G\) in the order given by a breadth-first or depth-first traversal.

\text{traversal} must be one of the strings 'dfs' or 'bfs', representing depth-first traversal or breadth-first traversal, respectively.

The generated sequence has the property that for each node except the first, at least one neighbor appeared earlier in the sequence.

\(G\) is a NetworkX graph. \text{colors} is ignored.

3.11.3 networkx.algorithms.coloring.strategy_connected_sequential_dfs

strategy_connected_sequential_dfs \((G, \text{colors})\)

Returns an iterable over nodes in \(G\) in the order given by a depth-first traversal.

The generated sequence has the property that for each node except the first, at least one neighbor appeared earlier in the sequence.

\(G\) is a NetworkX graph. \text{colors} is ignored.

3.11.4 networkx.algorithms.coloring.strategy_connected_sequential_bfs

strategy_connected_sequential_bfs \((G, \text{colors})\)

Returns an iterable over nodes in \(G\) in the order given by a breadth-first traversal.

The generated sequence has the property that for each node except the first, at least one neighbor appeared earlier in the sequence.

\(G\) is a NetworkX graph. \text{colors} is ignored.

3.11.5 networkx.algorithms.coloring.strategy_independent_set

strategy_independent_set \((G, \text{colors})\)

Uses a greedy independent set removal strategy to determine the colors.

This function updates \text{colors} \text{in-place} and return None, unlike the other strategy functions in this module.

This algorithm repeatedly finds and removes a maximal independent set, assigning each node in the set an unused color.

\(G\) is a NetworkX graph.

This strategy is related to strategy_smallest_last(): in that strategy, an independent set of size one is chosen at each step instead of a maximal independent set.

3.11.6 networkx.algorithms.coloring.strategy_largest_first

strategy_largest_first \((G, \text{colors})\)

Returns a list of the nodes of \(G\) in decreasing order by degree.

\(G\) is a NetworkX graph. \text{colors} is ignored.
3.11.7 networkx.algorithms.coloring.strategy_random_sequential

strategy_random_sequential \((G, colors)\)
Returns a random permutation of the nodes of \(G\) as a list.
\(G\) is a NetworkX graph. \(colors\) is ignored.

3.11.8 networkx.algorithms.coloring.strategy_saturation_largest_first

strategy_saturation_largest_first \((G, colors)\)
Iterates over all the nodes of \(G\) in “saturation order” (also known as “DSATUR”).
\(G\) is a NetworkX graph. \(colors\) is a dictionary mapping nodes of \(G\) to colors, for those nodes that have already been colored.

3.11.9 networkx.algorithms.coloring.strategy_smallest_last

strategy_smallest_last \((G, colors)\)
Returns a deque of the nodes of \(G\), “smallest” last.
Specifically, the degrees of each node are tracked in a bucket queue. From this, the node of minimum degree is repeatedly popped from the graph, updating its neighbors’ degrees.
\(G\) is a NetworkX graph. \(colors\) is ignored.
This implementation of the strategy runs in \(O(n + m)\) time (ignoring polylogarithmic factors), where \(n\) is the number of nodes and \(m\) is the number of edges.
This strategy is related to strategy_independent_set(): if we interpret each node removed as an independent set of size one, then this strategy chooses an independent set of size one instead of a maximal independent set.

3.12 Communicability

Communicability.

<table>
<thead>
<tr>
<th>communicability ((G))</th>
<th>Return communicability between all pairs of nodes in (G).</th>
</tr>
</thead>
<tbody>
<tr>
<td>communicability_exp ((G))</td>
<td>Return communicability between all pairs of nodes in (G).</td>
</tr>
</tbody>
</table>

3.12.1 networkx.algorithms.communicability_alg.communicability

communicability \((G)\)
Return communicability between all pairs of nodes in \(G\).

The communicability between pairs of nodes in \(G\) is the sum of closed walks of different lengths starting at node \(u\) and ending at node \(v\).

Parameters

- \(G\) (graph)

Returns

- \(comm\) – Dictionary of dictionaries keyed by nodes with communicability as the value.

Return type
dictionary of dictionaries

Raises

- NetworkXError – If the graph is not undirected and simple.
See also:

`communicability_exp()` Communicability between all pairs of nodes in G using spectral decomposition.

`communicability_betweenness_centrality()` Communicability betweenness centrality for each node in G.

Notes

This algorithm uses a spectral decomposition of the adjacency matrix. Let G=(V,E) be a simple undirected graph. Using the connection between the powers of the adjacency matrix and the number of walks in the graph, the communicability between nodes \( u \) and \( v \) based on the graph spectrum is

\[
C(u, v) = \sum_{j=1}^{n} \phi_j(u)\phi_j(v)e^{\lambda_j},
\]

where \( \phi_j(u) \) is the \( j \)th element of the \( j \)th orthonormal eigenvector of the adjacency matrix associated with the eigenvalue \( \lambda_j \).

References

Examples

```python
>>> G = nx.Graph([(0,1),(1,2),(1,5),(5,4),(2,4),(2,3),(4,3),(3,6)])
>>> c = nx.communicability(G)
```

3.12.2 `networkx.algorithms.communicability_alg.communicability_exp`

`communicability_exp(G)`

Return communicability between all pairs of nodes in G.

Communicability between pair of node \((u,v)\) of node in G is the sum of closed walks of different lengths starting at node \( u \) and ending at node \( v \).

Parameters  

\( G \) (graph)

Returns  

\( \text{comm} \) – Dictionary of dictionaries keyed by nodes with communicability as the value.

Return type  

dictionary of dictionaries

Raises  

`NetworkXError` – If the graph is not undirected and simple.

See also:

`communicability()` Communicability between pairs of nodes in G.

`communicability_betweenness_centrality()` Communicability betweenness centrality for each node in G.

---

Notes

This algorithm uses matrix exponentiation of the adjacency matrix.


$$C(u, v) = (e^A)_{uv},$$

where $A$ is the adjacency matrix of $G$.

References

Examples

```python
>>> G = nx.Graph([(0,1),(1,2),(1,5),(5,4),(2,4),(2,3),(4,3),(3,6)])
>>> c = nx.communicability_exp(G)
```

3.13 Communities

Functions for computing and measuring community structure.

The functions in this class are not imported into the top-level networkx namespace. You can access these functions by importing the `networkx.algorithms.community` module, then accessing the functions as attributes of `community`. For example:

```python
>>> import networkx as nx
>>> from networkx.algorithms import community
>>> G = nx.barbell_graph(5, 1)
>>> communities_generator = community.girvan_newman(G)
>>> top_level_communities = next(communities_generator)
>>> next_level_communities = next(communities_generator)
>>> sorted(map(sorted, next_level_communities))
[[0, 1, 2, 3, 4], [5], [6, 7, 8, 9, 10]]
```

3.13.1 Bipartitions

Functions for computing the Kernighan–Lin bipartition algorithm.

```python
kernighan_lin_bisection(G[, partition, ...])  Partition a graph into two blocks using the Kernighan–Lin algorithm.
```

```
networkx.algorithms.community.kernighan_lin.kernighan_lin_bisection

kernighan_lin_bisection (G, partition=None, max_iter=10, weight='weight')

Partition a graph into two blocks using the Kernighan–Lin algorithm.

This algorithm partitions a network into two sets by iteratively swapping pairs of nodes to reduce the edge cut
```
between the two sets.

**Parameters**

- **G** (*graph*)
- **partition** (*tuple*) – Pair of iterables containing an initial partition. If not specified, a random balanced partition is used.
- **max_iter** (*int*) – Maximum number of times to attempt swaps to find an improvement before giving up.
- **weight** (*key*) – Edge data key to use as weight. If None, the weights are all set to one.

**Returns**

- **partition** – A pair of sets of nodes representing the bipartition.

**Return type**

tuple

**Raises**

- NetworkXError – If partition is not a valid partition of the nodes of the graph.

### References

#### 3.13.2 Generators

Functions for generating graphs with community structure.

```python
LFR_benchmark_graph(n, tau1, tau2, mu[, . . .])
```

Returns the LFR benchmark graph for testing community-finding algorithms.

```python
networkx.algorithms.community.community_generators.LFR_benchmark_graph
```

LFR_benchmark_graph (n, tau1, tau2, mu, average_degree=None, min_degree=None, max_degree=None, min_community=None, max_community=None, tol=1e-07, max_iters=500, seed=None)

Returns the LFR benchmark graph for testing community-finding algorithms.

This algorithm proceeds as follows:

1. Find a degree sequence with a power law distribution, and minimum value `min_degree`, which has approximate average degree `average_degree`. This is accomplished by either
   - (a) specifying `min_degree` and not `average_degree`,
   - (b) specifying `average_degree` and not `min_degree`, in which case a suitable minimum degree will be found.

   `max_degree` can also be specified, otherwise it will be set to `n`. Each node `u` will have `mu * mathrm{deg}(u)` edges joining it to nodes in communities other than its own and `(1 - mu) * mathrm{deg}(u)` edges joining it to nodes in its own community.

2. Generate community sizes according to a power law distribution with exponent `tau2`. If `min_community` and `max_community` are not specified they will be selected to be `min_degree` and `max_degree`, respectively. Community sizes are generated until the sum of their sizes equals `n`.

3. Each node will be randomly assigned a community with the condition that the community is large enough for the node’s intra-community degree, `(1 - mu) * mathrm{deg}(u)` as described in step 2. If a community grows too large, a random node will be selected for reassignment to a new community, until all nodes have been assigned a community.
4. Each node $u$ then adds $(1 - \mu) \text{deg}(u)$ intra-community edges and $\mu \text{deg}(u)$ inter-community edges.

Parameters

- **n (int)** – Number of nodes in the created graph.
- **tau1 (float)** – Power law exponent for the degree distribution of the created graph. This value must be strictly greater than one.
- **tau2 (float)** – Power law exponent for the community size distribution in the created graph. This value must be strictly greater than one.
- **mu (float)** – Fraction of intra-community edges incident to each node. This value must be in the interval $[0, 1]$.
- **average_degree (float)** – Desired average degree of nodes in the created graph. This value must be in the interval $[0, n]$. Exactly one of this and **min_degree** must be specified, otherwise a **NetworkXError** is raised.
- **min_degree (int)** – Minimum degree of nodes in the created graph. This value must be in the interval $[0, n]$. Exactly one of this and **average_degree** must be specified, otherwise a **NetworkXError** is raised.
- **max_degree (int)** – Maximum degree of nodes in the created graph. If not specified, this is set to $n$, the total number of nodes in the graph.
- **min_community (int)** – Minimum size of communities in the graph. If not specified, this is set to **min_degree**.
- **max_community (int)** – Maximum size of communities in the graph. If not specified, this is set to $n$, the total number of nodes in the graph.
- **tol (float)** – Tolerance when comparing floats, specifically when comparing average degree values.
- **max_iters (int)** – Maximum number of iterations to try to create the community sizes, degree distribution, and community affiliations.
- **seed (int)** – A seed for the random number generator.

Returns

- **G** – The LFR benchmark graph generated according to the specified parameters.

Each node in the graph has a node attribute 'community' that stores the community (that is, the set of nodes) that includes it.

**Return type** NetworkX graph

**Raises**

- **NetworkXError** – If any of the parameters do not meet their upper and lower bounds:
  - **tau1** and **tau2** must be less than or equal to one.
  - **mu** must be in $[0, 1]$.
  - **max_degree** must be in $[1, \ldots, n]$.
  - **min_community** and **max_community** must be in $[0, \ldots, n]$.

If not exactly one of **average_degree** and **min_degree** is specified.

If **min_degree** is not specified and a suitable **min_degree** cannot be found.
• ExceededMaxIterations – If a valid degree sequence cannot be created within \( \text{max\_iters} \) number of iterations.

If a valid set of community sizes cannot be created within \( \text{max\_iters} \) number of iterations.

If a valid community assignment cannot be created within \( 10 * n * \text{max\_iters} \) number of iterations.

**Examples**

Basic usage:

```python
>>> from networkx.algorithms.community import LFR_benchmark_graph
>>> n = 250
>>> tau1 = 3
>>> tau2 = 1.5
>>> mu = 0.1
>>> G = LFR_benchmark_graph(n, tau1, tau2, mu, average_degree=5,
...                          min_community=20, seed=10)
```

Continuing the example above, you can get the communities from the node attributes of the graph:

```python
>>> communities = {frozenset(G.nodes[v]['community']) for v in G}
```

**Notes**

This algorithm differs slightly from the original way it was presented in [1].

1. Rather than connecting the graph via a configuration model then rewiring to match the intra-community and inter-community degrees, we do this wiring explicitly at the end, which should be equivalent.

2. The code posted on the author’s website [2] calculates the random power law distributed variables and their average using continuous approximations, whereas we use the discrete distributions here as both degree and community size are discrete.

Though the authors describe the algorithm as quite robust, testing during development indicates that a somewhat narrower parameter set is likely to successfully produce a graph. Some suggestions have been provided in the event of exceptions.

**References**

3.13.3 K-Clique

**networkx.algorithms.community.kclique.k_clique_communities**

\( k\_\text{clique\_communities}(G, k[, \text{cliques}]) \)

Find k-clique communities in graph using the percolation method.

A k-clique community is the union of all cliques of size k that can be reached through adjacent (sharing k-1 nodes) k-cliques.
Parameters

- \( G \) (NetworkX graph)
- \( k \) (int) – Size of smallest clique
- \( \text{cliques} \) (list or generator) – Precomputed cliques (use \text{networkx.find_cliques}(G))

Returns

Return type: Yields sets of nodes, one for each \( k \)-clique community.

Examples

```python
>>> from networkx.algorithms.community import k_clique_communities
>>> G = nx.complete_graph(5)
>>> K5 = nx.convert_node_labels_to_integers(G,first_label=2)
>>> G.add_edges_from(K5.edges())
>>> c = list(k_clique_communities(G, 4))
>>> list(c[0])
[0, 1, 2, 3, 4, 5, 6]
>>> list(k_clique_communities(G, 6))
[]
```

References

3.13.4 Modularity-based communities

Functions for detecting communities based on modularity.

```python
networkx.algorithms.community.modularity_max.greedy_modularity_communities
```

**greedy_modularity_communities** (\( G, \text{weight=None} \))

Find communities in graph using Clauset-Newman-Moore greedy modularity maximization. This method currently supports the Graph class and does not consider edge weights.

Greedy modularity maximization begins with each node in its own community and joins the pair of communities that most increases modularity until no such pair exists.

Parameters

- \( G \) (NetworkX graph)

Returns

Return type: Yields sets of nodes, one for each community.

Examples

```python
>>> from networkx.algorithms.community import greedy_modularity_communities
>>> G = nx.karate_club_graph()
>>> c = list(greedy_modularity_communities(G))
```
```python
>>> sorted(c[0])
[8, 14, 15, 18, 20, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33]
```

References

### 3.13.5 Label propagation

Label propagation community detection algorithms.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>asyn_lpa_communities(G[, weight])</code></td>
<td>Returns communities in ( G ) as detected by asynchronous label propagation.</td>
</tr>
<tr>
<td><code>label_propagation_communities(G)</code></td>
<td>Generates community sets determined by label propagation.</td>
</tr>
</tbody>
</table>

#### networkx.algorithms.community.label_propagation.asyn_lpa_communities

**asyn_lpa_communities \((G, weight=\text{None})\)**

Returns communities in \( G \) as detected by asynchronous label propagation.

The asynchronous label propagation algorithm is described in\(^1\). The algorithm is probabilistic and the found communities may vary on different executions.

The algorithm proceeds as follows. After initializing each node with a unique label, the algorithm repeatedly sets the label of a node to be the label that appears most frequently among that nodes neighbors. The algorithm halts when each node has the label that appears most frequently among its neighbors. The algorithm is asynchronous because each node is updated without waiting for updates on the remaining nodes.

This generalized version of the algorithm in\(^1\) accepts edge weights.

**Parameters**

- \( G \) (Graph)
- weight (string) – The edge attribute representing the weight of an edge. If None, each edge is assumed to have weight one. In this algorithm, the weight of an edge is used in determining the frequency with which a label appears among the neighbors of a node: a higher weight means the label appears more often.

**Returns**

- communities – Iterable of communities given as sets of nodes.

**Return type** iterable

**Notes**

Edge weight attributes must be numerical.

---

References

networkx.algorithms.community.label_propagation.label_propagation_communities

```
label_propagation_communities(G)
```

Generates community sets determined by label propagation

Finds communities in $G$ using a semi-synchronous label propagation method[1]_. This method combines the advantages of both the synchronous and asynchronous models. Not implemented for directed graphs.

**Parameters**

- $G$ (graph) – An undirected NetworkX graph.

**Yields**

- communities (generator) – Yields sets of the nodes in each community.

**Raises**

- NetworkXNotImplemented – If the graph is directed

References

3.13.6 Fluid Communities

Asynchronous Fluid Communities algorithm for community detection.

```
asyn_fluidc(G, k[, max_iter])
```

Returns communities in $G$ as detected by Fluid Communities algorithm.

networkx.algorithms.community.asyn_fluidc.asyn_fluidc

```
asyn_fluidc (G, k, max_iter=100)
```

Returns communities in $G$ as detected by Fluid Communities algorithm.

The asynchronous fluid communities algorithm is described in[1]. The algorithm is based on the simple idea of fluids interacting in an environment, expanding and pushing each other. It’s initialization is random, so found communities may vary on different executions.

The algorithm proceeds as follows. First each of the initial $k$ communities is initialized in a random vertex in the graph. Then the algorithm iterates over all vertices in a random order, updating the community of each vertex based on its own community and the communities of its neighbours. This process is performed several times until convergence. At all times, each community has a total density of 1, which is equally distributed among the vertices it contains. If a vertex changes of community, vertex densities of affected communities are adjusted immediately. When a complete iteration over all vertices is done, such that no vertex changes the community it belongs to, the algorithm has converged and returns.

This is the original version of the algorithm described in[1]. Unfortunately, it does not support weighted graphs yet.

**Parameters**

- $G$ (Graph)
- $k$ (integer) – The number of communities to be found.
- $max_iter$ (integer) – The number of maximum iterations allowed. By default 15.

**Returns**

- communities – Iterable of communities given as sets of nodes.

---

Return type  iterable

Notes

k variable is not an optional argument.

References

3.13.7 Measuring partitions

Functions for measuring the quality of a partition (into communities).

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>coverage(*)args,**kw</td>
<td>Returns the coverage of a partition.</td>
</tr>
<tr>
<td>performance(*)args,**kw</td>
<td>Returns the performance of a partition.</td>
</tr>
</tbody>
</table>

**networkx.algorithms.community.quality.coverage**

coverage(*args,**kw)

Returns the coverage of a partition.

The coverage of a partition is the ratio of the number of intra-community edges to the total number of edges in the graph.

Parameters

- G (NetworkX graph)
- partition (sequence) – Partition of the nodes of G, represented as a sequence of sets of nodes. Each block of the partition represents a community.

Returns  The coverage of the partition, as defined above.

Return type  float

Raises  NetworkXError – If partition is not a valid partition of the nodes of G.

Notes

If G is a multigraph, the multiplicity of edges is counted.

References

**networkx.algorithms.community.quality.performance**

performance(*args,**kw)

Returns the performance of a partition.

The performance of a partition is the ratio of the number of intra-community edges plus inter-community non-edges with the total number of potential edges.

Parameters

- G (NetworkX graph) – A simple graph (directed or undirected).
• **partition** (*sequence*) – Partition of the nodes of \(G\), represented as a sequence of sets of nodes. Each block of the partition represents a community.

**Returns** The performance of the partition, as defined above.

**Return type** `float`

**Raises** `NetworkXError` – If `partition` is not a valid partition of the nodes of \(G\).

---

### 3.13.8 Partitions via centrality measures

Functions for computing communities based on centrality notions.

<table>
<thead>
<tr>
<th><code>girvan_newman(G[, most_valuable_edge])</code></th>
<th>Finds communities in a graph using the Girvan–Newman method.</th>
</tr>
</thead>
</table>

`networkx.algorithms.community.centrality.girvan_newman`

`girvan_newman(G, most_valuable_edge=None)`

Finds communities in a graph using the Girvan–Newman method.

**Parameters**

- `G` (*NetworkX graph*)
- `most_valuable_edge` (*function*) – Function that takes a graph as input and outputs an edge. The edge returned by this function will be recomputed and removed at each iteration of the algorithm.

  If not specified, the edge with the highest `networkx.edge_betweenness_centrality()` will be used.

**Returns** Iterator over tuples of sets of nodes in \(G\). Each set of node is a community, each tuple is a sequence of communities at a particular level of the algorithm.

**Return type** iterator

---

### Examples

To get the first pair of communities:

```python
>>> G = nx.path_graph(10)
>>> comp = girvan_newman(G)
>>> tuple(sorted(c) for c in next(comp))
([0, 1, 2, 3, 4], [5, 6, 7, 8, 9])
```

To get only the first \(k\) tuples of communities, use `itertools.islice()`:

```python
>>> import itertools
>>> G = nx.path_graph(8)
>>> k = 2
>>> comp = girvan_newman(G)
>>> for communities in itertools.islice(comp, k):
```

(continues on next page)
... print(tuple(sorted(c) for c in communities))
...

([0, 1, 2, 3], [4, 5, 6, 7])
([0, 1], [2, 3], [4, 5, 6, 7])

To stop getting tuples of communities once the number of communities is greater than $k$, use `itertools.takewhile()`:

```python
>>> import itertools
>>> G = nx.path_graph(8)
>>> k = 4
>>> comp = girvan_newman(G)
>>> limited = itertools.takewhile(lambda c: len(c) <= k, comp)
>>> for communities in limited:
...     print(tuple(sorted(c) for c in communities))
...
([0, 1, 2, 3], [4, 5, 6, 7])
([0, 1], [2, 3], [4, 5, 6, 7])
([0, 1], [2, 3], [4, 5], [6, 7])
```

To just choose an edge to remove based on the weight:

```python
>>> from operator import itemgetter
>>> G = nx.path_graph(10)
>>> edges = G.edges()
>>> nx.set_edge_attributes(G, {(u, v): v for u, v in edges}, 'weight')
>>> def heaviest(G):
...     u, v, w = max(G.edges(data='weight'), key=itemgetter(2))
...     return (u, v)
...>>> comp = girvan_newman(G, most_valuable_edge=heaviest)
>>> tuple(sorted(c) for c in next(comp))
([0, 1, 2, 3, 4, 5, 6, 7, 8], [9])
```

To utilize edge weights when choosing an edge with, for example, the highest betweenness centrality:

```python
>>> from networkx import edge_betweenness_centrality as betweenness
>>> def most_central_edge(G):
...     centrality = betweenness(G, weight='weight')
...     return max(centrality, key=centrality.get)
...>>> G = nx.path_graph(10)
>>> comp = girvan_newman(G, most_valuable_edge=most_central_edge)
>>> tuple(sorted(c) for c in next(comp))
([0, 1, 2, 3, 4], [5, 6, 7, 8, 9])
```

To specify a different ranking algorithm for edges, use the `most_valuable_edge` keyword argument:

```python
>>> from networkx import edge_betweenness_centrality
>>> from random import random
>>> def most_central_edge(G):
...     centrality = edge_betweenness_centrality(G)
...     max_cent = max(centrality.values())
...     # Scale the centrality values so they are between 0 and 1, # and add some random noise.
...     centrality = {e: c / max_cent for e, c in centrality.items()}
...```
# Add some random noise.
centrality = {e: c + random() for e, c in centrality.items()}
return max(centrality, key=centrality.get)

>>> G = nx.path_graph(10)
>>> comp = girvan_newman(G, most_valuable_edge=most_central_edge)

Notes

The Girvan–Newman algorithm detects communities by progressively removing edges from the original graph. The algorithm removes the “most valuable” edge, traditionally the edge with the highest betweenness centrality, at each step. As the graph breaks down into pieces, the tightly knit community structure is exposed and the result can be depicted as a dendrogram.

3.13.9 Validating partitions

Helper functions for community-finding algorithms.

`is_partition(G, communities)`: Return True if and only if `communities` is a partition of the nodes of `G`.

`networkx.algorithms.community.community_utils.is_partition`

`is_partition(G, communities)`: Return True if and only if `communities` is a partition of the nodes of `G`.

A partition of a universe set is a family of pairwise disjoint sets whose union is the entire universe set.

`G` is a NetworkX graph.

`communities` is an iterable of sets of nodes of `G`. This iterable will be consumed multiple times during the execution of this function.

3.14 Components

3.14.1 Connectivity

`is_connected(G)`: Return True if the graph is connected, False otherwise.

`number_connected_components(G)`: Return the number of connected components.

`connected_components(G)`: Generate connected components.

`connected_component_subgraphs(G[, copy])`: DEPRECATED: Use `G.subgraph(c) for c in connected_components(G)`.

`node_connected_component(G, n)`: Return the set of nodes in the component of graph containing node `n`.

3.14. Components
**networkx.algorithms.components.is_connected**

**is_connected**(*G*)

Return True if the graph is connected, False otherwise.

**Parameters**

- **G** (*NetworkX Graph*) – An undirected graph.

**Returns**

- connected – True if the graph is connected, false otherwise.

**Return type**

bool

**Raises**

NetworkXNotImplemented: – If G is directed.

**Examples**

```python
>>> G = nx.path_graph(4)
>>> print(nx.is_connected(G))
True
```

**See also:**

- is_strongly_connected(), is_weakly_connected(), is_semiconnected(),
- is_biconnected(), connected_components()

**Notes**

For undirected graphs only.

**networkx.algorithms.components.number_connected_components**

**number_connected_components**(*G*)

Return the number of connected components.

**Parameters**

- **G** (*NetworkX graph*) – An undirected graph.

**Returns**

- n – Number of connected components

**Return type**

integer

**See also:**

- connected_components(), number_weakly_connected_components(),
- number_strongly_connected_components()

**Notes**

For undirected graphs only.

**networkx.algorithms.components.connected_components**

**connected_components**(*G*)

Generate connected components.

**Parameters**

- **G** (*NetworkX graph*) – An undirected graph
Returns **comp** – A generator of sets of nodes, one for each component of G.

Return type generator of sets

Raises NetworkXNotImplemented: – If G is directed.

Examples

Generate a sorted list of connected components, largest first.

```python
>>> G = nx.path_graph(4)
>>> nx.add_path(G, [10, 11, 12])
>>> [len(c) for c in sorted(nx.connected_components(G), key=len, reverse=True)]
[4, 3]
```

If you only want the largest connected component, it's more efficient to use max instead of sort.

```python
>>> largest_cc = max(nx.connected_components(G), key=len)
```

See also:

* `strongly_connected_components()`
* `weakly_connected_components()`

Notes

For undirected graphs only.

```
networkx.algorithms.components.connected_component_subgraphs

connected_component_subgraphs (G, copy=True)
DEPRECATED: Use (G.subgraph(c) for c in connected_components(G))
Or (G.subgraph(c).copy() for c in connected_components(G))
```

```
networkx.algorithms.components.node_connected_component

node_connected_component (G, n)
Return the set of nodes in the component of graph containing node n.

Parameters

- G (NetworkX Graph) – An undirected graph.
- n (node label) – A node in G

Returns **comp** – A set of nodes in the component of G containing node n.

Return type set

Raises NetworkXNotImplemented: – If G is directed.

See also:

* `connected_components()`
```
Notes

For undirected graphs only.

### 3.14.2 Strong connectivity

<table>
<thead>
<tr>
<th>Function Name</th>
<th>Description</th>
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</thead>
<tbody>
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<td><code>is_strongly_connected(G)</code></td>
<td>Test directed graph for strong connectivity.</td>
</tr>
<tr>
<td><code>number_strongly_connected_components(G)</code></td>
<td>Return number of strongly connected components in graph.</td>
</tr>
<tr>
<td><code>strongly_connected_components(G)</code></td>
<td>Generate nodes in strongly connected components of graph.</td>
</tr>
<tr>
<td><code>strongly_connected_component_subgraphs(G[, copy])</code></td>
<td>DEPRECATED: Use <code>(G.subgraph(c) for c in strongly_connected_components(G))</code>.</td>
</tr>
<tr>
<td><code>strongly_connected_components_recursive(G)</code></td>
<td>Generate nodes in strongly connected components of graph.</td>
</tr>
<tr>
<td><code>kosaraju_strongly_connected_components(G[, ...])</code></td>
<td>Generate nodes in strongly connected components of graph.</td>
</tr>
<tr>
<td><code>condensation(G[, scc])</code></td>
<td>Returns the condensation of G.</td>
</tr>
</tbody>
</table>

#### `networkx.algorithms.components.is_strongly_connected`

**`is_strongly_connected(G)`**

Test directed graph for strong connectivity.

A directed graph is strongly connected if and only if every vertex in the graph is reachable from every other vertex.

**Parameters**
- **G** (*NetworkX Graph*) – A directed graph.

**Returns**
- **connected** – True if the graph is strongly connected, False otherwise.

**Return type**
- **bool**

**Raises**
- `NetworkXNotImplemented` – If G is undirected.

**See also:**
- `is_weakly_connected()`, `is_semi_connected()`, `is_connected()`, `is_biconnected()`, `strongly_connected_components()`

#### Notes

For directed graphs only.

#### `networkx.algorithms.components.number_strongly_connected_components`

**`number_strongly_connected_components(G)`**

Return number of strongly connected components in graph.

**Parameters**
- **G** (*NetworkX graph*) – A directed graph.

**Returns**
- **n** – Number of strongly connected components

**Return type**
- **integer**

**Raises**
- `NetworkXNotImplemented` – If G is undirected.
See also:

- `strongly_connected_components()`, `number_connected_components()`, `number_weakly_connected_components()`

Notes

For directed graphs only.

networkx.algorithms.components.strongly_connected_components

`strongly_connected_components(G)`

Generate nodes in strongly connected components of graph.

**Parameters**

- `G` (*NetworkX Graph*) – A directed graph.

**Returns**

- `comp` – A generator of sets of nodes, one for each strongly connected component of `G`.

**Return type**

generator of sets

**Raises**

- `NetworkXNotImplemented` – If `G` is undirected.

Examples

Generate a sorted list of strongly connected components, largest first.

```python
>>> G = nx.cycle_graph(4, create_using=nx.DiGraph())
>>> nx.add_cycle(G, [10, 11, 12])
>>> [len(c) for c in sorted(nx.strongly_connected_components(G),
...     key=len, reverse=True)]
[4, 3]
```

If you only want the largest component, it’s more efficient to use `max` instead of `sort`.

```python
>>> largest = max(nx.strongly_connected_components(G), key=len)
```

See also:

- `connected_components()`, `weakly_connected_components()`, `kosaraju_strongly_connected_components()`

Notes


References

networkx.algorithms.components.strongly_connected_component_subgraphs

`strongly_connected_component_subgraphs(G, copy=True)`

DEPRECATED: Use `(G.subgraph(c) for c in strongly_connected_components(G))`

Or `(G.subgraph(c).copy() for c in strongly_connected_components(G))`
networkx.algorithms.components.strongly_connected_components_recursive

`strongly_connected_components_recursive(G)`
Generate nodes in strongly connected components of graph.

Recursive version of algorithm.

Parameters

- **G** (*NetworkX Graph*) – A directed graph.

Returns

- `comp` – A generator of sets of nodes, one for each strongly connected component of G.

Return type

- generator of sets

Raises `NetworkXNotImplemented` – If G is undirected.

Examples

Generate a sorted list of strongly connected components, largest first.

```python
>>> G = nx.cycle_graph(4, create_using=nx.DiGraph())
>>> nx.add_cycle(G, [10, 11, 12])
>>> [len(c) for c in sorted(nx.strongly_connected_components_recursive(G), key=len, reverse=True)]
[4, 3]
```

If you only want the largest component, it’s more efficient to use max instead of sort.

```python
>>> largest = max(nx.strongly_connected_components_recursive(G), key=len)
```

See also:

- connected_components()

Notes

Uses Tarjan’s algorithm[1] with Nuutila’s modifications[2].

References

networkx.algorithms.components.kosaraju_strongly_connected_components

`kosaraju_strongly_connected_components(G, source=None)`
Generate nodes in strongly connected components of graph.

Parameters

- **G** (*NetworkX Graph*) – A directed graph.

Returns

- `comp` – A generator of sets of nodes, one for each strongly connected component of G.

Return type

- generator of sets

Raises `NetworkXNotImplemented` – If G is undirected.
Examples

Generate a sorted list of strongly connected components, largest first.

```python
>>> G = nx.cycle_graph(4, create_using=nx.DiGraph())
>>> nx.add_cycle(G, [10, 11, 12])
>>> [len(c) for c in sorted(nx.kosaraju_strongly_connected_components(G), ...
    key=len, reverse=True)]
[4, 3]
```

If you only want the largest component, it’s more efficient to use max instead of sort.

```python
>>> largest = max(nx.kosaraju_strongly_connected_components(G), key=len)
```

See also:

`strongly_connected_components()`

Notes

Uses Kosaraju’s algorithm.

networkx.algorithms.components.condensation

**condensation** *(G, scc=None)*

Returns the condensation of G.

The condensation of G is the graph with each of the strongly connected components contracted into a single node.

Parameters

- **G** *(NetworkX DiGraph)* – A directed graph.
- **scc** *(list or generator (optional, default=None))* – Strongly connected components. If provided, the elements in scc must partition the nodes in G. If not provided, it will be calculated as scc=nx.strongly_connected_components(G).

Returns **C** – The condensation graph C of G. The node labels are integers corresponding to the index of the component in the list of strongly connected components of G. C has a graph attribute named ‘mapping’ with a dictionary mapping the original nodes to the nodes in C to which they belong. Each node in C also has a node attribute ‘members’ with the set of original nodes in G that form the SCC that the node in C represents.

Return type **NetworkX DiGraph**

Raises **NetworkXNotImplemented** – If G is undirected.

Notes

After contracting all strongly connected components to a single node, the resulting graph is a directed acyclic graph.
### 3.14.3 Weak connectivity

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td><code>is_weakly_connected(G)</code></td>
<td>Test directed graph for weak connectivity.</td>
</tr>
<tr>
<td><code>number_weakly_connected_components(G)</code></td>
<td>Return the number of weakly connected components in G.</td>
</tr>
<tr>
<td><code>weakly_connected_components(G)</code></td>
<td>Generate weakly connected components of G.</td>
</tr>
<tr>
<td><code>weakly_connected_component_subgraphs(G[, copy])</code></td>
<td>DEPRECATED: Use (G.subgraph(c) for c in weakly_connected_components(G)).</td>
</tr>
</tbody>
</table>

#### networkx.algorithms.components.is_weakly_connected

**is_weakly_connected** *(G)*  
Test directed graph for weak connectivity.

A directed graph is weakly connected if and only if the graph is connected when the direction of the edge between nodes is ignored.

Note that if a graph is strongly connected (i.e., the graph is connected even when we account for directionality), it is by definition weakly connected as well.

**Parameters**  
* G *(NetworkX Graph)* – A directed graph.

**Returns**  
* connected – True if the graph is weakly connected, False otherwise.  

**Return type**  
* bool  

**Raises**  
* NetworkXNotImplemented: – If G is undirected.

**See also:**  
* `is_strongly_connected()`, `is_semi_connected()`, `is_connected()`, `is_biconnected()`.  

**Notes**  
* For directed graphs only.

#### networkx.algorithms.components.number_weakly_connected_components

**number_weakly_connected_components** *(G)*  
Return the number of weakly connected components in G.

**Parameters**  
* G *(NetworkX graph)* – A directed graph.

**Returns**  
* n – Number of weakly connected components

**Return type**  
* integer

**Raises**  
* NetworkXNotImplemented: – If G is undirected.

**See also:**
* `weakly_connected_components()`, `number_connected_components()`,  

**Notes**  
* For directed graphs only.
networkx.algorithms.components.weakly_connected_components

weakly_connected_components(G)
Generate weakly connected components of G.

Parameters:
G (NetworkX graph) – A directed graph

Returns:
comp – A generator of sets of nodes, one for each weakly connected component of G.

Return type:
generator of sets

Raises:
NetworkXNotImplemented: – If G is undirected.

Examples

Generate a sorted list of weakly connected components, largest first.

```python
>>> G = nx.path_graph(4, create_using=nx.DiGraph())
>>> nx.add_path(G, [10, 11, 12])
>>> [len(c) for c in sorted(nx.weakly_connected_components(G), key=len, reverse=True)]
[4, 3]
```

If you only want the largest component, it’s more efficient to use max instead of sort:

```python
>>> largest_cc = max(nx.weakly_connected_components(G), key=len)
```

See also:

connected_components(), strongly_connected_components()

Notes

For directed graphs only.

networkx.algorithms.components.weakly_connected_component_subgraphs

weakly_connected_component_subgraphs(G, copy=True)
DEPRECATED: Use (G.subgraph(c) for c in weakly_connected_components(G))
Or (G.subgraph(c).copy() for c in weakly_connected_components(G))

3.14.4 Attracting components

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>is_attracting_component(G)</td>
<td>Returns True if G consists of a single attracting component.</td>
</tr>
<tr>
<td>number_attracting_components(G)</td>
<td>Returns the number of attracting components in G.</td>
</tr>
<tr>
<td>attracting_components(G)</td>
<td>Generates the attracting components in G.</td>
</tr>
<tr>
<td>attracting_component_subgraphs(G[, copy])</td>
<td>DEPRECATED: Use (G.subgraph(c) for c in attracting_components(G)).</td>
</tr>
</tbody>
</table>
networkx.algorithms.components.is_attracting_component

**is_attracting_component** *(G)*
Returns True if \( G \) consists of a single attracting component.

**Parameters**
\( G \) *(DiGraph, MultiDiGraph)* – The graph to be analyzed.

**Returns**
\( \text{attracting} \) – True if \( G \) has a single attracting component. Otherwise, False.

**Return type**
\( \text{bool} \)

**Raises**
\( \text{NetworkXNotImplemented} \) – If the input graph is undirected.

**See also:**
\( \text{attracting_components()}, \text{number_attracting_components()} \)

networkx.algorithms.components.number_attracting_components

**number_attracting_components** *(G)*
Returns the number of attracting components in \( G \).

**Parameters**
\( G \) *(DiGraph, MultiDiGraph)* – The graph to be analyzed.

**Returns**
\( n \) – The number of attracting components in \( G \).

**Return type**
\( \text{int} \)

**Raises**
\( \text{NetworkXNotImplemented} \) – If the input graph is undirected.

**See also:**
\( \text{attracting_components()}, \text{is_attracting_component()} \)

networkx.algorithms.components.attracting_components

**attracting_components** *(G)*
Generates the attracting components in \( G \).

An attracting component in a directed graph \( G \) is a strongly connected component with the property that a random walker on the graph will never leave the component, once it enters the component.

The nodes in attracting components can also be thought of as recurrent nodes. If a random walker enters the attractor containing the node, then the node will be visited infinitely often.

**Parameters**
\( G \) *(DiGraph, MultiDiGraph)* – The graph to be analyzed.

**Returns**
\( \text{attractors} \) – A generator of sets of nodes, one for each attracting component of \( G \).

**Return type**
\( \text{generator of sets} \)

**Raises**
\( \text{NetworkXNotImplemented} \) – If the input graph is undirected.

**See also:**
\( \text{number_attracting_components()}, \text{is_attracting_component()} \)
3.14.5 Biconnected components

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td><code>networkx.algorithms.components.is_biconnected(G)</code></td>
<td>Return True if the graph is biconnected, False otherwise.</td>
</tr>
<tr>
<td><code>networkx.algorithms.components.biconnected_components(G)</code></td>
<td>Return a generator of sets of nodes, one set for each biconnected component of the graph</td>
</tr>
<tr>
<td><code>networkx.algorithms.components.biconnected_component_edges(G)</code></td>
<td>Return a generator of lists of edges, one list for each biconnected component of the input graph.</td>
</tr>
<tr>
<td><code>networkx.algorithms.components.biconnected_component_subgraphs(G[, copy])</code></td>
<td>DEPRECATED: Use (G.subgraph(c) for c in biconnected_components(G)).</td>
</tr>
<tr>
<td><code>networkx.algorithms.components.articulation_points(G)</code></td>
<td>Yield the articulation points, or cut vertices, of a graph.</td>
</tr>
</tbody>
</table>

**is_biconnected(G)**

Return True if the graph is biconnected, False otherwise.

A graph is biconnected if, and only if, it cannot be disconnected by removing only one node (and all edges incident on that node). If removing a node increases the number of disconnected components in the graph, that node is called an articulation point, or cut vertex. A biconnected graph has no articulation points.

**Parameters**

- **G** (*NetworkX Graph*) – An undirected graph.

**Returns**

- **biconnected** – True if the graph is biconnected, False otherwise.

**Return type**

- **bool**

**Raises**

- **NetworkXNotImplemented** – If the input graph is not undirected.

**Examples**

```python
>>> G = nx.path_graph(4)
>>> print(nx.is_biconnected(G))
False
>>> G.add_edge(0, 3)
>>> print(nx.is_biconnected(G))
True
```

**See also:**

- `biconnected_components()`, `articulation_points()`, `biconnected_component_edges()`, `is_strongly_connected()`, `is_weakly_connected()`, `is_connected()`, `is_semiconnected()`

**Notes**

The algorithm to find articulation points and biconnected components is implemented using a non-recursive depth-first-search (DFS) that keeps track of the highest level that back edges reach in the DFS tree. A node n
is an articulation point if, and only if, there exists a subtree rooted at \( n \) such that there is no back edge from any successor of \( n \) that links to a predecessor of \( n \) in the DFS tree. By keeping track of all the edges traversed by the DFS we can obtain the biconnected components because all edges of a bicomponent will be traversed consecutively between articulation points.

References

networkx.algorithms.components.biconnected_components

biconnected_components \((G)\)

Return a generator of sets of nodes, one set for each biconnected component of the graph

Biconnected components are maximal subgraphs such that the removal of a node (and all edges incident on that node) will not disconnect the subgraph. Note that nodes may be part of more than one biconnected component. Those nodes are articulation points, or cut vertices. The removal of articulation points will increase the number of connected components of the graph.

Notice that by convention a dyad is considered a biconnected component.

**Parameters**

- \( G \) (NetworkX Graph) – An undirected graph.

**Returns**

- nodes – Generator of sets of nodes, one set for each biconnected component.

**Return type**

generator

**Raises**

- NetworkXNotImplemented – If the input graph is not undirected.

See also:

- k_components() this function is a special case where \( k=2 \)
- bridge_components() similar to this function, but is defined using 2-edge-connectivity instead of 2-node-connectivity.

Examples

```python
>>> G = nx.lollipop_graph(5, 1)
>>> print(nx.is_biconnected(G))
False
>>> bicomponents = list(nx.biconnected_components(G))
>>> len(bicomponents)
2
>>> G.add_edge(0, 5)
>>> print(nx.is_biconnected(G))
True
>>> bicomponents = list(nx.biconnected_components(G))
>>> len(bicomponents)
1
```

You can generate a sorted list of biconnected components, largest first, using sort.

```python
>>> G.remove_edge(0, 5)
>>> [len(c) for c in sorted(nx.biconnected_components(G), key=len, reverse=True)]
[5, 2]
```

If you only want the largest connected component, it’s more efficient to use max instead of sort.
```python
>>> Gc = max(nx.biconnected_components(G), key=len)
```

See also:

```
is_biconnected(), articulation_points(), biconnected_component_edges()
```

Notes

The algorithm to find articulation points and biconnected components is implemented using a non-recursive depth-first-search (DFS) that keeps track of the highest level that back edges reach in the DFS tree. A node \( n \) is an articulation point if, and only if, there exists a subtree rooted at \( n \) such that there is no back edge from any successor of \( n \) that links to a predecessor of \( n \) in the DFS tree. By keeping track of all the edges traversed by the DFS we can obtain the biconnected components because all edges of a bicomponent will be traversed consecutively between articulation points.

References

```
networkx.algorithms.components.biconnected_component_edges
```

```
biconnected_component_edges(G)
```

Return a generator of lists of edges, one list for each biconnected component of the input graph.

Biconnected components are maximal subgraphs such that the removal of a node (and all edges incident on that node) will not disconnect the subgraph. Note that nodes may be part of more than one biconnected component. Those nodes are articulation points, or cut vertices. However, each edge belongs to one, and only one, biconnected component.

Notice that by convention a dyad is considered a biconnected component.

**Parameters**

\( G \) (*NetworkX Graph*) – An undirected graph.

**Returns**

edges – Generator of lists of edges, one list for each bicomponent.

**Return type**

generator of lists

**Raises**

`NetworkXNotImplemented` – If the input graph is not undirected.

Examples

```python
>>> G = nx.barbell_graph(4, 2)
>>> print(nx.is_biconnected(G))
False
>>> bicomponents_edges = list(nx.biconnected_component_edges(G))
>>> len(bicomponents_edges)
5
>>> G.add_edge(2, 8)
>>> print(nx.is_biconnected(G))
True
>>> bicomponents_edges = list(nx.biconnected_component_edges(G))
>>> len(bicomponents_edges)
1
```

See also:

```
is_biconnected(), biconnected_components(), articulation_points()
```
Notes

The algorithm to find articulation points and biconnected components is implemented using a non-recursive depth-first-search (DFS) that keeps track of the highest level that back edges reach in the DFS tree. A node \( n \) is an articulation point if, and only if, there exists a subtree rooted at \( n \) such that there is no back edge from any successor of \( n \) that links to a predecessor of \( n \) in the DFS tree. By keeping track of all the edges traversed by the DFS we can obtain the biconnected components because all edges of a bicomponent will be traversed consecutively between articulation points.

References

networkx.algorithms.components.biconnected_component_subgraphs

biconnected_component_subgraphs \((G, \text{copy}=\text{True})\)

DEPRECATED: Use \((G\text{.subgraph}(c) \text{ for } c \text{ in } \text{biconnected_components}(G))\)

Or \((G\text{.subgraph}(c).\text{copy()} \text{ for } c \text{ in } \text{biconnected_components}(G))\)

networkx.algorithms.components.articulation_points

articulation_points \((G)\)

Yield the articulation points, or cut vertices, of a graph.

An articulation point or cut vertex is any node whose removal (along with all its incident edges) increases the number of connected components of a graph. An undirected connected graph without articulation points is biconnected. Articulation points belong to more than one biconnected component of a graph.

Notice that by convention a dyad is considered a biconnected component.

Parameters G (NetworkX Graph) – An undirected graph.

Yields node – An articulation point in the graph.

Raises NetworkXNotImplemented : – If the input graph is not undirected.

Examples

```python
>>> G = nx.barbell_graph(4, 2)
>>> print(nx.is_biconnected(G))
False
>>> len(list(nx.articulation_points(G)))
4
>>> G.add_edge(2, 8)
>>> print(nx.is_biconnected(G))
True
>>> len(list(nx.articulation_points(G)))
0
```

See also:

is_biconnected(), biconnected_components(), biconnected_component_edges()
Notes

The algorithm to find articulation points and biconnected components is implemented using a non-recursive depth-first-search (DFS) that keeps track of the highest level that back edges reach in the DFS tree. A node \( n \) is an articulation point if, and only if, there exists a subtree rooted at \( n \) such that there is no back edge from any successor of \( n \) that links to a predecessor of \( n \) in the DFS tree. By keeping track of all the edges traversed by the DFS we can obtain the biconnected components because all edges of a bicomponent will be traversed consecutively between articulation points.

References

3.14.6 Semiconnectedness

\texttt{is\_semiconnected(G)}

Return True if the graph is semiconnected, False otherwise.

\texttt{networkx.algorithms.components.is\_semiconnected}

\texttt{is\_semiconnected}(G)

Return True if the graph is semiconnected, False otherwise.

A graph is semiconnected if, and only if, for any pair of nodes, either one is reachable from the other, or they are mutually reachable.

Parameters  
\( G \) (NetworkX graph) – A directed graph.

Returns  
\texttt{semiconnected} – True if the graph is semiconnected, False otherwise.

Return type  
\texttt{bool}

Raises  

- \texttt{NetworkXNotImplemented} – If the input graph is undirected.
- \texttt{NetworkXPointlessConcept} – If the graph is empty.

Examples

```python
>>> G=nx.path_graph(4,create_using=nx.DiGraph())
>>> print(nx.is_semiconnected(G))
True
>>> G=nx.DiGraph([(1, 2), (3, 2)])
>>> print(nx.is_semiconnected(G))
False
```

See also:

\texttt{is\_strongly\_connected()}, \texttt{is\_weakly\_connected()}, \texttt{is\_connected()}, \texttt{is\_biconnected()}

3.15 Connectivity

Connectivity and cut algorithms
3.15.1 Edge-augmentation

Algorithms for finding k-edge-augmentations

A k-edge-augmentation is a set of edges, that once added to a graph, ensures that the graph is k-edge-connected; i.e. the graph cannot be disconnected unless k or more edges are removed. Typically, the goal is to find the augmentation with minimum weight. In general, it is not guaranteed that a k-edge-augmentation exists.

See also:

edge_kcomponents algorithms for finding k-edge-connected components

connectivity algorithms for determening edge connectivity.

networkx.algorithms.connectivity.edge_augmentation.k_edge_augmentation

k_edge_augmentation(G, k[, avail, weight, ...]) Finds set of edges to k-edge-connect G.

Adding edges from the augmentation to G make it impossible to disconnect G unless k or more edges are removed. This function uses the most efficient function available (depending on the value of k and if the problem is weighted or unweighted) to search for a minimum weight subset of available edges that k-edge-connects G. In general, finding a k-edge-augmentation is NP-hard, so solutions are not guaranteed to be minimal. Furthermore, a k-edge-augmentation may not exist.

Parameters

• G (NetworkX graph) – An undirected graph.

• k (integer) – Desired edge connectivity

• avail (dict or a set of 2 or 3 tuples) – The available edges that can be used in the augmentation.

If unspecified, then all edges in the complement of G are available. Otherwise, each item is an available edge (with an optional weight).

In the unweighted case, each item is an edge (u, v).

In the weighted case, each item is a 3-tuple (u, v, d) or a dict with items (u, v): d. The third item, d, can be a dictionary or a real number. If d is a dictionary d[weight] corresponds to the weight.

• weight (string) – key to use to find weights if avail is a set of 3-tuples where the third item in each tuple is a dictionary.

• partial (boolean) – If partial is True and no feasible k-edge-augmentation exists, then all a partial k-edge-augmentation is generated. Adding the edges in a partial augmentation to G, minimizes the number of k-edge-connected components and maximizes the edge connectivity between those components. For details, see partial_k_edge_augmentation().

Yields edge (tuple) – Edges that, once added to G, would cause G to become k-edge-connected.

If partial is False, an error is raised if this is not possible. Otherwise, generated edges form a partial augmentation, which k-edge-connects any part of G where it is possible, and maximally connects the remaining parts.
Raises

- NetworkXUnfeasible: – If partial is False and no k-edge-augmentation exists.
- NetworkXNotImplemented: – If the input graph is directed or a multigraph.
- ValueError: – If k is less than 1

Notes

When k=1 this returns an optimal solution.

When k=2 and avail is None, this returns an optimal solution. Otherwise when k=2, this returns a 2-approximation of the optimal solution.

For k>3, this problem is NP-hard and this uses a randomized algorithm that produces a feasible solution, but provides no guarantees on the solution weight.

Example

```python
code
>>> # Unweighted cases
>>> G = nx.path_graph((1, 2, 3, 4))
>>> G.add_node(5)
>>> sorted(nx.k_edge_augmentation(G, k=1))
[(1, 5)]
>>> sorted(nx.k_edge_augmentation(G, k=2))
[(1, 5), (5, 4)]
>>> sorted(nx.k_edge_augmentation(G, k=3))
[(1, 4), (1, 5), (2, 5), (3, 5), (4, 5)]
>>> complement = list(nx.k_edge_augmentation(G, k=5, partial=True))
>>> G.add_edges_from(complement)
>>> nx.edge_connectivity(G)
4
```

Example

```python
code
>>> # Weighted cases
>>> G = nx.path_graph((1, 2, 3, 4))
>>> G.add_node(5)
>>> # avail can be a tuple with a dict
>>> avail = [(1, 5, {'weight': 11}), (2, 5, {'weight': 10})]
>>> sorted(nx.k_edge_augmentation(G, k=1, avail=avail, weight='weight'))
[(2, 5)]
>>> # or avail can be a 3-tuple with a real number
>>> avail = [(1, 5, 11), (2, 5, 10), (4, 3, 1), (4, 5, 51)]
>>> sorted(nx.k_edge_augmentation(G, k=2, avail=avail))
[(1, 5), (2, 5), (4, 5)]
>>> # or avail can be a dict
>>> avail = {(1, 5): 11, (2, 5): 10, (4, 3): 1, (4, 5): 51}
>>> sorted(nx.k_edge_augmentation(G, k=2, avail=avail))
[(1, 5), (2, 5), (4, 5)]
>>> # If augmentation is infeasible, then a partial solution can be found
>>> avail = {(1, 5): 11}
>>> sorted(nx.k_edge_augmentation(G, k=2, avail=avail, partial=True))
[(1, 5)]
```
networkx.algorithms.connectivity.edge_augmentation.is_k_edge_connected

is_k_edge_connected(G, k)
Tests to see if a graph is k-edge-connected.

Is it impossible to disconnect the graph by removing fewer than k edges? If so, then G is k-edge-connected.

Parameters

• G (NetworkX graph) – An undirected graph.
• k (integer) – edge connectivity to test for

Returns True if G is k-edge-connected.

Return type boolean

See also:

is_locally_k_edge_connected()

Example

```python
>>> G = nx.barbell_graph(10, 0)
>>> nx.is_k_edge_connected(G, k=1)
True
>>> nx.is_k_edge_connected(G, k=2)
False
```

networkx.algorithms.connectivity.edge_augmentation.is_locally_k_edge_connected

is_locally_k_edge_connected(G, s, t, k)
Tests to see if an edge in a graph is locally k-edge-connected.

Is it impossible to disconnect s and t by removing fewer than k edges? If so, then s and t are locally k-edge-connected in G.

Parameters

• G (NetworkX graph) – An undirected graph.
• s (node) – Source node
• t (node) – Target node
• k (integer) – local edge connectivity for nodes s and t

Returns True if s and t are locally k-edge-connected in G.

Return type boolean

See also:

is_k_edge_connected()

Example

```python
```
>>> from networkx.algorithms.connectivity import is_locally_k_edge_connected
>>> G = nx.barbell_graph(10, 0)
>>> is_locally_k_edge_connected(G, 5, 15, k=1)
True
>>> is_locally_k_edge_connected(G, 5, 15, k=2)
False
>>> is_locally_k_edge_connected(G, 1, 5, k=2)
True

3.15.2 K-edge-components

Algorithms for finding k-edge-connected components and subgraphs.

A k-edge-connected component (k-edge-cc) is a maximal set of nodes in G, such that all pairs of node have an edge-connectivity of at least k.

A k-edge-connected subgraph (k-edge-subgraph) is a maximal set of nodes in G, such that the subgraph of G defined by the nodes has an edge-connectivity at least k.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>k_edge_components(G, k)</code></td>
<td>Generates nodes in each maximal k-edge-connected component in G.</td>
</tr>
<tr>
<td><code>k_edge_subgraphs(G, k)</code></td>
<td>Generates nodes in each maximal k-edge-connected subgraph in G.</td>
</tr>
<tr>
<td><code>bridge_components(G)</code></td>
<td>Finds all bridge-connected components G.</td>
</tr>
<tr>
<td><code>EdgeComponentAuxGraph</code></td>
<td>A simple algorithm to find all k-edge-connected components in a graph.</td>
</tr>
</tbody>
</table>

networkx.algorithms.connectivity.edge_kcomponents.k_edge_components

`k_edge_components(G, k)`
Generates nodes in each maximal k-edge-connected component in G.

Parameters
- `G` (*NetworkX graph*)
- `k` (*Integer*) – Desired edge connectivity

Returns `k_edge_components` – will have k-edge-connectivity in the graph G.

Return type a generator of k-edge-ccs. Each set of returned nodes

See also:
- `local_edge_connectivity()`
- `k_edge_subgraphs()` similar to this function, but the subgraph defined by the nodes must also have k-edge-connectivity.
- `k_components()` similar to this function, but uses node-connectivity instead of edge-connectivity

Raises
- `NetworkXNotImplemented`: – If the input graph is a multigraph.
- `ValueError`: – If k is less than 1
Notes

Attempts to use the most efficient implementation available based on k. If k=1, this is simply simply connected
components for directed graphs and connected components for undirected graphs. If k=2 on an efficient bridge
connected component algorithm from _[1]_ is run based on the chain decomposition. Otherwise, the algorithm
from _[2]_ is used.

Example

```python
>>> import itertools as it
>>> from networkx.utils import pairwise

>>> paths = [
... (1, 2, 4, 3, 1, 4),
... (5, 6, 7, 8, 5, 7, 8, 6),
... ]

>>> G = nx.Graph()

>>> G.add_nodes_from(it.chain(*paths))

>>> G.add_edges_from(it.chain(*[pairwise(path) for path in paths]))

# note this returns {1, 4} unlike k_edge_subgraphs

>>> sorted(map(sorted, nx.k_edge_components(G, k=3)))

[[1, 4], [2], [3], [5, 6, 7, 8]]
```

References

networkx.algorithms.connectivity.edge_kcomponents.k_edge_subgraphs

k_edge_subgraphs(G, k)
Generates nodes in each maximal k-edge-connected subgraph in G.

Parameters

- G (NetworkX graph)
- k (Integer) – Desired edge connectivity

Returns k_edge_subgraphs – Each k-edge-subgraph is a maximal set of nodes that defines a sub-
graph of G that is k-edge-connected.

Return type a generator of k-edge-subgraphs

See also:

dge_connectivity()

k_edge_components() similar to this function, but nodes only need to have k-edge-connectivity within the
graph G and the subgraphs might not be k-edge-connected.

Raises

- NetworkXNotImplemented: – If the input graph is a multigraph.
- ValueError: – If k is less than 1
Notes

Attempts to use the most efficient implementation available based on k. If k=1, or k=2 and the graph is undirected, then this simply calls \texttt{k\_edge\_components}. Otherwise the algorithm from \cite{1} is used.

Example

```python
>>> import itertools as it
>>> from networkx.utils import pairwise

>>> paths = [
    ...   (1, 2, 4, 3, 1, 4),
    ...   (5, 6, 7, 8, 5, 7, 8, 6),
    ... ]

>>> G = nx.Graph()

>>> G.add_nodes_from(it.chain(*paths))

>>> G.add_edges_from(it.chain(*[pairwise(path) for path in paths]))

>>> # note this does not return \{1, 4\} unlike \texttt{k\_edge\_components}

>>> sorted(map(sorted, nx.k_edge_subgraphs(G, k=3)))
[[1], [2], [3], [4], [5, 6, 7, 8]]
```

References

\texttt{networkx.algorithms.connectivity.edge_kcomponents.bridge\_components}

\texttt{bridge\_components} \((G)\)

Finds all bridge-connected components \(G\).

\begin{description}
\item[Parameters] \(G\) (\textit{NetworkX undirected graph})
\item[Returns] \texttt{bridge\_components}
\item[Return type] a generator of 2-edge-connected components
\end{description}

See also:

\texttt{k\_edge\_subgraphs()} this function is a special case for an undirected graph where \(k=2\).

\texttt{biconnected\_components()} similar to this function, but is defined using 2-node-connectivity instead of 2-edge-connectivity.

\begin{description}
\item[Raises] \texttt{NetworkXNotImplemented}: – If the input graph is directed or a multigraph.
\end{description}

Notes

Bridge-connected components are also known as 2-edge-connected components.

Example

```python
>>> # The barbell graph with parameter zero has a single bridge
>>> G = nx.barbell_graph(5, 0)

>>> from networkx.algorithms.connectivity.edge_kcomponents import bridge_components

... components
```

(continues on next page)
networkx.algorithms.connectivity.edge_kcomponents.EdgeComponentAuxGraph

class EdgeComponentAuxGraph

A simple algorithm to find all \(k\)-edge-connected components in a graph.

Constructing the AuxiliaryGraph (which may take some time) allows for the \(k\)-edge-ccs to be found in linear time for arbitrary \(k\).

**Notes**

This implementation is based on\(^1\). The idea is to construct an auxiliary graph from which the \(k\)-edge-ccs can be extracted in linear time. The auxiliary graph is constructed in \(O(|V| \cdot F)\) operations, where \(F\) is the complexity of max flow. Querying the components takes an additional \(O(|V|)\) operations. This algorithm can be slow for large graphs, but it handles an arbitrary \(k\) and works for both directed and undirected inputs.

The undirected case for \(k=1\) is exactly connected components. The undirected case for \(k=2\) is exactly bridge connected components. The directed case for \(k=1\) is exactly strongly connected components.

**References**

**Example**

```python
>>> import itertools as it
>>> from networkx.utils import pairwise
>>> from networkx.algorithms.connectivity import EdgeComponentAuxGraph
>>> # Build an interesting graph with multiple levels of k-edge-ccs
>>> paths = [
...     (1, 2, 3, 4, 1, 3, 4, 2),  # a 3-edge-cc (a 4 clique)
...     (5, 6, 7, 5),  # a 2-edge-cc (a 3 clique)
...     (1, 5),  # combine first two ccs into a 1-edge-cc
...     (0,),  # add an additional disconnected 1-edge-cc
...     ]  >>> G = nx.Graph()
>>> G.add_nodes_from(it.chain(*paths))
>>> G.add_edges_from(it.chain(*[pairwise(path) for path in paths]))
>>> # Constructing the AuxGraph takes about O(n ** 4)
>>> aux_graph = EdgeComponentAuxGraph.construct(G)
>>> # Once constructed, querying takes O(n)
>>> sorted(map(sorted, aux_graph.k_edge_components(k=1)))
[[0], [1, 2, 3, 4, 5, 6, 7]]
>>> sorted(map(sorted, aux_graph.k_edge_components(k=2)))
[[0], [1, 2, 3, 4], [5, 6, 7]]
>>> sorted(map(sorted, aux_graph.k_edge_components(k=3)))
[[0], [1, 2, 3, 4], [5], [6], [7]]
>>> sorted(map(sorted, aux_graph.k_edge_components(k=4)))
[[0], [1], [2], [3], [4], [5], [6], [7]]
```

Example

```python
>>> # The auxiliary graph is primarily used for k-edge-ccs but it
>>> # can also speed up the queries of k-edge-subgraphs by refining the
>>> # search space.
>>> import itertools as it
>>> from networkx.utils import pairwise
>>> from networkx.algorithms.connectivity import EdgeComponentAuxGraph
>>> paths = [(1, 2, 4, 3, 1, 4), ...]
>>> G = nx.Graph()
>>> G.add_nodes_from(it.chain(*paths))
>>> G.add_edges_from(it.chain(*[pairwise(path) for path in paths]))
>>> aux_graph = EdgeComponentAuxGraph.construct(G)
>>> sorted(map(sorted, aux_graph.k_edge_subgraphs(k=3)))
[[1], [2], [3], [4]]
>>> sorted(map(sorted, aux_graph.k_edge_components(k=3)))
[[1, 4], [2], [3]]
```

__init__()

`x.__init__(...)` initializes x; see help(type(x)) for signature

Methods

<table>
<thead>
<tr>
<th>construct(G)</th>
<th>Builds an auxiliary graph encoding edge-connectivity between nodes.</th>
</tr>
</thead>
<tbody>
<tr>
<td>k_edge_components(k)</td>
<td>Queries the auxiliary graph for k-edge-connected components.</td>
</tr>
<tr>
<td>k_edge_subgraphs(k)</td>
<td>Queries the auxiliary graph for k-edge-connected subgraphs.</td>
</tr>
</tbody>
</table>

3.15.3 K-node-components

Moody and White algorithm for k-components

```python
k_components(G[, flow_func]) Returns the k-component structure of a graph G.
```

`networkx.algorithms.connectivity.kcomponents.k_components`

`k_components(G, flow_func=None)`

Returns the k-component structure of a graph G.

A k-component is a maximal subgraph of a graph G that has, at least, node connectivity k: we need to remove at least k nodes to break it into more components. k-components have an inherent hierarchical structure because they are nested in terms of connectivity: a connected graph can contain several 2-components, each of which can contain one or more 3-components, and so forth.

Parameters

- G (NetworkX graph)
- flow_func (function) – Function to perform the underlying flow computations. Default value

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edmonds_karp(). This function performs better in sparse graphs with right tailed degree distributions. shortest_augmenting_path() will perform better in denser graphs.

**Returns** k_components – Dictionary with all connectivity levels k in the input Graph as keys and a list of sets of nodes that form a k-component of level k as values.

**Return type** dict

**Raises** NetworkXNotImplemented: – If the input graph is directed.

### Examples

```python
>>> # Petersen graph has 10 nodes and it is triconnected, thus all
>>> # nodes are in a single component on all three connectivity levels
>>> G = nx.petersen_graph()
>>> k_components = nx.k_components(G)
```

### Notes

Moody and White¹ (appendix A) provide an algorithm for identifying k-components in a graph, which is based on Kanevsky’s algorithm² for finding all minimum-size node cut-sets of a graph (implemented in all_node_cuts() function):

1. Compute node connectivity, k, of the input graph G.
2. Identify all k-cutsets at the current level of connectivity using Kanevsky’s algorithm.
3. Generate new graph components based on the removal of these cutsets. Nodes in a cutset belong to both sides of the induced cut.
4. If the graph is neither complete nor trivial, return to 1; else end.

This implementation also uses some heuristics (see³ for details) to speed up the computation.

**See also:**

node_connectivity(), all_node_cuts()

biconnected_components() special case of this function when k=2

k_edge_components() similar to this function, but uses edge-connectivity instead of node-connectivity

### References

3.15.4 K-node-cutsets

Kanevsky all minimum node k cutsets algorithm.

all_node_cuts(G[, k, flow_func])

Returns all minimum k cutsets of an undirected graph G.

---


networkx.algorithms.connectivity.kcutsets.all_node_cuts

all_node_cuts (G, k=None, flow_func=None)
Returns all minimum k cutsets of an undirected graph G.

This implementation is based on Kanevsky’s algorithm\(^1\) for finding all minimum-size node cut-sets of an undirected graph G; i.e. the set (or sets) of nodes of cardinality equal to the node connectivity of G. Thus if removed, would break G into two or more connected components.

**Parameters**

- **G** (NetworkX graph) – Undirected graph
- **k** (Integer) – Node connectivity of the input graph. If k is None, then it is computed. Default value: None.
- **flow_func** (function) – Function to perform the underlying flow computations. Default value edmonds_karp. This function performs better in sparse graphs with right tailed degree distributions. shortest_augmenting_path will perform better in denser graphs.

**Returns**

**cuts** – Each node cutset has cardinality equal to the node connectivity of the input graph.

**Return type**
a generator of node cutsets

**Examples**

```python
>>> # A two-dimensional grid graph has 4 cutsets of cardinality 2
>>> G = nx.grid_2d_graph(5, 5)
>>> cutsets = list(nx.all_node_cuts(G))
>>> len(cutsets)
4
>>> all(2 == len(cutset) for cutset in cutsets)
True
>>> nx.node_connectivity(G)
2
```

**Notes**

This implementation is based on the sequential algorithm for finding all minimum-size separating vertex sets in a graph\(^1\). The main idea is to compute minimum cuts using local maximum flow computations among a set of nodes of highest degree and all other non-adjacent nodes in the Graph. Once we find a minimum cut, we add an edge between the high degree node and the target node of the local maximum flow computation to make sure that we will not find that minimum cut again.

**See also:**

node_connectivity(), edmonds_karp(), shortest_augmenting_path()

**References**

3.15.5 Flow-based disjoint paths

Flow based node and edge disjoint paths.

---

edge_disjoint_paths(G, s, t[, flow_func, ...]) Returns the edges disjoint paths between source and target.

node_disjoint_paths(G, s, t[, flow_func, ...]) Computes node disjoint paths between source and target.

networkx.algorithms.connectivity.disjoint_paths.edge_disjoint_paths

def edge_disjoint_paths(G, s, t, flow_func=None, cutoff=None, auxiliary=None, residual=None):
    Returns the edges disjoint paths between source and target.

    Edge disjoint paths are paths that do not share any edge. The number of edge disjoint paths between source and
target is equal to their edge connectivity.

    Parameters

    - G (NetworkX graph)
    - s (node) – Source node for the flow.
    - t (node) – Sink node for the flow.
    - flow_func (function) – A function for computing the maximum flow among a pair of
      nodes. The function has to accept at least three parameters: a Digraph, a source node,
      and a target node. And return a residual network that follows NetworkX conventions (see
      maximum_flow() for details). If flow_func is None, the default maximum flow function
      (edmonds_karp()) is used. The choice of the default function may change from version
      to version and should not be relied on. Default value: None.
    - cutoff (int) – Maximum number of paths to yield. Some of the maximum flow algorithms,
      such as edmonds_karp() (the default) and shortest_augmenting_path() support
      the cutoff parameter, and will terminate when the flow value reaches or exceeds the
      cutoff. Other algorithms will ignore this parameter. Default value: None.
    - auxiliary (NetworkX DiGraph) – Auxiliary digraph to compute flow based edge connectivity.
      It has to have a graph attribute called mapping with a dictionary mapping node names
      in G and in the auxiliary digraph. If provided it will be reused instead of recreated. Default
      value: None.
    - residual (NetworkX DiGraph) – Residual network to compute maximum flow. If provided
      it will be reused instead of recreated. Default value: None.

    Returns paths – A generator of edge independent paths.

    Return type generator

    Raises

    - NetworkXNoPath : exception – If there is no path between source and target.
    - NetworkXError : exception – If source or target are not in the graph G.

    See also:

    node_disjoint_paths(), edge_connectivity(), maximum_flow(), edmonds_karp(),
preflow_push(), shortest_augmenting_path()

    Examples

    We use in this example the platonic icosahedral graph, which has node edge connectivity 5, thus there are 5 edge
disjoint paths between any pair of nodes.
If you need to compute edge disjoint paths on several pairs of nodes in the same graph, it is recommended that you reuse the data structures that NetworkX uses in the computation: the auxiliary digraph for edge connectivity, and the residual network for the underlying maximum flow computation.

Example of how to compute edge disjoint paths among all pairs of nodes of the platonic icosahedral graph reusing the data structures.

```python
>>> import itertools

>>> # You also have to explicitly import the function for
>>> # building the auxiliary digraph from the connectivity package
>>> from networkx.algorithms.connectivity import build_auxiliary_edge_connectivity
>>> H = build_auxiliary_edge_connectivity(G)

>>> # And the function for building the residual network from the
>>> # flow package
>>> from networkx.algorithms.flow import build_residual_network

>>> R = build_residual_network(H, 'capacity')

>>> result = {n: {} for n in G}

>>> # Reuse the auxiliary digraph and the residual network by passing them
>>> # as arguments
>>> for u, v in itertools.combinations(G, 2):
...    k = len(list(nx.edge_disjoint_paths(G, u, v, auxiliary=H, residual=R)))
...    result[u][v] = k
>>> all(result[u][v] == 5 for u, v in itertools.combinations(G, 2))
True
```

You can also use alternative flow algorithms for computing edge disjoint paths. For instance, in dense networks the algorithm `shortest_augmenting_path()` will usually perform better than the default `edmonds_karp()` which is faster for sparse networks with highly skewed degree distributions. Alternative flow functions have to be explicitly imported from the flow package.

```python
>>> from networkx.algorithms.flow import shortest_augmenting_path

>>> len(list(nx.edge_disjoint_paths(G, 0, 6, flow_func=shortest_augmenting_path)))
5
```

**Notes**

This is a flow based implementation of edge disjoint paths. We compute the maximum flow between source and target on an auxiliary directed network. The saturated edges in the residual network after running the maximum flow algorithm correspond to edge disjoint paths between source and target in the original network. This function handles both directed and undirected graphs, and can use all flow algorithms from NetworkX flow package.

networkx.algorithms.connectivity.disjoint_paths.node_disjoint_paths

`node_disjoint_paths(G, s, t, flow_func=None, cutoff=None, auxiliary=None, residual=None)`

Computes node disjoint paths between source and target.

Node disjoint paths are paths that only share their first and last nodes. The number of node independent paths between two nodes is equal to their local node connectivity.
Parameters

- **G** *(NetworkX graph)*
- **s** *(node)* – Source node.
- **t** *(node)* – Target node.
- **flow_func** *(function)* – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see `maximum_flow()` for details). If `flow_func` is None, the default maximum flow function (`edmonds_karp()` is used. See below for details. The choice of the default function may change from version to version and should not be relied on. Default value: None.
- **cutoff** *(int)* – Maximum number of paths to yield. Some of the maximum flow algorithms, such as `edmonds_karp()` (the default) and `shortest_augmenting_path()` support the cutoff parameter, and will terminate when the flow value reaches or exceeds the cutoff. Other algorithms will ignore this parameter. Default value: None.
- **auxiliary** *(NetworkX DiGraph)* – Auxiliary digraph to compute flow based node connectivity. It has to have a graph attribute called mapping with a dictionary mapping node names in G and in the auxiliary digraph. If provided it will be reused instead of recreated. Default value: None.
- **residual** *(NetworkX DiGraph)* – Residual network to compute maximum flow. If provided it will be reused instead of recreated. Default value: None.

Returns **paths** – Generator of node disjoint paths.

Return type **generator**

Raises

- **NetworkXNoPath** : exception – If there is no path between source and target.
- **NetworkXError** : exception – If source or target are not in the graph G.

Examples

We use in this example the platonic icosahedral graph, which has node node connectivity 5, thus there are 5 node disjoint paths between any pair of non neighbor nodes.

```python
>>> G = nx.icosahedral_graph()
>>> len(list(nx.node_disjoint_paths(G, 0, 6)))
5
```

If you need to compute node disjoint paths between several pairs of nodes in the same graph, it is recommended that you reuse the data structures that NetworkX uses in the computation: the auxiliary digraph for node connectivity and node cuts, and the residual network for the underlying maximum flow computation.

Example of how to compute node disjoint paths reusing the data structures:

```python
>>> # You also have to explicitly import the function for
>>> # building the auxiliary digraph from the connectivity package
>>> from networkx.algorithms.connectivity import (...
>>>     build_auxiliary_node_connectivity)
>>> H = build_auxiliary_node_connectivity(G)
>>> # And the function for building the residual network from the
>>> # flow package
```

(continues on next page)
You can also use alternative flow algorithms for computing node disjoint paths. For instance, in dense networks the algorithm `shortest_augmenting_path()` will usually perform better than the default `edmonds_karp()` which is faster for sparse networks with highly skewed degree distributions. Alternative flow functions have to be explicitly imported from the flow package.

```python
>>> from networkx.algorithms.flow import shortest_augmenting_path
>>> len(list(nx.node_disjoint_paths(G, 0, 6, flow_func=shortest_augmenting_path)))
5
```

**Notes**

This is a flow based implementation of node disjoint paths. We compute the maximum flow between source and target on an auxiliary directed network. The saturated edges in the residual network after running the maximum flow algorithm correspond to node disjoint paths between source and target in the original network. This function handles both directed and undirected graphs, and can use all flow algorithms from NetworkX flow package.

**See also:**
- `edge_disjoint_paths()`, `node_connectivity()`, `maximum_flow()`, `edmonds_karp()`, `preflow_push()`, `shortest_augmenting_path()`

### 3.15.6 Flow-based Connectivity

Flow based connectivity algorithms

```python
average_node_connectivity(G[, flow_func])
```

Returns the average connectivity of a graph G.

```python
all_pairs_node_connectivity(G[, nbunch, ...])
```

Compute node connectivity between all pairs of nodes of G.

```python
edge_connectivity(G[, s, t, flow_func, cutoff])
```

Returns the edge connectivity of the graph or digraph G.

```python
local_edge_connectivity(G[, s, t[, ...]])
```

Returns local edge connectivity for nodes s and t in G.

```python
local_node_connectivity(G[, s, t[, ...]])
```

Computes local node connectivity for nodes s and t.

```python
node_connectivity(G[, s, t, flow_func])
```

Returns node connectivity for a graph or digraph G.

```python
networkx.algorithms.connectivity.connectivity.average_node_connectivity
```

**average_node_connectivity** *(G, flow_func=None)*

Returns the average connectivity of a graph G.

The average connectivity $\bar{\kappa}$ of a graph G is the average of local node connectivity over all pairs of
nodes of $G$.

$$\bar{\kappa}(G) = \frac{\sum_{u,v} \kappa_G(u,v)}{|E|^2}$$

**Parameters**

- $G$ (*NetworkX graph*) – Undirected graph
- `flow_func` (*function*) – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see `maximum_flow()` for details). If `flow_func` is None, the default maximum flow function (`edmonds_karp()`) is used. See `local_node_connectivity()` for details. The choice of the default function may change from version to version and should not be relied on. Default value: None.

**Returns** $K$ – Average node connectivity

**Return type** `float`

**See also:**

`local_node_connectivity()`, `node_connectivity()`, `edge_connectivity()`, `maximum_flow()`, `edmonds_karp()`, `preflow_push()`, `shortest_augmenting_path()`

**References**

networkx.algorithms.connectivity.connectivity.all_pairs_node_connectivity

`all_pairs_node_connectivity(G, nbunch=None, flow_func=None)`

Compute node connectivity between all pairs of nodes of $G$.

**Parameters**

- $G$ (*NetworkX graph*) – Undirected graph
- `nbunch` (*container*) – Container of nodes. If provided node connectivity will be computed only over pairs of nodes in `nbunch`.
- `flow_func` (*function*) – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see `maximum_flow()` for details). If `flow_func` is None, the default maximum flow function (`edmonds_karp()`) is used. See below for details. The choice of the default function may change from version to version and should not be relied on. Default value: None.

**Returns** `all_pairs` – A dictionary with node connectivity between all pairs of nodes in $G$, or in `nbunch` if provided.

**Return type** `dict`

**See also:**

`local_node_connectivity()`, `edge_connectivity()`, `local_edge_connectivity()`, `maximum_flow()`, `edmonds_karp()`, `preflow_push()`, `shortest_augmenting_path()`

---


Chapter 3. Algorithms
edge_connectivity \( (G, s=None, t=None, flow_func=None, cutoff=None) \)

Returns the edge connectivity of the graph or digraph \( G \).

The edge connectivity is equal to the minimum number of edges that must be removed to disconnect \( G \) or render it trivial. If source and target nodes are provided, this function returns the local edge connectivity: the minimum number of edges that must be removed to break all paths from source to target in \( G \).

Parameters

- \( G \) (NetworkX graph) – Undirected or directed graph
- \( s \) (node) – Source node. Optional. Default value: None.
- \( t \) (node) – Target node. Optional. Default value: None.
- \( flow_func \) (function) – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see \( \text{maximum_flow()} \) for details). If \( flow_func \) is None, the default maximum flow function (\( \text{edmonds_karp()} \)) is used. See below for details. The choice of the default function may change from version to version and should not be relied on. Default value: None.
- \( cutoff \) (integer, float) – If specified, the maximum flow algorithm will terminate when the flow value reaches or exceeds the cutoff. This is only for the algorithms that support the cutoff parameter: \( \text{edmonds_karp()} \) and \( \text{shortest_augmenting_path()} \). Other algorithms will ignore this parameter. Default value: None.

Returns \( K \) – Edge connectivity for \( G \), or local edge connectivity if source and target were provided

Return type integer

Examples

```python
>>> # Platonic icosahedral graph is 5-edge-connected
>>> G = nx.icosahedral_graph()
>>> nx.edge_connectivity(G)
5
```

You can use alternative flow algorithms for the underlying maximum flow computation. In dense networks the algorithm \( \text{shortest_augmenting_path()} \) will usually perform better than the default \( \text{edmonds_karp()} \), which is faster for sparse networks with highly skewed degree distributions. Alternative flow functions have to be explicitly imported from the flow package.

```python
>>> from networkx.algorithms.flow import shortest_augmenting_path
>>> nx.edge_connectivity(G, flow_func=shortest_augmenting_path)
5
```

If you specify a pair of nodes (source and target) as parameters, this function returns the value of local edge connectivity.

```python
>>> nx.edge_connectivity(G, 3, 7)
5
```

If you need to perform several local computations among different pairs of nodes on the same graph, it is recommended that you reuse the data structures used in the maximum flow computations. See \( \text{local_edge_connectivity()} \) for details.
Notes

This is a flow based implementation of global edge connectivity. For undirected graphs the algorithm works by finding a ‘small’ dominating set of nodes of G (see algorithm 7 in\(^1\)) and computing local maximum flow (see `local_edge_connectivity()` between an arbitrary node in the dominating set and the rest of nodes in it. This is an implementation of algorithm 6 in\(^1\). For directed graphs, the algorithm does \(n\) calls to the maximum flow function. This is an implementation of algorithm 8 in\(^1\).

See also:

`local_edge_connectivity()`, `local_node_connectivity()`, `node_connectivity()`, `maximum_flow()`, `edmonds_karp()`, `preflow_push()`, `shortest_augmenting_path()`, `k_edge_components()`, `k_edge_subgraphs()`

References

networkx.algorithms.connectivity.connectivity.local_edge_connectivity

`local_edge_connectivity(G, s, t, flow_func=None, auxiliary=None, residual=None, cutoff=None)`

Returns local edge connectivity for nodes \(s\) and \(t\) in \(G\).

Local edge connectivity for two nodes \(s\) and \(t\) is the minimum number of edges that must be removed to disconnect them.

This is a flow based implementation of edge connectivity. We compute the maximum flow on an auxiliary digraph build from the original network (see below for details). This is equal to the local edge connectivity because the value of a maximum \(s\)-\(t\)-flow is equal to the capacity of a minimum \(s\)-\(t\)-cut (Ford and Fulkerson theorem)\(^1\).

Parameters

- \(G\) (NetworkX graph) – Undirected or directed graph
- \(s\) (node) – Source node
- \(t\) (node) – Target node
- `flow_func` (function) – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see `maximum_flow()` for details). If `flow_func` is None, the default maximum flow function (`edmonds_karp()`) is used. See below for details. The choice of the default function may change from version to version and should not be relied on. Default value: None.
- `auxiliary` (NetworkX DiGraph) – Auxiliary digraph for computing flow based edge connectivity. If provided it will be reused instead of recreated. Default value: None.
- `residual` (NetworkX DiGraph) – Residual network to compute maximum flow. If provided it will be reused instead of recreated. Default value: None.
- `cutoff` (integer, float) – If specified, the maximum flow algorithm will terminate when the flow value reaches or exceeds the cutoff. This is only for the algorithms that support the cutoff parameter: `edmonds_karp()` and `shortest_augmenting_path()`. Other algorithms will ignore this parameter. Default value: None.

Returns \(K\) – local edge connectivity for nodes \(s\) and \(t\).


Return type  integer

Examples

This function is not imported in the base NetworkX namespace, so you have to explicitly import it from the connectivity package:

```python
>>> from networkx.algorithms.connectivity import local_edge_connectivity
```

We use in this example the platonic icosahedral graph, which has edge connectivity 5.

```python
>>> G = nx.icosahedral_graph()
>>> local_edge_connectivity(G, 0, 6)
5
```

If you need to compute local connectivity on several pairs of nodes in the same graph, it is recommended that you reuse the data structures that NetworkX uses in the computation: the auxiliary digraph for edge connectivity, and the residual network for the underlying maximum flow computation.

Example of how to compute local edge connectivity among all pairs of nodes of the platonic icosahedral graph reusing the data structures.

```python
>>> import itertools

>>> # You also have to explicitly import the function for
>>> # building the auxiliary digraph from the connectivity package
>>> from networkx.algorithms.connectivity import build_auxiliary_edge_connectivity

>>> H = build_auxiliary_edge_connectivity(G)

>>> # And the function for building the residual network from the
>>> # flow package
>>> from networkx.algorithms.flow import build_residual_network

>>> # Note that the auxiliary digraph has an edge attribute named capacity
>>> R = build_residual_network(H, 'capacity')

>>> result = dict.fromkeys(G, dict())

>>> # Reuse the auxiliary digraph and the residual network by passing them
>>> # as parameters
>>> for u, v in itertools.combinations(G, 2):
...     k = local_edge_connectivity(G, u, v, auxiliary=H, residual=R)
...     result[u][v] = k
>>> all(result[u][v] == 5 for u, v in itertools.combinations(G, 2))
True
```

You can also use alternative flow algorithms for computing edge connectivity. For instance, in dense networks the algorithm `shortest_augmenting_path()` will usually perform better than the default `edmonds_karp()` which is faster for sparse networks with highly skewed degree distributions. Alternative flow functions have to be explicitly imported from the flow package.

```python
>>> from networkx.algorithms.flow import shortest_augmenting_path

>>> local_edge_connectivity(G, 0, 6, flow_func=shortest_augmenting_path)
5
```

Notes

This is a flow based implementation of edge connectivity. We compute the maximum flow using, by default, the `edmonds_karp()` algorithm on an auxiliary digraph build from the original input graph:
If the input graph is undirected, we replace each edge \((u, v)\) with two reciprocal arcs \((u, v)\) and \((v, u)\) and then we set the attribute ‘capacity’ for each arc to 1. If the input graph is directed we simply add the ‘capacity’ attribute. This is an implementation of algorithm 1 in\(^1\).

The maximum flow in the auxiliary network is equal to the local edge connectivity because the value of a maximum s-t-flow is equal to the capacity of a minimum s-t-cut (Ford and Fulkerson theorem).

See also:

- edge_connectivity()
- local_node_connectivity()
- node_connectivity()
- maximum_flow()
- edmonds_karp()
- preflow_push()
- shortest_augmenting_path()

References

networkx.algorithms.connectivity.connectivity.local_node_connectivity

local_node_connectivity \((G, s, t, flow_func=None, auxiliary=None, residual=None, cutoff=None)\)

Computes local node connectivity for nodes \(s\) and \(t\).

Local node connectivity for two non adjacent nodes \(s\) and \(t\) is the minimum number of nodes that must be removed (along with their incident edges) to disconnect them.

This is a flow based implementation of node connectivity. We compute the maximum flow on an auxiliary digraph build from the original input graph (see below for details).

Parameters

- \(G\) (NetworkX graph) – Undirected graph
- \(s\) (node) – Source node
- \(t\) (node) – Target node
- \(flow\_func\) (function) – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see maximum_flow() for details). If \(flow\_func\) is None, the default maximum flow function (edmonds_karp()) is used. See below for details. The choice of the default function may change from version to version and should not be relied on. Default value: None.
- \(auxiliary\) (NetworkX DiGraph) – Auxiliary digraph to compute flow based node connectivity. It has to have a graph attribute called mapping with a dictionary mapping node names in \(G\) and in the auxiliary digraph. If provided it will be reused instead of recreated. Default value: None.
- \(residual\) (NetworkX DiGraph) – Residual network to compute maximum flow. If provided it will be reused instead of recreated. Default value: None.
- \(cutoff\) (integer, float) – If specified, the maximum flow algorithm will terminate when the flow value reaches or exceeds the cutoff. This is only for the algorithms that support the cutoff parameter: edmonds_karp() and shortest_augmenting_path(). Other algorithms will ignore this parameter. Default value: None.

Returns \(K\) – local node connectivity for nodes \(s\) and \(t\)

Return type integer
Examples

This function is not imported in the base NetworkX namespace, so you have to explicitly import it from the connectivity package:

```python
>>> from networkx.algorithms.connectivity import local_node_connectivity
```

We use in this example the platonic icosahedral graph, which has node connectivity 5.

```python
>>> G = nx.icosahedral_graph()
>>> local_node_connectivity(G, 0, 6)
5
```

If you need to compute local connectivity on several pairs of nodes in the same graph, it is recommended that you reuse the data structures that NetworkX uses in the computation: the auxiliary digraph for node connectivity, and the residual network for the underlying maximum flow computation.

Example of how to compute local node connectivity among all pairs of nodes of the platonic icosahedral graph reusing the data structures.

```python
>>> import itertools

>>> # You also have to explicitly import the function for
>>> # building the auxiliary digraph from the connectivity package
>>> from networkx.algorithms.connectivity import (...
   build_auxiliary_node_connectivity)
...
>>> H = build_auxiliary_node_connectivity(G)
>>> # And the function for building the residual network from the
>>> # flow package
>>> from networkx.algorithms.flow import build_residual_network
>>> # Note that the auxiliary digraph has an edge attribute named capacity
>>> R = build_residual_network(H, 'capacity')
>>> result = dict.fromkeys(G, dict())
>>> # Reuse the auxiliary digraph and the residual network by passing them
>>> # as parameters
>>> for u, v in itertools.combinations(G, 2):
   ...   k = local_node_connectivity(G, u, v, auxiliary=H, residual=R)
   ...   result[u][v] = k
   ...
>>> all(result[u][v] == 5 for u, v in itertools.combinations(G, 2))
True
```

You can also use alternative flow algorithms for computing node connectivity. For instance, in dense networks the algorithm `shortest_augmenting_path()` will usually perform better than the default `edmonds_karp()` which is faster for sparse networks with highly skewed degree distributions. Alternative flow functions have to be explicitly imported from the flow package.

```python
>>> from networkx.algorithms.flow import shortest_augmenting_path
>>> local_node_connectivity(G, 0, 6, flow_func=shortest_augmenting_path)
5
```

Notes

This is a flow based implementation of node connectivity. We compute the maximum flow using, by default, the `edmonds_karp()` algorithm (see: `maximum_flow()`) on an auxiliary digraph build from the original input graph:

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For an undirected graph \( G \) having \( n \) nodes and \( m \) edges we derive a directed graph \( H \) with \( 2n \) nodes and \( 2m+n \) arcs by replacing each original node \( v \) with two nodes \( v_A, v_B \) linked by an (internal) arc in \( H \). Then for each edge \((u, v)\) in \( G \) we add two arcs \((u_B, v_A)\) and \((v_B, u_A)\) in \( H \). Finally we set the attribute capacity = 1 for each arc in \( H \).

For a directed graph \( G \) having \( n \) nodes and \( m \) arcs we derive a directed graph \( H \) with \( 2n \) nodes and \( m+n \) arcs by replacing each original node \( v \) with two nodes \( v_A, v_B \) linked by an (internal) arc \((v_A, v_B)\) in \( H \). Then for each arc \((u, v)\) in \( G \) we add one arc \((u_B, v_A)\) in \( H \). Finally we set the attribute capacity = 1 for each arc in \( H \).

This is equal to the local node connectivity because the value of a maximum s-t-flow is equal to the capacity of a minimum s-t-cut.

See also:

- `local_edge_connectivity()`, `node_connectivity()`, `minimum_node_cut()`, `maximum_flow()`, `edmonds_karp()`, `preflow_push()`, `shortest_augmenting_path()`

References

networkx.algorithms.connectivity.connectivity.node_connectivity

`node_connectivity(G, s=None, t=None, flow_func=None)`

Returns node connectivity for a graph or digraph \( G \).

Node connectivity is equal to the minimum number of nodes that must be removed to disconnect \( G \) or render it trivial. If source and target nodes are provided, this function returns the local node connectivity: the minimum number of nodes that must be removed to break all paths from source to target in \( G \).

Parameters

- \( G \) (\textit{NetworkX graph}) – Undirected graph
- \( s \) (\textit{node}) – Source node. Optional. Default value: None.
- \( t \) (\textit{node}) – Target node. Optional. Default value: None.
- \( \text{flow\_func} \) (\textit{function}) – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see `maximum_flow()` for details). If \( \text{flow\_func} \) is None, the default maximum flow function (`edmonds_karp()`) is used. See below for details. The choice of the default function may change from version to version and should not be relied on. Default value: None.

Returns \( K \) – Node connectivity of \( G \), or local node connectivity if source and target are provided.

Return type integer

Examples

```python
>>> # Platonic icosahedral graph is 5-node-connected
>>> G = nx.icosahedral_graph()
>>> nx.node_connectivity(G)
5
```
You can use alternative flow algorithms for the underlying maximum flow computation. In dense networks the algorithm `shortest_augmenting_path()` will usually perform better than the default `edmonds_karp()`, which is faster for sparse networks with highly skewed degree distributions. Alternative flow functions have to be explicitly imported from the flow package.

```python
>>> from networkx.algorithms.flow import shortest_augmenting_path
>>> nx.node_connectivity(G, flow_func=shortest_augmenting_path)
5
```

If you specify a pair of nodes (source and target) as parameters, this function returns the value of local node connectivity.

```python
>>> nx.node_connectivity(G, 3, 7)
5
```

If you need to perform several local computations among different pairs of nodes on the same graph, it is recommended that you reuse the data structures used in the maximum flow computations. See `local_node_connectivity()` for details.

**Notes**

This is a flow based implementation of node connectivity. The algorithm works by solving $O((n - \delta - 1 + \delta(\delta - 1))/2)$ maximum flow problems on an auxiliary digraph. Where $\delta$ is the minimum degree of $G$. For details about the auxiliary digraph and the computation of local node connectivity see `local_node_connectivity()`. This implementation is based on algorithm 11 in

### See also:

- `local_node_connectivity()`, `edge_connectivity()`, `maximum_flow()`, `edmonds_karp()`, `preflow_push()`, `shortest_augmenting_path()`

**References**

### 3.15.7 Flow-based Minimum Cuts

Flow based cut algorithms

```python
def minimum_edge_cut(G, s=None, t=None, flow_func=None):
    """Returns a set of edges of minimum cardinality that disconnects G."
    """
```

```python
def minimum_node_cut(G, s=None, t=None, flow_func=None):
    """Returns a set of nodes of minimum cardinality that disconnects G."
    """
```

```python
def minimum_st_edge_cut(G, s, t, flow_func=None):
    """Returns the edges of the cut-set of a minimum (s, t)-cut."
    """
```

```python
def minimum_st_node_cut(G, s, t, flow_func=None):
    """Returns a set of nodes of minimum cardinality that disconnect source from target in G."
    """
```

**References**

3.15.7 Flow-based Minimum Cuts

Flow based cut algorithms

### 3.15.7 Flow-based Minimum Cuts

Flow based cut algorithms

```python
def minimum_edge_cut(G, s=None, t=None, flow_func=None):
    """Returns a set of edges of minimum cardinality that disconnects G."
    """
```

```python
def minimum_node_cut(G, s=None, t=None, flow_func=None):
    """Returns a set of nodes of minimum cardinality that disconnects G."
    """
```

```python
def minimum_st_edge_cut(G, s, t, flow_func=None):
    """Returns the edges of the cut-set of a minimum (s, t)-cut."
    """
```

```python
def minimum_st_node_cut(G, s, t, flow_func=None):
    """Returns a set of nodes of minimum cardinality that disconnect source from target in G."
    """
```

The `networkx.algorithms.connectivity.cuts.minimum_edge_cut` function

```python
minimum_edge_cut (G, s=None, t=None, flow_func=None)
```

Returns a set of edges of minimum cardinality that disconnects $G$.

If source and target nodes are provided, this function returns the set of edges of minimum cardinality that, if

---

1 Abdol-Hossein Esfahanian. Connectivity Algorithms. [http://www.cse.msu.edu/~cse835/Papers/Graph_connectivity_revised.pdf](http://www.cse.msu.edu/~cse835/Papers/Graph_connectivity_revised.pdf)
removed, would break all paths among source and target in G. If not, it returns a set of edges of minimum
Cardinality that disconnects G.

Parameters

- **G** (*NetworkX graph*)
- **s** (*node*) – Source node. Optional. Default value: None.
- **t** (*node*) – Target node. Optional. Default value: None.
- **flow_func** (*function*) – A function for computing the maximum flow among a pair of
  nodes. The function has to accept at least three parameters: a Digraph, a source node,
  and a target node. And return a residual network that follows NetworkX conventions (see
  `maximum_flow()` for details). If flow_func is None, the default maximum flow function
  (`edmonds_karp()`) is used. See below for details. The choice of the default function
  may change from version to version and should not be relied on. Default value: None.

Returns **cutset** – Set of edges that, if removed, would disconnect G. If source and target nodes are
provided, the set contains the edges that if removed, would destroy all paths between source and
target.

Return type *set*

Examples

```python
>>> # Platonic icosahedral graph has edge connectivity 5
>>> G = nx.icosahedral_graph()
>>> len(nx.minimum_edge_cut(G))
5
```

You can use alternative flow algorithms for the underlying maximum flow computation. In dense net-
works the algorithm `shortest_augmenting_path()` will usually perform better than the default
`edmonds_karp()`, which is faster for sparse networks with highly skewed degree distributions. Alternative
flow functions have to be explicitly imported from the flow package.

```python
>>> from networkx.algorithms.flow import shortest_augmenting_path
>>> len(nx.minimum_edge_cut(G, flow_func=shortest_augmenting_path))
5
```

If you specify a pair of nodes (source and target) as parameters, this function returns the value of local edge
connectivity.

```python
>>> nx.edge_connectivity(G, 3, 7)
5
```

If you need to perform several local computations among different pairs of nodes on the same graph,
it is recommended that you reuse the data structures used in the maximum flow computations. See
`local_edge_connectivity()` for details.

Notes

This is a flow based implementation of minimum edge cut. For undirected graphs the algorithm works by
finding a ‘small’ dominating set of nodes of G (see algorithm 7 in\(^1\)) and computing the maximum flow between
an arbitrary node in the dominating set and the rest of nodes in it. This is an implementation of algorithm 6

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\(^1\) Abdol-Hossein Esfahanian. Connectivity Algorithms. [http://www.cse.msu.edu/~cse835/Papers/Graph_connectivity_revised.pdf](http://www.cse.msu.edu/~cse835/Papers/Graph_connectivity_revised.pdf)
For directed graphs, the algorithm does \( n \) calls to the max flow function. The function raises an error if the directed graph is not weakly connected and returns an empty set if it is weakly connected. It is an implementation of algorithm 8 in\(^1\).

**See also:**

- `minimum_st_edge_cut()`, `minimum_node_cut()`, `stoer_wagner()`, `node_connectivity()`, `edge_connectivity()`, `maximum_flow()`, `edmonds_karp()`, `preflow_push()`, `shortest_augmenting_path()`

**References**

`networkx.algorithms.connectivity.cuts.minimum_node_cut`

`minimum_node_cut(G, s=None, t=None, flow_func=None)`

Returns a set of nodes of minimum cardinality that disconnects \( G \).

If source and target nodes are provided, this function returns the set of nodes of minimum cardinality that, if removed, would destroy all paths among source and target in \( G \). If not, it returns a set of nodes of minimum cardinality that disconnects \( G \).

**Parameters**

- \( G \) (NetworkX graph)
- \( s \) (node) – Source node. Optional. Default value: None.
- \( t \) (node) – Target node. Optional. Default value: None.
- \( flow_func \) (function) – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see `maximum_flow()` for details). If `flow_func` is None, the default maximum flow function (`edmonds_karp()`) is used. See below for details. The choice of the default function may change from version to version and should not be relied on. Default value: None.

**Returns**

- `cutset` – Set of nodes that, if removed, would disconnect \( G \). If source and target nodes are provided, the set contains the nodes that if removed, would destroy all paths between source and target.

**Return type**

- `set`

**Examples**

```python
>>> # Platonic icosahedral graph has node connectivity 5
>>> G = nx.icosahedral_graph()
>>> node_cut = nx.minimum_node_cut(G)
>>> len(node_cut)
5
```

You can use alternative flow algorithms for the underlying maximum flow computation. In dense networks the algorithm `shortest_augmenting_path()` will usually perform better than the default `edmonds_karp()`, which is faster for sparse networks with highly skewed degree distributions. Alternative flow functions have to be explicitly imported from the flow package.
NetworkX Reference, Release 2.2rc1.dev20180319181321

```python
>>> from networkx.algorithms.flow import shortest_augmenting_path
>>> node_cut == nx.minimum_node_cut(G, flow_func=shortest_augmenting_path)
True
```

If you specify a pair of nodes (source and target) as parameters, this function returns a local st node cut.

```python
>>> len(nx.minimum_node_cut(G, 3, 7))
5
```

If you need to perform several local st cuts among different pairs of nodes on the same graph, it is recommended that you reuse the data structures used in the maximum flow computations. See `minimum_st_node_cut()` for details.

**Notes**

This is a flow based implementation of minimum node cut. The algorithm is based in solving a number of maximum flow computations to determine the capacity of the minimum cut on an auxiliary directed network that corresponds to the minimum node cut of G. It handles both directed and undirected graphs. This implementation is based on algorithm 11 in\(^1\).

See also:

- `minimum_st_node_cut()`, `minimum_cut()`, `minimum_edge_cut()`, `stoer_wagner()`, `node_connectivity()`, `edge_connectivity()`, `maximum_flow()`, `edmonds_karp()`, `preflow_push()`, `shortest_augmenting_path()`

**References**

`networkx.algorithms.connectivity.cuts.minimum_st_edge_cut`

```python
minimum_st_edge_cut(G, s, t, flow_func=None, auxiliary=None, residual=None)
```

Returns the edges of the cut-set of a minimum (s, t)-cut.

This function returns the set of edges of minimum cardinality that, if removed, would destroy all paths among source and target in G. Edge weights are not considered. See `minimum_cut()` for computing minimum cuts considering edge weights.

**Parameters**

- **G** (*NetworkX graph*)
- **s** (*node*) – Source node for the flow.
- **t** (*node*) – Sink node for the flow.
- **auxiliary** (*NetworkX DiGraph*) – Auxiliary digraph to compute flow based node connectivity. It has to have a graph attribute called mapping with a dictionary mapping node names in G and in the auxiliary digraph. If provided it will be reused instead of recreated. Default value: None.
- **flow_func** (*function*) – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see `maximum_flow()` for details). If flow_func is None, the default maximum flow function (`edmonds_karp()`) is used. See `node_connectivity()` for details. The choice of


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the default function may change from version to version and should not be relied on. Default value: None.

- **residual** (*NetworkX DiGraph*) – Residual network to compute maximum flow. If provided it will be reused instead of recreated. Default value: None.

**Returns** cutset – Set of edges that, if removed from the graph, will disconnect it.

**Return type** set

**See also:**

minimum_cut(), minimum_node_cut(), minimum_edge_cut(), stoer_wagner(),
node_connectivity(), edge_connectivity(), maximum_flow(), edmonds_karp(),
preflow_push(), shortest_augmenting_path()

**Examples**

This function is not imported in the base NetworkX namespace, so you have to explicitly import it from the connectivity package:

```python
>>> from networkx.algorithms.connectivity import minimum_st_edge_cut
```

We use in this example the platonic icosahedral graph, which has edge connectivity 5.

```python
>>> G = nx.icosahedral_graph()
>>> len(minimum_st_edge_cut(G, 0, 6))
5
```

If you need to compute local edge cuts on several pairs of nodes in the same graph, it is recommended that you reuse the data structures that NetworkX uses in the computation: the auxiliary digraph for edge connectivity, and the residual network for the underlying maximum flow computation.

Example of how to compute local edge cuts among all pairs of nodes of the platonic icosahedral graph reusing the data structures.

```python
>>> import itertools

>>> # You also have to explicitly import the function for
>>> # building the auxiliary digraph from the connectivity package
>>> from networkx.algorithms.connectivity import (...
...     build_auxiliary_edge_connectivity)
>>> H = build_auxiliary_edge_connectivity(G)
>>> # And the function for building the residual network from the
>>> # flow package
>>> from networkx.algorithms.flow import build_residual_network

>>> # Note that the auxiliary digraph has an edge attribute named capacity
>>> R = build_residual_network(H, 'capacity')
>>> result = dict.fromkeys(G, dict())

>>> # Reuse the auxiliary digraph and the residual network by passing them
>>> # as parameters
>>> for u, v in itertools.combinations(G, 2):
...     k = len(minimum_st_edge_cut(G, u, v, auxiliary=H, residual=R))
...     result[u][v] = k
>>> all(result[u][v] == 5 for u, v in itertools.combinations(G, 2))
True
```

You can also use alternative flow algorithms for computing edge cuts. For instance, in dense networks the algorithm shortest_augmenting_path() will usually perform better than the default edmonds_karp()
which is faster for sparse networks with highly skewed degree distributions. Alternative flow functions have to be explicitly imported from the flow package.

```python
>>> from networkx.algorithms.flow import shortest_augmenting_path
>>> len(minimum_st_edge_cut(G, 0, 6, flow_func=shortest_augmenting_path))
5
```

networkx.algorithms.connectivity.cuts.minimum_st_node_cut

**minimum_st_node_cut** *(G, s, t, flow_func=None, auxiliary=None, residual=None)*

Returns a set of nodes of minimum cardinality that disconnect source from target in G.

This function returns the set of nodes of minimum cardinality that, if removed, would destroy all paths among source and target in G.

**Parameters**

- **G** *(NetworkX graph)*
- **s** *(node)* – Source node.
- **t** *(node)* – Target node.
- **flow_func** *(function)* – A function for computing the maximum flow among a pair of nodes. The function has to accept at least three parameters: a Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see `maximum_flow()` for details). If `flow_func` is None, the default maximum flow function (`edmonds_karp()`) is used. See below for details. The choice of the default function may change from version to version and should not be relied on. Default value: None.
- **auxiliary** *(NetworkX DiGraph)* – Auxiliary digraph to compute flow based node connectivity. It has to have a graph attribute called mapping with a dictionary mapping node names in G and in the auxiliary digraph. If provided it will be reused instead of recreated. Default value: None.
- **residual** *(NetworkX DiGraph)* – Residual network to compute maximum flow. If provided it will be reused instead of recreated. Default value: None.

**Returns**

- cutset – Set of nodes that, if removed, would destroy all paths between source and target in G.

**Return type** `set`

**Examples**

This function is not imported in the base NetworkX namespace, so you have to explicitly import it from the connectivity package:

```python
>>> from networkx.algorithms.connectivity import minimum_st_node_cut

We use in this example the platonic icosahedral graph, which has node connectivity 5.

```python
>>> G = nx.icosahedral_graph()
>>> len(minimum_st_node_cut(G, 0, 6))
5
```
If you need to compute local st cuts between several pairs of nodes in the same graph, it is recommended that you reuse the data structures that NetworkX uses in the computation: the auxiliary digraph for node connectivity and node cuts, and the residual network for the underlying maximum flow computation.

Example of how to compute local st node cuts reusing the data structures:

```python
>>> # You also have to explicitly import the function for
>>> # building the auxiliary digraph from the connectivity package
>>> from networkx.algorithms.connectivity import (...
...   build_auxiliary_node_connectivity)
>>> H = build_auxiliary_node_connectivity(G)
>>> # And the function for building the residual network from the
>>> # flow package
>>> from networkx.algorithms.flow import build_residual_network
>>> # Note that the auxiliary digraph has an edge attribute named capacity
>>> R = build_residual_network(H, 'capacity')
>>> # Reuse the auxiliary digraph and the residual network by passing them
>>> # as parameters
>>> len(minimum_st_node_cut(G, 0, 6, auxiliary=H, residual=R))
5
```

You can also use alternative flow algorithms for computing minimum st node cuts. For instance, in dense networks the algorithm `shortest_augmenting_path()` will usually perform better than the default `edmonds_karp()` which is faster for sparse networks with highly skewed degree distributions. Alternative flow functions have to be explicitly imported from the flow package.

```python
>>> from networkx.algorithms.flow import shortest_augmenting_path
>>> len(minimum_st_node_cut(G, 0, 6, flow_func=shortest_augmenting_path))
5
```

Notes

This is a flow based implementation of minimum node cut. The algorithm is based in solving a number of maximum flow computations to determine the capacity of the minimum cut on an auxiliary directed network that corresponds to the minimum node cut of G. It handles both directed and undirected graphs. This implementation is based on algorithm 11 in\(^1\).

See also:

- `minimum_node_cut()`, `minimum_edge_cut()`, `stoer_wagner()`, `node_connectivity()`, `edge_connectivity()`, `maximum_flow()`, `edmonds_karp()`, `preflow_push()`, `shortest_augmenting_path()`

References

3.15.8 Stoer-Wagner minimum cut

Stoer-Wagner minimum cut algorithm.

```python
stoer_wagner(G[, weight, heap])
```

Returns the weighted minimum edge cut using the Stoer-Wagner algorithm.

networkx.algorithms.connectivity.stoerwagner.stoer_wagner

**stoer_wagner** *(G, weight='weight', heap=<class 'networkx.utils.heaps.BinaryHeap'>)*

Returns the weighted minimum edge cut using the Stoer-Wagner algorithm.

Determine the minimum edge cut of a connected graph using the Stoer-Wagner algorithm. In weighted cases, all weights must be nonnegative.

The running time of the algorithm depends on the type of heaps used:

<table>
<thead>
<tr>
<th>Type of heap</th>
<th>Running time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binary heap</td>
<td>$O(n(m + n) \log n)$</td>
</tr>
<tr>
<td>Fibonacci heap</td>
<td>$O(nm + n^2 \log n)$</td>
</tr>
<tr>
<td>Pairing heap</td>
<td>$O(2^{2V \log \log n} nm + n^2 \log n)$</td>
</tr>
</tbody>
</table>

**Parameters**

- **G** *(NetworkX graph)* – Edges of the graph are expected to have an attribute named by the weight parameter below. If this attribute is not present, the edge is considered to have unit weight.

- **weight** *(string)* – Name of the weight attribute of the edges. If the attribute is not present, unit weight is assumed. Default value: ‘weight’.

- **heap** *(class)* – Type of heap to be used in the algorithm. It should be a subclass of MinHeap or implement a compatible interface.

If a stock heap implementation is to be used, BinaryHeap is recommended over PairingHeap for Python implementations without optimized attribute accesses (e.g., CPython) despite a slower asymptotic running time. For Python implementations with optimized attribute accesses (e.g., PyPy), PairingHeap provides better performance. Default value: BinaryHeap.

**Returns**

- **cut_value** *(integer or float)* – The sum of weights of edges in a minimum cut.

- **partition** *(pair of node lists)* – A partitioning of the nodes that defines a minimum cut.

**Raises**

- **NetworkXNotImplemented** – If the graph is directed or a multigraph.

- **NetworkXError** – If the graph has less than two nodes, is not connected or has a negative-weighted edge.

**Examples**

```python
>>> G = nx.Graph()
>>> G.add_edge('x', 'a', weight=3)
>>> G.add_edge('x', 'b', weight=1)
>>> G.add_edge('a', 'c', weight=3)
>>> G.add_edge('b', 'c', weight=5)
>>> G.add_edge('b', 'd', weight=4)
>>> G.add_edge('d', 'e', weight=2)
>>> G.add_edge('e', 'y', weight=2)
>>> G.add_edge('e', 'y', weight=3)
>>> cut_value, partition = nx.stoer_wagner(G)
```
3.15.9 Utils for flow-based connectivity

Utilities for connectivity package

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>build_auxiliary_edge_connectivity(G)</code></td>
<td>Auxiliary digraph for computing flow based edge connectivity</td>
</tr>
<tr>
<td><code>build_auxiliary_node_connectivity(G)</code></td>
<td>Creates a directed graph D from an undirected graph G to compute flow based node connectivity.</td>
</tr>
</tbody>
</table>

`networkx.algorithms.connectivity.utils.build_auxiliary_edge_connectivity`

`build_auxiliary_edge_connectivity(G)`

Auxiliary digraph for computing flow based edge connectivity

If the input graph is undirected, we replace each edge \((u, v)\) with two reciprocal arcs \((u, v)\) and \((v, u)\) and then we set the attribute ‘capacity’ for each arc to 1. If the input graph is directed we simply add the ‘capacity’ attribute. Part of algorithm 1 in ¹.

References

`networkx.algorithms.connectivity.utils.build_auxiliary_node_connectivity`

`build_auxiliary_node_connectivity(G)`

Creates a directed graph D from an undirected graph G to compute flow based node connectivity.

For an undirected graph G having \(n\) nodes and \(m\) edges we derive a directed graph D with \(2n\) nodes and \(2m+n\) arcs by replacing each original node \(v\) with two nodes \(v_A, v_B\) linked by an (internal) arc in D. Then for each edge \((u, v)\) in G we add two arcs \((uB, v_A)\) and \((vB, u_A)\) in D. Finally we set the attribute capacity = 1 for each arc in D ¹.

For a directed graph having \(n\) nodes and \(m\) arcs we derive a directed graph D with \(2n\) nodes and \(m+n\) arcs by replacing each original node \(v\) with two nodes \(v_A, v_B\) linked by an (internal) arc \((v_A, v_B)\) in D. Then for each arc \((u, v)\) in G we add one arc \((uB, v_B)\) in D. Finally we set the attribute capacity = 1 for each arc in D.

A dictionary with a mapping between nodes in the original graph and the auxiliary digraph is stored as a graph attribute: H.graph[‘mapping’].

References

3.16 Cores

Find the k-cores of a graph.

¹ Abdol-Hossein Esfahanian. Connectivity Algorithms. (this is a chapter, look for the reference of the book). http://www.cse.msu.edu/~cse835/Papers/Graph_connectivity_revised.pdf

The k-core is found by recursively pruning nodes with degrees less than k.

See the following references for details:


For directed graphs a more general notion is that of D-cores which looks at (k, l) restrictions on (in, out) degree. The (k, k) D-core is the k-core.


<table>
<thead>
<tr>
<th>core_number(G)</th>
<th>Return the core number for each vertex.</th>
</tr>
</thead>
<tbody>
<tr>
<td>k_core(G[, k, core_number])</td>
<td>Return the k-core of G.</td>
</tr>
<tr>
<td>k_shell(G[, k, core_number])</td>
<td>Return the k-shell of G.</td>
</tr>
<tr>
<td>k_crust(G[, k, core_number])</td>
<td>Return the k-crust of G.</td>
</tr>
<tr>
<td>k_corona(G, k[, core_number])</td>
<td>Return the k-corona of G.</td>
</tr>
</tbody>
</table>

### 3.16.1 networkx.algorithms.core.core_number

**core_number(G)**  
Return the core number for each vertex.

A k-core is a maximal subgraph that contains nodes of degree k or more.

The core number of a node is the largest value k of a k-core containing that node.

**Parameters**  
G (*NetworkX graph*) – A graph or directed graph

**Returns**  
core_number – A dictionary keyed by node to the core number.

**Return type**  
dictionary

**Raises**  
NetworkXError – The k-core is not implemented for graphs with self loops or parallel edges.

**Notes**

Not implemented for graphs with parallel edges or self loops.

For directed graphs the node degree is defined to be the in-degree + out-degree.

**References**

### 3.16.2 networkx.algorithms.core.k_core

**k_core(G, k=None, core_number=None)**  
Return the k-core of G.

A k-core is a maximal subgraph that contains nodes of degree k or more.

**Parameters**

- G (*NetworkX graph*) – A graph or directed graph
• **k** *(int, optional)* – The order of the core. If not specified return the main core.

• **core_number** *(dictionary, optional)* – Precomputed core numbers for the graph G.

Returns  

G – The k-core subgraph

Return type  

NetworkX graph

Raises  

NetworkXError – The k-core is not defined for graphs with self loops or parallel edges.

Notes

The main core is the core with the largest degree.

Not implemented for graphs with parallel edges or self loops.

For directed graphs the node degree is defined to be the in-degree + out-degree.

Graph, node, and edge attributes are copied to the subgraph.
References

3.16.4 networkx.algorithms.core.k_crust

k_crust \((G, k=None, core_number=None)\)

Return the k-crust of G.

The k-crust is the graph G with the k-core removed.

Parameters

- \(G\) (NetworkX graph) – A graph or directed graph.
- \(k\) (int, optional) – The order of the shell. If not specified return the main crust.
- core_number (dictionary, optional) – Precomputed core numbers for the graph G.

Returns \(G\) – The k-crust subgraph

Return type NetworkX graph

Raises NetworkXError – The k-crust is not implemented for graphs with self loops or parallel edges.

Notes

This definition of k-crust is different than the definition in\(^1\). The k-crust in\(^1\) is equivalent to the k+1 crust of this algorithm.

Not implemented for graphs with parallel edges or self loops.

For directed graphs the node degree is defined to be the in-degree + out-degree.

Graph, node, and edge attributes are copied to the subgraph.

See also:

core_number()

References

3.16.5 networkx.algorithms.core.k_corona

k_corona \((G, k, core_number=None)\)

Return the k-corona of G.

The k-corona is the subgraph of nodes in the k-core which have exactly k neighbours in the k-core.

Parameters

- \(G\) (NetworkX graph) – A graph or directed graph
- \(k\) (int) – The order of the corona.
- core_number (dictionary, optional) – Precomputed core numbers for the graph G.

Returns \(G\) – The k-corona subgraph

Return type NetworkX graph

\(^1\) A model of Internet topology using k-shell decomposition Shai Carmi, Shlomo Havlin, Scott Kirkpatrick, Yuval Shavitt, and Eran Shir, PNAS July 3, 2007 vol. 104 no. 27 11150-11154 http://www.pnas.org/content/104/27/11150.full
Notes

Not implemented for graphs with parallel edges or self loops.
For directed graphs the node degree is defined to be the in-degree + out-degree.
Graph, node, and edge attributes are copied to the subgraph.
See also:
core_number()

References

3.17 Covering

Functions related to graph covers.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>min_edge_cover(G[, matching_algorithm])</code></td>
<td>Returns a set of edges which constitutes the minimum edge cover of the graph.</td>
</tr>
<tr>
<td><code>is_edge_cover(G, cover)</code></td>
<td>Decides whether a set of edges is a valid edge cover of the graph.</td>
</tr>
</tbody>
</table>

3.17.1 networkx.algorithms.covering.min_edge_cover

`min_edge_cover (G, matching_algorithm=None)`

Returns a set of edges which constitutes the minimum edge cover of the graph.

A smallest edge cover can be found in polynomial time by finding a maximum matching and extending it greedily so that all nodes are covered.

Parameters

- `G` (NetworkX graph) – An undirected bipartite graph.
- `matching_algorithm` (function) – A function that returns a maximum cardinality matching in a given bipartite graph. The function must take one input, the graph `G`, and return a dictionary mapping each node to its mate. If not specified, hopcroft_karp_matching() will be used. Other possibilities include eppstein_matching(), or matching algorithms in the networkx.algorithms.matching module.

Returns `min_cover` – It contains all the edges of minimum edge cover in form of tuples. It contains both the edges `(u, v)` and `(v, u)` for given nodes `u` and `v` among the edges of minimum edge cover.

Return type set

Notes

An edge cover of a graph is a set of edges such that every node of the graph is incident to at least one edge of the set. The minimum edge cover is an edge covering of smallest cardinality.
Due to its implementation, the worst-case running time of this algorithm is bounded by the worst-case running time of the function `matching_algorithm`.

Minimum edge cover for bipartite graph can also be found using the function present in `networkx.algorithms.bipartite.covering`.

### 3.17.2 `networkx.algorithms.covering.is_edge_cover`

`is_edge_cover(G, cover)` Decides whether a set of edges is a valid edge cover of the graph.

Given a set of edges, whether it is an edge covering can be decided if we just check whether all nodes of the graph has an edge from the set, incident on it.

**Parameters**

- `G (NetworkX graph)` – An undirected bipartite graph.
- `cover (set)` – Set of edges to be checked.

**Returns** Whether the set of edges is a valid edge cover of the graph.

**Return type** `bool`

**Notes**

An edge cover of a graph is a set of edges such that every node of the graph is incident to at least one edge of the set.

### 3.18 Cycles

#### 3.18.1 Cycle finding algorithms

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>cycle_basis(G[, root])</code></td>
<td>Returns a list of cycles which form a basis for cycles of G.</td>
</tr>
<tr>
<td><code>simple_cycles(G)</code></td>
<td>Find simple cycles (elementary circuits) of a directed graph.</td>
</tr>
<tr>
<td><code>find_cycle(G[, source, orientation])</code></td>
<td>Returns the edges of a cycle found via a directed, depth-first traversal.</td>
</tr>
<tr>
<td><code>minimum_cycle_basis(G[, weight])</code></td>
<td>Returns a minimum weight cycle basis for G</td>
</tr>
</tbody>
</table>

#### 3.18.2 `networkx.algorithms.cycles.cycle_basis`

`cycle_basis(G, root=None)` Returns a list of cycles which form a basis for cycles of G.

A basis for cycles of a network is a minimal collection of cycles such that any cycle in the network can be written as a sum of cycles in the basis. Here summation of cycles is defined as “exclusive or” of the edges. Cycle bases are useful, e.g. when deriving equations for electric circuits using Kirchhoff’s Laws.

**Parameters**

- `G (NetworkX Graph)`
- `root (node, optional)` – Specify starting node for basis.
Returns

- A list of cycle lists. Each cycle list is a list of nodes
- which forms a cycle (loop) in G.

Examples

```python
>>> G = nx.Graph()
>>> nx.add_cycle(G, [0, 1, 2, 3])
>>> nx.add_cycle(G, [0, 3, 4, 5])
>>> print(nx.cycle_basis(G, 0))
[[3, 4, 5, 0], [1, 2, 3, 0]]
```

Notes

This is adapted from algorithm CACM 491.

References

See also:

```
simple_cycles()
```

3.18.3 networkx.algorithms.cycles.simple_cycles

`simple_cycles(G)`

Find simple cycles (elementary circuits) of a directed graph.

A simple cycle, or elementary circuit, is a closed path where no node appears twice. Two elementary circuits are distinct if they are not cyclic permutations of each other.

This is a nonrecursive, iterator/generator version of Johnson’s algorithm\(^1\). There may be better algorithms for some cases\(^2\).

Parameters

- G (NetworkX DiGraph) – A directed graph

Returns `cycle_generator` – A generator that produces elementary cycles of the graph. Each cycle is represented by a list of nodes along the cycle.

Return type generator

Examples


To filter the cycles so that they don’t include certain nodes or edges, copy your graph and eliminate those nodes or edges before calling

```python
>>> copyG = G.copy()
>>> copyG.remove_nodes_from([1])
>>> copyG.remove_edges_from([(0, 1)])
>>> len(list(nx.simple_cycles(copyG)))
3
```

### Notes

The implementation follows pp. 79-80 in\(^1\).

The time complexity is \(O((n + e)(c + 1))\) for \(n\) nodes, \(e\) edges and \(c\) elementary circuits.

### References

See also:

`cycle_basis()`

#### 3.18.4 networkx.algorithms.cycles.find_cycle

**find_cycle** \((G, source=None, orientation='original')\)

Returns the edges of a cycle found via a directed, depth-first traversal.

**Parameters**

- **G** *(graph)* – A directed/undirected graph/multigraph.
- **source** *(node, list of nodes)* – The node from which the traversal begins. If None, then a source is chosen arbitrarily and repeatedly until all edges from each node in the graph are searched.
- **orientation** *(‘original’ | ‘reverse’ | ‘ignore’)* – For directed graphs and directed multigraphs, edge traversals need not respect the original orientation of the edges. When set to ‘reverse’, then every edge will be traversed in the reverse direction. When set to ‘ignore’, then each directed edge is treated as a single undirected edge that can be traversed in either direction. For undirected graphs and undirected multigraphs, this parameter is meaningless and is not consulted by the algorithm.

**Returns** *edges* – A list of directed edges indicating the path taken for the loop. If no cycle is found, then an exception is raised. For graphs, an edge is of the form \((u, v)\) where \(u\) and \(v\) are the tail and head of the edge as determined by the traversal. For multigraphs, an edge is of the form \((u, v, key)\), where \(key\) is the key of the edge. When the graph is directed, then \(u\) and \(v\) are always in the order of the actual directed edge. If orientation is ‘ignore’, then an edge takes the form \((u, v, key, direction)\) where direction indicates if the edge was followed in the forward (tail to head) or reverse (head to tail) direction. When the direction is forward, the value of direction is ‘forward’. When the direction is reverse, the value of direction is ‘reverse’.
Return type directed edges

Raises NetworkXNoCycle – If no cycle was found.

Examples

In this example, we construct a DAG and find, in the first call, that there are no directed cycles, and so an exception is raised. In the second call, we ignore edge orientations and find that there is an undirected cycle. Note that the second call finds a directed cycle while effectively traversing an undirected graph, and so, we found an “undirected cycle”. This means that this DAG structure does not form a directed tree (which is also known as a polytree).

```python
>>> import networkx as nx
>>> G = nx.DiGraph([(0, 1), (0, 2), (1, 2)])
>>> try:
...     nx.find_cycle(G, orientation='original')
... except:
...     pass
... >>> list(nx.find_cycle(G, orientation='ignore'))
[(0, 1, 'forward'), (1, 2, 'forward'), (0, 2, 'reverse')]
```

3.18.5 networkx.algorithms.cycles.minimum_cycle_basis

minimum_cycle_basis (G, weight=None)

Returns a minimum weight cycle basis for G

Minimum weight means a cycle basis for which the total weight (length for unweighted graphs) of all the cycles is minimum.

Parameters

- G (NetworkX Graph)
- weight (string) – name of the edge attribute to use for edge weights

Returns

- A list of cycle lists. Each cycle list is a list of nodes
- which forms a cycle (loop) in G. Note that the nodes are not necessarily returned in a order by which they appear in the cycle

Examples

```python
>>> G=nx.Graph()
>>> G.add_cycle([0,1,2,3])
>>> G.add_cycle([0,3,4,5])
>>> print(nx.minimum_cycle_basis(G))
[[0, 1, 2, 3], [0, 3, 4, 5]]
```
References


See also:

\texttt{simple_cycles()}, \texttt{cycle_basis()}

3.19 Cuts

Functions for finding and evaluating cuts in a graph.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>\texttt{boundary_expansion}</td>
<td>Returns the boundary expansion of the set $S$.</td>
</tr>
<tr>
<td>\texttt{conductance}</td>
<td>Returns the conductance of two sets of nodes.</td>
</tr>
<tr>
<td>\texttt{cut_size}</td>
<td>Returns the size of the cut between two sets of nodes.</td>
</tr>
<tr>
<td>\texttt{edge_expansion}</td>
<td>Returns the edge expansion between two node sets.</td>
</tr>
<tr>
<td>\texttt{mixing_expansion}</td>
<td>Returns the mixing expansion between two node sets.</td>
</tr>
<tr>
<td>\texttt{node_expansion}</td>
<td>Returns the node expansion of the set $S$.</td>
</tr>
<tr>
<td>\texttt{normalized_cut_size}</td>
<td>Returns the normalized size of the cut between two sets of nodes.</td>
</tr>
<tr>
<td>\texttt{volume}</td>
<td>Returns the volume of a set of nodes.</td>
</tr>
</tbody>
</table>

3.19.1 networkx.algorithms.cuts.boundary_expansion

\texttt{boundary_expansion} \((G, S)\)

Returns the boundary expansion of the set $S$.

The \textit{boundary expansion} is the quotient of the size of the edge boundary and the cardinality of $S$. [1]

**Parameters**

- $G$ (NetworkX graph)
- $S$ (sequence) – A sequence of nodes in $G$.

**Returns** The boundary expansion of the set $S$.

**Return type** number

See also:

\texttt{edge_expansion()}, \texttt{mixing_expansion()}, \texttt{node_expansion()}

References

3.19.2 networkx.algorithms.cuts.conductance

\texttt{conductance} \((G, S, T=\text{None}, \text{weight}=\text{None})\)

Returns the conductance of two sets of nodes.

The \textit{conductance} is the quotient of the cut size and the smaller of the volumes of the two sets. [1]
• **G (NetworkX graph)**

• **S (sequence)** – A sequence of nodes in G.

• **T (sequence)** – A sequence of nodes in G.

• **weight (object)** – Edge attribute key to use as weight. If not specified, edges have weight one.

**Returns** The conductance between the two sets S and T.

**Return type** number

**See also:**

*cut_size(), edge_expansion(), normalized_cut_size(), volume()*

**References**

### 3.19.3 networkx.algorithms.cuts.cut_size

`cut_size(G, S, T=None, weight=None)`

Returns the size of the cut between two sets of nodes.

A cut is a partition of the nodes of a graph into two sets. The cut size is the sum of the weights of the edges “between” the two sets of nodes.

**Parameters**

• **G (NetworkX graph)**

• **S (sequence)** – A sequence of nodes in G.

• **T (sequence)** – A sequence of nodes in G. If not specified, this is taken to be the set complement of S.

• **weight (object)** – Edge attribute key to use as weight. If not specified, edges have weight one.

**Returns** Total weight of all edges from nodes in set S to nodes in set T (and, in the case of directed graphs, all edges from nodes in T to nodes in S).

**Return type** number

**Examples**

In the graph with two cliques joined by a single edges, the natural bipartition of the graph into two blocks, one for each clique, yields a cut of weight one:

```python
>>> G = nx.barbell_graph(3, 0)
>>> S = {0, 1, 2}
>>> T = {3, 4, 5}
>>> nx.cut_size(G, S, T)
1
```

Each parallel edge in a multigraph is counted when determining the cut size:
>> G = nx.MultiGraph(['ab', 'ab'])
>>> S = {'a'}
>>> T = {'b'}
>>> nx.cut_size(G, S, T)
2

Notes

In a multigraph, the cut size is the total weight of edges including multiplicity.

3.19.4 Networkx.algorithms.cuts.edge_expansion

edge_expansion (G, S, T=None, weight=None)

Returns the edge expansion between two node sets.

The edge expansion is the quotient of the cut size and the smaller of the cardinalities of the two sets. [1]

Parameters

- G (NetworkX graph)
- S (sequence) – A sequence of nodes in G.
- T (sequence) – A sequence of nodes in G.
- weight (object) – Edge attribute key to use as weight. If not specified, edges have weight one.

Returns The edge expansion between the two sets S and T.

Return type number

See also:

boundary_expansion(), mixing_expansion(), node_expansion()

References

3.19.5 Networkx.algorithms.cuts.mixing_expansion

mixing_expansion (G, S, T=None, weight=None)

Returns the mixing expansion between two node sets.

The mixing expansion is the quotient of the cut size and twice the number of edges in the graph. [1]

Parameters

- G (NetworkX graph)
- S (sequence) – A sequence of nodes in G.
- T (sequence) – A sequence of nodes in G.
- weight (object) – Edge attribute key to use as weight. If not specified, edges have weight one.

Returns The mixing expansion between the two sets S and T.

Return type number
See also:

boundary_expansion(), edge_expansion(), node_expansion()

References

3.19.6 networkx.algorithms.cuts.node_expansion

def node_expansion(G, S):
    """Returns the node expansion of the set S.

    The node expansion is the quotient of the size of the node boundary of S and the cardinality of S. [1]
    """
    Parameters
    ----------
    G : NetworkX graph
    S : sequence
        A sequence of nodes in G.
    Returns
    -------
    The node expansion of the set S.
    Return type
    number

    See also:
    boundary_expansion(), edge_expansion(), mixing_expansion()

References

3.19.7 networkx.algorithms.cuts.normalized_cut_size

def normalized_cut_size(G, S, T=None, weight=None):
    """Returns the normalized size of the cut between two sets of nodes.

    The normalized cut size is the cut size times the sum of the reciprocal sizes of the volumes of the two sets. [1]
    """
    Parameters
    ----------
    G : NetworkX graph
    S : sequence
        A sequence of nodes in G.
    T : sequence
        A sequence of nodes in G.
    weight : object
        Edge attribute key to use as weight. If not specified, edges have weight one.
    Returns
    -------
    The normalized cut size between the two sets S and T.
    Return type
    number

Notes

In a multigraph, the cut size is the total weight of edges including multiplicity.

See also:

cut_size(), edge_expansion(), volume()
References

3.19.8 networkx.algorithms.cuts.volume

volume \((G, S, weight=None)\)

Returns the volume of a set of nodes.

The volume of a set \(S\) is the sum of the (out-)degrees of nodes in \(S\) (taking into account parallel edges in multigraphs). [1]

Parameters

- \(G\) (NetworkX graph)
- \(S\) (sequence) – A sequence of nodes in \(G\).
- \(weight\) (object) – Edge attribute key to use as weight. If not specified, edges have weight one.

Returns The volume of the set of nodes represented by \(S\) in the graph \(G\).

Return type number

See also:

- conductance()
- cut_size()
- edge_expansion()
- edge_boundary()
- normalized_cut_size()

References

3.20 Directed Acyclic Graphs

Algorithms for directed acyclic graphs (DAGs).

Note that most of these functions are only guaranteed to work for DAGs. In general, these functions do not check for acyclic-ness, so it is up to the user to check for that.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ancestors(G, source)</td>
<td>Return all nodes having a path to source in G.</td>
</tr>
<tr>
<td>descendants(G, source)</td>
<td>Return all nodes reachable from source in G.</td>
</tr>
<tr>
<td>topological_sort(G)</td>
<td>Return a generator of nodes in topologically sorted order.</td>
</tr>
<tr>
<td>lexicographical_topological_sort(G[, key])</td>
<td>Return a generator of nodes in lexicographically topologically sorted order.</td>
</tr>
<tr>
<td>is_directed_acyclic_graph(G)</td>
<td>Return True if the graph (G) is a directed acyclic graph (DAG) or False if not.</td>
</tr>
<tr>
<td>is_aperiodic(G)</td>
<td>Return True if (G) is aperiodic.</td>
</tr>
<tr>
<td>transitive_closure(G)</td>
<td>Returns transitive closure of a directed graph</td>
</tr>
<tr>
<td>transitive_reduction(G)</td>
<td>Returns transitive reduction of a directed graph</td>
</tr>
<tr>
<td>antichains(G)</td>
<td>Generates antichains from a directed acyclic graph (DAG).</td>
</tr>
<tr>
<td>dag_longest_path(G[, weight, default_weight])</td>
<td>Returns the longest path in a directed acyclic graph (DAG).</td>
</tr>
<tr>
<td>dag_longest_path_length(G[, weight, ...])</td>
<td>Returns the longest path length in a DAG</td>
</tr>
<tr>
<td>dag_to_branching(G)</td>
<td>Returns a branching representing all (overlapping) paths from root nodes to leaf nodes in the given directed acyclic graph.</td>
</tr>
</tbody>
</table>
3.20.1 networkx.algorithms.dag.ancestors

ancestors \((G, \text{source})\)
Return all nodes having a path to source in G.

Parameters

- **G** (*NetworkX DiGraph*) – A directed acyclic graph (DAG)
- **source** (node in G)

Returns The ancestors of source in G
Return type set()

3.20.2 networkx.algorithms.dag.descendants

descendants \((G, \text{source})\)
Return all nodes reachable from source in G.

Parameters

- **G** (*NetworkX DiGraph*) – A directed acyclic graph (DAG)
- **source** (node in G)

Returns The descendants of source in G
Return type set()

3.20.3 networkx.algorithms.dag.topological_sort

topological_sort \((G)\)
Return a generator of nodes in topologically sorted order.

A topological sort is a nonunique permutation of the nodes such that an edge from u to v implies that u appears before v in the topological sort order.

Parameters **G** (*NetworkX digraph*) – A directed acyclic graph (DAG)

Returns An iterable of node names in topological sorted order.
Return type iterable

Raises

- **NetworkXError** – Topological sort is defined for directed graphs only. If the graph G is undirected, a NetworkXError is raised.
- **NetworkXUnfeasible** – If G is not a directed acyclic graph (DAG) no topological sort exists and a NetworkXUnfeasible exception is raised. This can also be raised if G is changed while the returned iterator is being processed.
- **RuntimeError** – If G is changed while the returned iterator is being processed.

Examples

To get the reverse order of the topological sort:
```python
>>> DG = nx.DiGraph([(1, 2), (2, 3)])
>>> list(reversed(list(nx.topological_sort(DG))))
[3, 2, 1]
```

Notes

This algorithm is based on a description and proof in “Introduction to Algorithms: A Creative Approach”\(^1\). See also: `is_directed_acyclic_graph()`, `lexicographical_topological_sort()`

References

3.20.4 networkx.algorithms.dag.lexicographical_topological_sort

`lexicographical_topological_sort(G, key=None)`

Return a generator of nodes in lexicographically topologically sorted order.

A topological sort is a nonunique permutation of the nodes such that an edge from u to v implies that u appears before v in the topological sort order.

Parameters

- **G** (*NetworkX digraph*) – A directed acyclic graph (DAG)
- **key** (*function, optional*) – This function maps nodes to keys with which to resolve ambiguities in the sort order. Defaults to the identity function.

Returns

An iterable of node names in lexicographical topological sort order.

Return type

`iterable`

Raises

- `NetworkXError` – Topological sort is defined for directed graphs only. If the graph G is undirected, a `NetworkXError` is raised.
- `NetworkXUnfeasible` – If G is not a directed acyclic graph (DAG) no topological sort exists and a `NetworkXUnfeasible` exception is raised. This can also be raised if G is changed while the returned iterator is being processed.
- `RuntimeError` – If G is changed while the returned iterator is being processed.

Notes

This algorithm is based on a description and proof in “Introduction to Algorithms: A Creative Approach”\(^1\). See also: `topological_sort()`


References

3.20.5 networkx.algorithms.dag.is_directed_acyclic_graph

is_directed_acyclic_graph (G)
  Return True if the graph G is a directed acyclic graph (DAG) or False if not.
  Parameters  G (NetworkX graph)
  Returns  True if G is a DAG, False otherwise
  Return type  bool

3.20.6 networkx.algorithms.dag.is_aperiodic

is_aperiodic (G)
  Return True if G is aperiodic.
  A directed graph is aperiodic if there is no integer k > 1 that divides the length of every cycle in the graph.
  Parameters  G (NetworkX DiGraph) – A directed graph
  Returns  True if the graph is aperiodic False otherwise
  Return type  bool
  Raises  NetworkXError – If G is not directed

Notes

This uses the method outlined in\(^1\), which runs in \(O(m)\) time given \(m\) edges in G. Note that a graph is not aperiodic if it is acyclic as every integer trivial divides length 0 cycles.

References

3.20.7 networkx.algorithms.dag.transitive_closure

transitive_closure (G)
  Returns transitive closure of a directed graph
  The transitive closure of G = (V,E) is a graph G+ = (V,E+) such that for all v,w in V there is an edge (v,w) in E+
  if and only if there is a non-null path from v to w in G.
  Parameters  G (NetworkX DiGraph) – A directed graph
  Returns  The transitive closure of G
  Return type  NetworkX DiGraph
  Raises  NetworkXNotImplemented – If G is not directed

---

3.20.8 networkx.algorithms.dag.transitive_reduction

transitive_reduction \((G)\)

Returns transitive reduction of a directed graph

The transitive reduction of \(G = (V,E)\) is a graph \(G^- = (V,E^-)\) such that for all \(v,w\) in \(V\) there is an edge \((v,w)\) in \(E^-\) if and only if \((v,w)\) is in \(E\) and there is no path from \(v\) to \(w\) in \(G\) with length greater than 1.

**Parameters**

\(G \quad (\text{NetworkX DiGraph})\) – A directed acyclic graph (DAG)

**Returns**

The transitive reduction of \(G\)

**Return type**

NetworkX DiGraph

**Raises**

NetworkXError – If \(G\) is not a directed acyclic graph (DAG) transitive reduction is not uniquely defined and a NetworkXError exception is raised.

References

https://en.wikipedia.org/wiki/Transitive_reduction

3.20.9 networkx.algorithms.dag.antichains

antichains \((G)\)

Generates antichains from a directed acyclic graph (DAG).

An antichain is a subset of a partially ordered set such that any two elements in the subset are incomparable.

**Parameters**

\(G \quad (\text{NetworkX DiGraph})\) – A directed acyclic graph (DAG)

**Returns**

**Return type**

generator object

**Raises**

- NetworkXNotImplemented – If \(G\) is not directed
- NetworkXUnfeasible – If \(G\) contains a cycle

Notes

This function was originally developed by Peter Jipsen and Franco Saliola for the SAGE project. It’s included in NetworkX with permission from the authors. Original SAGE code at:

https://github.com/sagemath/sage/blob/master/src/sage/combinat/posets/hasse_diagram.py

References

3.20.10 networkx.algorithms.dag.dag_longest_path

dag_longest_path \((G, weight='weight', default_weight=1)\)

Returns the longest path in a directed acyclic graph (DAG).
If $G$ has edges with `weight` attribute the edge data are used as weight values.

**Parameters**

- **$G$** (*NetworkX DiGraph*) – A directed acyclic graph (DAG)
- **`weight`** (*str, optional*) – Edge data key to use for weight
- **`default_weight`** (*int, optional*) – The weight of edges that do not have a weight attribute

**Returns**  
Longest path

**Return type**  
list

**Raises**  
`NetworkXNotImplemented` – If $G$ is not directed

See also:

*dag_longest_path_length()*

### 3.20.11 `networkx.algorithms.dag.dag_longest_path_length`

*dag_longest_path_length*($G$, `weight`=`'weight'`, `default_weight`=1)  
Returns the longest path length in a DAG

**Parameters**

- **$G$** (*NetworkX DiGraph*) – A directed acyclic graph (DAG)
- **`weight`** (*string, optional*) – Edge data key to use for weight
- **`default_weight`** (*int, optional*) – The weight of edges that do not have a weight attribute

**Returns**  
Longest path length

**Return type**  
int

**Raises**  
`NetworkXNotImplemented` – If $G$ is not directed

See also:

*dag_longest_path_length()*

### 3.20.12 `networkx.algorithms.dag.dag_to_branching`

*dag_to_branching*($G$)  
Returns a branching representing all (overlapping) paths from root nodes to leaf nodes in the given directed acyclic graph.

As described in *networkx.algorithms.tree.recognition*, a *branching* is a directed forest in which each node has at most one parent. In other words, a branching is a disjoint union of *arborescences*. For this function, each node of in-degree zero in $G$ becomes a root of one of the arborescences, and there will be one leaf node for each distinct path from that root to a leaf node in $G$.

Each node $v$ in $G$ with $k$ parents becomes $k$ distinct nodes in the returned branching, one for each parent, and the sub-DAG rooted at $v$ is duplicated for each copy. The algorithm then recurses on the children of each copy of $v$.

**Parameters**  
$G$ (*NetworkX graph*) – A directed acyclic graph.
Returns

The branching in which there is a bijection between root-to-leaf paths in $G$ (in which multiple paths may share the same leaf) and root-to-leaf paths in the branching (in which there is a unique path from a root to a leaf).

Each node has an attribute ‘source’ whose value is the original node to which this node corresponds. No other graph, node, or edge attributes are copied into this new graph.

Return type $\text{DiGraph}$

Raises

- $\text{NetworkXNotImplemented}$ – If $G$ is not directed, or if $G$ is a multigraph.
- $\text{HasACycle}$ – If $G$ is not acyclic.

Examples

To examine which nodes in the returned branching were produced by which original node in the directed acyclic graph, we can collect the mapping from source node to new nodes into a dictionary. For example, consider the directed diamond graph:

```python
>>> from collections import defaultdict
>>> from operator import itemgetter

>>> G = nx.DiGraph(nx.utils.pairwise('abd'))
>>> G.add_edges_from(nx.utils.pairwise('acd'))
>>> B = nx.dag_to_branching(G)

>>> sources = defaultdict(set)
>>> for v, source in B.nodes(data='source'):
...     sources[source].add(v)

>>> len(sources['a'])
1
>>> len(sources['d'])
2
```

To copy node attributes from the original graph to the new graph, you can use a dictionary like the one constructed in the above example:

```python
>>> for source, nodes in sources.items():
...     for v in nodes:
...         B.node[v].update(G.node[source])
```

Notes

This function is not idempotent in the sense that the node labels in the returned branching may be uniquely generated each time the function is invoked. In fact, the node labels may not be integers; in order to relabel the nodes to be more readable, you can use the `networkx.convert_node_labels_to_integers()` function.

The current implementation of this function uses `networkx.prefix_tree()`, so it is subject to the limitations of that function.
3.21 Dispersion

3.21.1 Dispersion

dispersion(G[, u, v, normalized, alpha, b, c]) Calculate dispersion between u and v in G.

networkx.algorithms.centrality.dispersion

dispersion (G, u=None, v=None, normalized=True, alpha=1.0, b=0.0, c=0.0)

Calculate dispersion between u and v in G.

A link between two actors (u and v) has a high dispersion when their mutual ties (s and t) are not well connected with each other.

Parameters

• G (graph) – A NetworkX graph.
• u (node, optional) – The source for the dispersion score (e.g. ego node of the network).
• v (node, optional) – The target of the dispersion score if specified.
• normalized (bool) – If True (default) normalize by the embeddedness of the nodes (u and v).

Returns nodes – If u (v) is specified, returns a dictionary of nodes with dispersion score for all “target” (“source”) nodes. If neither u nor v is specified, returns a dictionary of dictionaries for all nodes 'u' in the graph with a dispersion score for each node ‘v’.

Return type dictionary

Notes

This implementation follows Lars Backstrom and Jon Kleinberg\(^1\). Typical usage would be to run dispersion on the ego network \(G_u\) if \(u\) were specified. Running dispersion() with neither \(u\) nor \(v\) specified can take some time to complete.

References

3.22 Distance Measures

Graph diameter, radius, eccentricity and other properties.

center(G[, e, usebounds]) Return the center of the graph G.
diameter(G[, e, usebounds]) Return the diameter of the graph G.
eccentricity(G[, v, sp]) Return the eccentricity of nodes in G.
periphery(G[, e, usebounds]) Return the periphery of the graph G.
radius(G[, e, usebounds]) Return the radius of the graph G.

3.22.1 networkx.algorithms.distance_measures.center

center \((G, e=None, usebounds=False)\)

Return the center of the graph \(G\).

The center is the set of nodes with eccentricity equal to radius.

Parameters

- \(G\) (NetworkX graph) – A graph
- \(e\) (eccentricity dictionary, optional) – A precomputed dictionary of eccentricities.

Returns c – List of nodes in center

Return type list

3.22.2 networkx.algorithms.distance_measures.diameter

diameter \((G, e=None, usebounds=False)\)

Return the diameter of the graph \(G\).

The diameter is the maximum eccentricity.

Parameters

- \(G\) (NetworkX graph) – A graph
- \(e\) (eccentricity dictionary, optional) – A precomputed dictionary of eccentricities.

Returns d – Diameter of graph

Return type integer

See also:

eccentricity()

3.22.3 networkx.algorithms.distance_measures.eccentricity

eccentricity \((G, v=None, sp=None)\)

Return the eccentricity of nodes in \(G\).

The eccentricity of a node \(v\) is the maximum distance from \(v\) to all other nodes in \(G\).

Parameters

- \(G\) (NetworkX graph) – A graph
- \(v\) (node, optional) – Return value of specified node
- \(sp\) (dict of dicts, optional) – All pairs shortest path lengths as a dictionary of dictionaries

Returns ecc – A dictionary of eccentricity values keyed by node.

Return type dictionary
3.22.4 networkx.algorithms.distance_measures.periphery

periphery \((G, e=None, usebounds=False)\)

Return the periphery of the graph \(G\).

The periphery is the set of nodes with eccentricity equal to the diameter.

**Parameters**

- \(G\) (NetworkX graph) – A graph
- \(e\) (eccentricity dictionary, optional) – A precomputed dictionary of eccentricities.

**Returns** \(p\) – List of nodes in periphery

**Return type** list

3.22.5 networkx.algorithms.distance_measures.radius

radius \((G, e=None, usebounds=False)\)

Return the radius of the graph \(G\).

The radius is the minimum eccentricity.

**Parameters**

- \(G\) (NetworkX graph) – A graph
- \(e\) (eccentricity dictionary, optional) – A precomputed dictionary of eccentricities.

**Returns** \(r\) – Radius of graph

**Return type** integer

3.23 Distance-Regular Graphs

3.23.1 Distance-regular graphs

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>is_distance_regular(G)</td>
<td>Returns True if the graph is distance regular, False otherwise.</td>
</tr>
<tr>
<td>is_strongly_regular(G)</td>
<td>Returns True if and only if the given graph is strongly regular.</td>
</tr>
<tr>
<td>intersection_array(G)</td>
<td>Returns the intersection array of a distance-regular graph.</td>
</tr>
<tr>
<td>global_parameters(b, c)</td>
<td>Return global parameters for a given intersection array.</td>
</tr>
</tbody>
</table>

3.23.2 networkx.algorithms.distance_regular.is_distance_regular

is_distance_regular \((G)\)

Returns True if the graph is distance regular, False otherwise.

A connected graph \(G\) is distance-regular if for any nodes \(x,y\) and any integers \(i,j=0,1,\ldots,d\) (where \(d\) is the graph diameter), the number of vertices at distance \(i\) from \(x\) and distance \(j\) from \(y\) depends only on \(i,j\) and the graph distance between \(x\) and \(y\), independently of the choice of \(x\) and \(y\).

**Parameters** \(G\) (Networkx graph undirected))

**Returns** True if the graph is Distance Regular, False otherwise
Return type  bool

Examples

>>> G=nx.hypercube_graph(6)
>>> nx.is_distance_regular(G)
True

See also:
intersection_array(), global_parameters()

Notes
For undirected and simple graphs only

References

3.23.3 networkx.algorithms.distance_regular.is_strongly_regular

is_strongly_regular(G)
Returns True if and only if the given graph is strongly regular.

An undirected graph is strongly regular if
• it is regular,
• each pair of adjacent vertices has the same number of neighbors in common,
• each pair of nonadjacent vertices has the same number of neighbors in common.

Each strongly regular graph is a distance-regular graph. Conversely, if a distance-regular graph has diameter two, then it is a strongly regular graph. For more information on distance-regular graphs, see is_distance_regular().

Parameters  G (NetworkX graph) – An undirected graph.

Returns  Whether G is strongly regular.

Return type  bool

Examples

The cycle graph on five vertices is strongly regular. It is two-regular, each pair of adjacent vertices has no shared neighbors, and each pair of nonadjacent vertices has one shared neighbor:

>>> import networkx as nx
>>> G = nx.cycle_graph(5)
>>> nx.is_strongly_regular(G)
True
3.23.4 networkx.algorithms.distance_regular.intersection_array

intersection_array(G)
Returns the intersection array of a distance-regular graph.

Given a distance-regular graph G with integers $b_i, c_i, i = 0, \ldots, d$ such that for any 2 vertices $x, y$ in G at a distance $i = d(x, y)$, there are exactly $c_i$ neighbors of $y$ at a distance of $i - 1$ from $x$ and $b_i$ neighbors of $y$ at a distance of $i + 1$ from $x$.

A distance regular graph’s intersection array is given by, $[b_0, b_1, \ldots, b_{d-1}; c_1, c_2, \ldots, c_d]$

Parameters G (Networkx graph (undirected))
Returns b,c
Return type tuple of lists

Examples

>>> G=nx.icosahedral_graph()
>>> nx.intersection_array(G)
([5, 2, 1], [1, 2, 5])

References

See also:
global_parameters()

3.23.5 networkx.algorithms.distance_regular.global_parameters

global_parameters(b, c)
Return global parameters for a given intersection array.

Given a distance-regular graph G with integers $b_i, c_i, i = 0, \ldots, d$ such that for any 2 vertices $x, y$ in G at a distance $i = d(x, y)$, there are exactly $c_i$ neighbors of $y$ at a distance of $i - 1$ from $x$ and $b_i$ neighbors of $y$ at a distance of $i + 1$ from $x$.

Thus, a distance regular graph has the global parameters, $[[c_0, a_0, b_0], [c_1, a_1, b_1], \ldots, [c_d, a_d, b_d]]$ for the intersection array $[b_0, b_1, \ldots, b_{d-1}; c_1, c_2, \ldots, c_d]$ where $a_i + b_i + c_i = k$, $k$= degree of every vertex.

Parameters
• b (list)
• c (list)

Returns An iterable over three tuples.
Return type iterable

Examples
```python
>>> G = nx.dodecahedral_graph()
>>> b, c = nx.intersection_array(G)
>>> list(nx.global_parameters(b, c))
[(0, 0, 3), (1, 0, 2), (1, 1, 1), (1, 1, 1), (2, 0, 1), (3, 0, 0)]
```

References

See also:

`intersection_array()`

### 3.24 Dominance

Dominance algorithms.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>immediate_dominators(G, start)</code></td>
<td>Returns the immediate dominators of all nodes of a directed graph.</td>
</tr>
<tr>
<td><code>dominance_frontiers(G, start)</code></td>
<td>Returns the dominance frontiers of all nodes of a directed graph.</td>
</tr>
</tbody>
</table>

#### 3.24.1 `networkx.algorithms.dominance.immediate_dominators`

`immediate_dominators(G, start)`

Returns the immediate dominators of all nodes of a directed graph.

**Parameters**

- `G` *(DiGraph or MultiDiGraph)* – The graph where dominance is to be computed.
- `start` *(node)* – The start node of dominance computation.

**Returns**

`idom` – A dict containing the immediate dominators of each node reachable from `start`.

**Return type**

dict keyed by nodes

**Raises**

- `NetworkXNotImplemented` – If `G` is undirected.
- `NetworkXError` – If `start` is not in `G`.

**Notes**

Except for `start`, the immediate dominators are the parents of their corresponding nodes in the dominator tree.

**Examples**

```python
>>> G = nx.DiGraph([(1, 2), (1, 3), (2, 5), (3, 4), (4, 5)])
>>> sorted(nx.immediate_dominators(G, 1).items())
[(1, 1), (2, 1), (3, 1), (4, 3), (5, 1)]
```
References

3.24.2 networkx.algorithms.dominance.dominance_frontiers

dominance_frontiers \((G, start)\)

Returns the dominance frontiers of all nodes of a directed graph.

Parameters

- \(G\) (a DiGraph or MultiDiGraph) – The graph where dominance is to be computed.
- \(start\) (node) – The start node of dominance computation.

Returns \(df\) – A dict containing the dominance frontiers of each node reachable from \(start\) as lists.

Return type: dict keyed by nodes

Raises

- NetworkXNotImplemented – If \(G\) is undirected.
- NetworkXError – If \(start\) is not in \(G\).

Examples

```python
>>> G = nx.DiGraph([(1, 2), (1, 3), (2, 5), (3, 4), (4, 5)])
>>> sorted((u, sorted(df)) for u, df in nx.dominance_frontiers(G, 1).items())
[(1, []), (2, [5]), (3, [5]), (4, [5]), (5, [])]
```

References

3.25 Dominating Sets

Functions for computing dominating sets in a graph.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>dominating_set ((G, start_with))</td>
<td>Finds a dominating set for the graph (G).</td>
</tr>
<tr>
<td>is_dominating_set ((G, nbunch))</td>
<td>Checks if (nbunch) is a dominating set for (G).</td>
</tr>
</tbody>
</table>

3.25.1 networkx.algorithms.dominating.dominating_set

dominating_set \((G, start\_with=None)\)

Finds a dominating set for the graph \(G\).

A dominating set for a graph with node set \(V\) is a subset \(D\) of \(V\) such that every node not in \(D\) is adjacent to at least one member of \(D\).

Parameters

- \(G\) (NetworkX graph)
- \(start\_with\) (node (default=None)) – Node to use as a starting point for the algorithm.

Returns \(D\) – A dominating set for \(G\).

References

1 https://en.wikipedia.org/wiki/Dominating_set
Return type  set

Notes

This function is an implementation of algorithm 7 in\(^2\) which finds some dominating set, not necessarily the smallest one.

See also:

is_dominating_set()

References

3.25.2 networkx.algorithms.dominating.is_dominating_set

is_dominating_set(\(G, \text{nbunch}\))

Checks if \(\text{nbunch}\) is a dominating set for \(G\).

A dominating set for a graph with node set \(V\) is a subset \(D\) of \(V\) such that every node not in \(D\) is adjacent to at least one member of \(D\).

Parameters

• \(G\) (NetworkX graph)

• \(\text{nbunch}\) (iterable) – An iterable of nodes in the graph \(G\).

See also:

dominating_set()

References

3.26 Efficiency

Provides functions for computing the efficiency of nodes and graphs.

<table>
<thead>
<tr>
<th>efficiency((G, u, v))</th>
<th>Returns the efficiency of a pair of nodes in a graph.</th>
</tr>
</thead>
<tbody>
<tr>
<td>local_efficiency((G))</td>
<td>Returns the average local efficiency of the graph.</td>
</tr>
<tr>
<td>global_efficiency((G))</td>
<td>Returns the average global efficiency of the graph.</td>
</tr>
</tbody>
</table>

3.26.1 networkx.algorithms.efficiency.efficiency

efficiency(\(G, u, v)\)

Returns the efficiency of a pair of nodes in a graph.

The efficiency of a pair of nodes is the multiplicative inverse of the shortest path distance between the nodes\(^1\). Returns 0 if no path between nodes.

---


\(^\text{1}\) https://en.wikipedia.org/wiki/Dominating_set
Parameters

- \( G \) (networkx.Graph) – An undirected graph for which to compute the average local efficiency.
- \( u, v \) (node) – Nodes in the graph \( G \).

Returns Multiplicative inverse of the shortest path distance between the nodes.

Return type float

Notes

Edge weights are ignored when computing the shortest path distances.

See also:

local_efficiency(), global_efficiency()

References

3.26.2 networkx.algorithms.efficiency.local_efficiency

local_efficiency \( (G) \)

Returns the average local efficiency of the graph.

The efficiency of a pair of nodes in a graph is the multiplicative inverse of the shortest path distance between the nodes. The local efficiency of a node in the graph is the average global efficiency of the subgraph induced by the neighbors of the node. The average local efficiency is the average of the local efficiencies of each node\(^1\).

Parameters \( G \) (networkx.Graph) – An undirected graph for which to compute the average local efficiency.

Returns The average local efficiency of the graph.

Return type float

Notes

Edge weights are ignored when computing the shortest path distances.

See also:

global_efficiency()

References

3.26.3 networkx.algorithms.efficiency.global_efficiency

global_efficiency \( (G) \)

Returns the average global efficiency of the graph.

The efficiency of a pair of nodes in a graph is the multiplicative inverse of the shortest path distance between the nodes. The average global efficiency of a graph is the average efficiency of all pairs of nodes.\(^1\)

**Parameters** \(G\) (networkx.Graph) – An undirected graph for which to compute the average global efficiency.

**Returns** The average global efficiency of the graph.

**Return type** float

**Notes**

Edge weights are ignored when computing the shortest path distances.

**See also:**

local_efficiency()

**References**

### 3.27 Eulerian

Eulerian circuits and graphs.

<table>
<thead>
<tr>
<th>is_eulerian((G))</th>
<th>Returns True if and only if (G) is Eulerian.</th>
</tr>
</thead>
<tbody>
<tr>
<td>eulerian_circuit((G[, source, keys]))</td>
<td>Returns an iterator over the edges of an Eulerian circuit in (G).</td>
</tr>
</tbody>
</table>

#### 3.27.1 networkx.algorithms.euler.is_eulerian

is_eulerian\((G)\)

Returns True if and only if \(G\) is Eulerian.

A graph is Eulerian if it has an Eulerian circuit. An Eulerian circuit is a closed walk that includes each edge of a graph exactly once.

**Parameters** \(G\) (NetworkX graph) – A graph, either directed or undirected.

**Examples**

```python
>>> nx.is_eulerian(nx.DiGraph({0: [3], 1: [2], 2: [3], 3: [0, 1]}))
True
>>> nx.is_eulerian(nx.complete_graph(5))
True
>>> nx.is_eulerian(nx.petersen_graph())
False
```

---

Notes

If the graph is not connected (or not strongly connected, for directed graphs), this function returns False.

3.27.2 networkx.algorithms.euler.eulerian_circuit

eulerian_circuit(G, source=None, keys=False)

Returns an iterator over the edges of an Eulerian circuit in G.

An Eulerian circuit is a closed walk that includes each edge of a graph exactly once.

Parameters

- G (NetworkX graph) – A graph, either directed or undirected.
- source (node, optional) – Starting node for circuit.
- keys (bool) – If False, edges generated by this function will be of the form \((u, v)\). Otherwise, edges will be of the form \((u, v, k)\). This option is ignored unless G is a multi-graph.

Returns edges – An iterator over edges in the Eulerian circuit.

Return type iterator

 Raises NetworkXError – If the graph is not Eulerian.

See also:

is_eulerian()

Notes

This is a linear time implementation of an algorithm adapted from\(^1\).

For general information about Euler tours, see\(^2\).

References

Examples

To get an Eulerian circuit in an undirected graph:

```python
>>> G = nx.complete_graph(3)
>>> list(nx.eulerian_circuit(G))
[(0, 2), (2, 1), (1, 0)]
>>> list(nx.eulerian_circuit(G, source=1))
[(1, 2), (2, 0), (0, 1)]
```

To get the sequence of vertices in an Eulerian circuit:

```python
>>> [u for u, v in nx.eulerian_circuit(G)]
[0, 2, 1]
```

---


\(^2\) https://en.wikipedia.org/wiki/Eulerian_path
3.28 Flows

3.28.1 Maximum Flow

maximum_flow(flowG, _s, _t[, capacity, ...]) Find a maximum single-commodity flow.
maximum_flow_value(flowG, _s, _t[, ...]) Find the value of maximum single-commodity flow.
minimum_cut(flowG, _s, _t[, capacity, flow_func]) Compute the value and the node partition of a minimum (s, t)-cut.
minimum_cut_value(flowG, _s, _t[, capacity, ...]) Compute the value of a minimum (s, t)-cut.

networkx.algorithms.flow.maximum_flow

maximum_flow (flowG, _s, _t, capacity='capacity', flow_func=None, **kwargs)
Find a maximum single-commodity flow.

Parameters

- flowG (NetworkX graph) – Edges of the graph are expected to have an attribute called ‘capacity’. If this attribute is not present, the edge is considered to have infinite capacity.
- _s (node) – Source node for the flow.
- _t (node) – Sink node for the flow.
- capacity (string) – Edges of the graph G are expected to have an attribute capacity that indicates how much flow the edge can support. If this attribute is not present, the edge is considered to have infinite capacity. Default value: ‘capacity’.
- flow_func (function) – A function for computing the maximum flow among a pair of nodes in a capacitated graph. The function has to accept at least three parameters: a Graph or Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see Notes). If flow_func is None, the default maximum flow function (preflow_push()) is used. See below for alternative algorithms. The choice of the default function may change from version to version and should not be relied on. Default value: None.
- kwargs (Any other keyword parameter is passed to the function that) – computes the maximum flow.

Returns

- flow_value (integer, float) – Value of the maximum flow, i.e., net outflow from the source.
- flow_dict (dict) – A dictionary containing the value of the flow that went through each edge.

Raises

- NetworkXError – The algorithm does not support MultiGraph and MultiDiGraph. If the input graph is an instance of one of these two classes, a NetworkXError is raised.
- NetworkXUnbounded – If the graph has a path of infinite capacity, the value of a feasible flow on the graph is unbounded above and the function raises a NetworkXUnbounded.

See also:

maximum_flow_value(), minimum_cut(), minimum_cut_value(), edmonds_karp(), preflow_push(), shortest_augmenting_path()
Notes

The function used in the flow_func parameter has to return a residual network that follows NetworkX conventions:

The residual network $R$ from an input graph $G$ has the same nodes as $G$. $R$ is a DiGraph that contains a pair of edges $(u, v)$ and $(v, u)$ iff $(u, v)$ is not a self-loop, and at least one of $(u, v)$ and $(v, u)$ exists in $G$.

For each edge $(u, v)$ in $R$, $R[u][v]['capacity']$ is equal to the capacity of $(u, v)$ in $G$ if it exists in $G$ or zero otherwise. If the capacity is infinite, $R[u][v]['capacity']$ will have a high arbitrary finite value that does not affect the solution of the problem. This value is stored in $R$.graph['inf']. For each edge $(u, v)$ in $R$, $R[u][v]['flow']$ represents the flow function of $(u, v)$ and satisfies $R[u][v]['flow'] = -R[v][u]['flow']$.

The flow value, defined as the total flow into $t$, the sink, is stored in $R$.graph['flow_value']. Reachability to $t$ using only edges $(u, v)$ such that $R[u][v]['flow'] < R[u][v]['capacity']$ induces a minimum s-t cut.

Specific algorithms may store extra data in $R$.

The function should support an optional boolean parameter value_only. When True, it can optionally terminate the algorithm as soon as the maximum flow value and the minimum cut can be determined.

Examples

```python
>>> import networkx as nx
>>> G = nx.DiGraph()
>>> G.add_edge('x','a', capacity=3.0)
>>> G.add_edge('x','b', capacity=1.0)
>>> G.add_edge('a','c', capacity=3.0)
>>> G.add_edge('b','c', capacity=5.0)
>>> G.add_edge('b','d', capacity=4.0)
>>> G.add_edge('d','e', capacity=2.0)
>>> G.add_edge('c','y', capacity=2.0)
>>> G.add_edge('e','y', capacity=3.0)
```

maximum_flow returns both the value of the maximum flow and a dictionary with all flows.

```python
>>> flow_value, flow_dict = nx.maximum_flow(G, 'x', 'y')
>>> flow_value
3.0
>>> print(flow_dict['x']['b'])
1.0
```

You can also use alternative algorithms for computing the maximum flow by using the flow_func parameter.

```python
>>> from networkx.algorithms.flow import shortest_augmenting_path
>>> flow_value == nx.maximum_flow(G, 'x', 'y', flow_func=shortest_augmenting_path)[0]
True
```

networkx.algorithms.flow.maximum_flow_value

maximum_flow_value(flowG, _s, _t, capacity='capacity', flow_func=None, **kwargs)

Find the value of maximum single-commodity flow.
Parameters

- **flowG** *(NetworkX graph)* – Edges of the graph are expected to have an attribute called ‘capacity’. If this attribute is not present, the edge is considered to have infinite capacity.
- **s** *(node)* – Source node for the flow.
- **t** *(node)* – Sink node for the flow.
- **capacity** *(string)* – Edges of the graph G are expected to have an attribute capacity that indicates how much flow the edge can support. If this attribute is not present, the edge is considered to have infinite capacity. Default value: ‘capacity’.
- **flow_func** *(function)* – A function for computing the maximum flow among a pair of nodes in a capacitated graph. The function has to accept at least three parameters: a Graph or DiGraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see Notes). If flow_func is None, the default maximum flow function *(preflow_push())* is used. See below for alternative algorithms. The choice of the default function may change from version to version and should not be relied on. Default value: None.
- **kwargs** *(Any other keyword parameter is passed to the function that)* – computes the maximum flow.

Returns **flow_value** – Value of the maximum flow, i.e., net outflow from the source.

Return type  integer, float

Raises

- **NetworkXError** – The algorithm does not support MultiGraph and MultiDiGraph. If the input graph is an instance of one of these two classes, a NetworkXError is raised.
- **NetworkXUnbounded** – If the graph has a path of infinite capacity, the value of a feasible flow on the graph is unbounded above and the function raises a NetworkXUnbounded.

See also:

maximum_flow(), minimum_cut(), minimum_cut_value(), edmonds_karp(), preflow_push(), shortest_augmenting_path()

Notes

The function used in the flow_func parameter has to return a residual network that follows NetworkX conventions:

The residual network R from an input graph G has the same nodes as G. R is a DiGraph that contains a pair of edges (u, v) and (v, u) iff (u, v) is not a self-loop, and at least one of (u, v) and (v, u) exists in G.

For each edge (u, v) in R, R[u][v][‘capacity’] is equal to the capacity of (u, v) in G if it exists in G or zero otherwise. If the capacity is infinite, R[u][v][‘capacity’] will have a high arbitrary finite value that does not affect the solution of the problem. This value is stored in R.graph[‘inf’]. For each edge (u, v) in R, R[u][v][‘flow’] represents the flow function of (u, v) and satisfies R[u][v][‘flow’] == -R[v][u][‘flow’].

The flow value, defined as the total flow into t, the sink, is stored in R.graph[‘flow_value’]. Reachability to t using only edges (u, v) such that R[u][v][‘flow’] < R[u][v][‘capacity’] induces a minimum s-t cut.

Specific algorithms may store extra data in R.
The function should support an optional boolean parameter `value_only`. When True, it can optionally terminate the algorithm as soon as the maximum flow value and the minimum cut can be determined.

### Examples

```python
>>> import networkx as nx
>>> G = nx.DiGraph()
>>> G.add_edge('x','a', capacity=3.0)
>>> G.add_edge('x','b', capacity=1.0)
>>> G.add_edge('a','c', capacity=3.0)
>>> G.add_edge('b','c', capacity=5.0)
>>> G.add_edge('b','d', capacity=4.0)
>>> G.add_edge('d','e', capacity=2.0)
>>> G.add_edge('c','y', capacity=2.0)
>>> G.add_edge('e','y', capacity=3.0)
```

`maximum_flow_value` computes only the value of the maximum flow:

```python
>>> flow_value = nx.maximum_flow_value(G, 'x', 'y')
>>> flow_value
3.0
```

You can also use alternative algorithms for computing the maximum flow by using the `flow_func` parameter.

```python
>>> from networkx.algorithms.flow import shortest_augmenting_path
>>> flow_value == nx.maximum_flow_value(G, 'x', 'y',
... flow_func=shortest_augmenting_path)
True
```

### `networkx.algorithms.flow.minimum_cut`

`minimum_cut` (flowG, s, t, capacity='capacity', flow_func=None, **kwargs)

Compute the value and the node partition of a minimum (s, t)-cut.

Use the max-flow min-cut theorem, i.e., the capacity of a minimum capacity cut is equal to the flow value of a maximum flow.

**Parameters**

- `flowG` *(NetworkX graph)* – Edges of the graph are expected to have an attribute called ‘capacity’. If this attribute is not present, the edge is considered to have infinite capacity.

- `_s` *(node)* – Source node for the flow.

- `_t` *(node)* – Sink node for the flow.

- `capacity` *(string)* – Edges of the graph G are expected to have an attribute capacity that indicates how much flow the edge can support. If this attribute is not present, the edge is considered to have infinite capacity. Default value: ‘capacity’.

- `flow_func` *(function)* – A function for computing the maximum flow among a pair of nodes in a capacitated graph. The function has to accept at least three parameters: a Graph or DiGraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see Notes). If flow_func is None, the default maximum flow function (`preflow_push()`) is used. See below for alternative algorithms. The choice of the default function may change from version to version and should not be relied on. Default value: None.
• **kwargs (Any other keyword parameter is passed to the function that) – computes the maximum flow.

**Returns**

• **cut_value** (integer, float) – Value of the minimum cut.

• **partition** (pair of node sets) – A partitioning of the nodes that defines a minimum cut.

**Raises** NetworkXUnbounded – If the graph has a path of infinite capacity, all cuts have infinite capacity and the function raises a NetworkXError.

**See also:**

maximum_flow(), maximum_flow_value(), minimum_cut_value(), edmonds_karp(), preflow_push(), shortest_augmenting_path()

**Notes**

The function used in the flow_func parameter has to return a residual network that follows NetworkX conventions:

The residual network $R$ from an input graph $G$ has the same nodes as $G$. $R$ is a DiGraph that contains a pair of edges $(u, v)$ and $(v, u)$ iff $(u, v)$ is not a self-loop, and at least one of $(u, v)$ and $(v, u)$ exists in $G$.

For each edge $(u, v)$ in $R$, $R[u][v]['capacity']$ is equal to the capacity of $(u, v)$ in $G$ if it exists in $G$ or zero otherwise. If the capacity is infinite, $R[u][v]['capacity']$ will have a high arbitrary finite value that does not affect the solution of the problem. This value is stored in $R$.graph['inf']. For each edge $(u, v)$ in $R$, $R[u][v]['flow']$ represents the flow function of $(u, v)$ and satisfies $R[u][v]['flow'] = -R[v][u]['flow']$.

The flow value, defined as the total flow into $t$, the sink, is stored in $R$.graph['flow_value']. Reachability to $t$ using only edges $(u, v)$ such that $R[u][v]['flow'] < R[u][v]['capacity']$ induces a minimum $s$-$t$ cut.

Specific algorithms may store extra data in $R$.

The function should supports an optional boolean parameter value_only. When True, it can optionally terminate the algorithm as soon as the maximum flow value and the minimum cut can be determined.

**Examples**

```python
>>> import networkx as nx
>>> G = nx.DiGraph()
>>> G.add_edge('x', 'a', capacity = 3.0)
>>> G.add_edge('x', 'b', capacity = 1.0)
>>> G.add_edge('a', 'c', capacity = 3.0)
>>> G.add_edge('b', 'c', capacity = 5.0)
>>> G.add_edge('b', 'd', capacity = 4.0)
>>> G.add_edge('d', 'e', capacity = 2.0)
>>> G.add_edge('c', 'y', capacity = 2.0)
>>> G.add_edge('e', 'y', capacity = 3.0)
```

minimum_cut computes both the value of the minimum cut and the node partition:

```python
>>> cut_value, partition = nx.minimum_cut(G, 'x', 'y')
>>> reachable, non_reachable = partition
```
‘partition’ here is a tuple with the two sets of nodes that define the minimum cut. You can compute the cut set of edges that induce the minimum cut as follows:

```python
>>> cutset = set()
>>> for u, nbrs in ((n, G[n]) for n in reachable):
...     cutset.update((u, v) for v in nbrs if v in non_reachable)
>>> print(sorted(cutset))
[('c', 'y'), ('x', 'b')]
>>> cut_value == sum(G.edges[(u, v)]['capacity'] for (u, v) in cutset)
True
```

You can also use alternative algorithms for computing the minimum cut by using the flow_func parameter.

```python
>>> from networkx.algorithms.flow import shortest_augmenting_path
>>> cut_value == nx.minimum_cut(G, 'x', 'y', flow_func=shortest_augmenting_path)[0]
True
```

"networkx.algorithms.flow.minimum_cut_value"

**minimum_cut_value** *(flowG, _s, _t, capacity='capacity', flow_func=None, **kwargs)*

Compute the value of a minimum \((s, t)\)-cut.

Use the max-flow min-cut theorem, i.e., the capacity of a minimum capacity cut is equal to the flow value of a maximum flow.

**Parameters**

- **flowG** *(NetworkX graph)* – Edges of the graph are expected to have an attribute called ‘capacity’. If this attribute is not present, the edge is considered to have infinite capacity.
- **_s** *(node)* – Source node for the flow.
- **_t** *(node)* – Sink node for the flow.
- **capacity** *(string)* – Edges of the graph G are expected to have an attribute capacity that indicates how much flow the edge can support. If this attribute is not present, the edge is considered to have infinite capacity. Default value: ‘capacity’.
- **flow_func** *(function)* – A function for computing the maximum flow among a pair of nodes in a capacitated graph. The function has to accept at least three parameters: a Graph or Digraph, a source node, and a target node. And return a residual network that follows NetworkX conventions (see Notes). If flow_func is None, the default maximum flow function *(preflow_push())* is used. See below for alternative algorithms. The choice of the default function may change from version to version and should not be relied on. Default value: None.
- **kwargs** *(Any other keyword parameter is passed to the function that)* – computes the maximum flow.

**Returns**

- **cut_value** – Value of the minimum cut.

**Return type**

- integer, float

**Raises**

- NetworkXUnbounded – If the graph has a path of infinite capacity, all cuts have infinite capacity and the function raises a NetworkXError.

**See also:**

- maximum_flow(), maximum_flow_value(), minimum_cut(), edmonds_karp(), preflow_push(), shortest_augmenting_path()
Notes

The function used in the `flow_func` parameter has to return a residual network that follows NetworkX conventions:

The residual network $R$ from an input graph $G$ has the same nodes as $G$. $R$ is a DiGraph that contains a pair of edges $(u, v)$ and $(v, u)$ iff $(u, v)$ is not a self-loop, and at least one of $(u, v)$ and $(v, u)$ exists in $G$.

For each edge $(u, v)$ in $R$, $R[u][v][\text{'capacity'}]$ is equal to the capacity of $(u, v)$ in $G$ if it exists in $G$ or zero otherwise. If the capacity is infinite, $R[u][v][\text{'capacity'}]$ will have a high arbitrary finite value that does not affect the solution of the problem. This value is stored in $R\.graph[\text{'inf']}$. For each edge $(u, v)$ in $R$, $R[u][v][\text{'flow'}]$ represents the flow function of $(u, v)$ and satisfies $R[u][v][\text{'flow'}] = -R[v][u][\text{'flow'}]$.

The flow value, defined as the total flow into $t$, the sink, is stored in $R\.graph[\text{'flow_value'}]$. Reachability to $t$ using only edges $(u, v)$ such that $R[u][v][\text{'flow'}] < R[u][v][\text{'capacity'}]$ induces a minimum $s$-$t$ cut.

Specific algorithms may store extra data in $R$.

The function should support an optional boolean parameter `value_only`. When True, it can optionally terminate the algorithm as soon as the maximum flow value and the minimum cut can be determined.

Examples

```python
>>> import networkx as nx
>>> G = nx.DiGraph()
>>> G.add_edge('x','a', capacity = 3.0)
>>> G.add_edge('x','b', capacity = 1.0)
>>> G.add_edge('a','c', capacity = 3.0)
>>> G.add_edge('b','c', capacity = 5.0)
>>> G.add_edge('b','d', capacity = 4.0)
>>> G.add_edge('d','e', capacity = 2.0)
>>> G.add_edge('c','y', capacity = 2.0)
>>> G.add_edge('e','y', capacity = 3.0)

minimum_cut_value computes only the value of the minimum cut:

```python
>>> cut_value = nx.minimum_cut_value(G, 'x', 'y')
>>> cut_value
3.0
```
edmonds_karp(G, s, t[, capacity, residual, ...])  
Find a maximum single-commodity flow using the Edmonds-Karp algorithm.

networkx.algorithms.flow.edmonds_karp

edmonds_karp (G, s, t, capacity='capacity', residual=None, value_only=False, cutoff=None)

Find a maximum single-commodity flow using the Edmonds-Karp algorithm.  
This function returns the residual network resulting after computing the maximum flow. See below for details about the conventions NetworkX uses for defining residual networks.  
This algorithm has a running time of \(O(nm^2)\) for \(n\) nodes and \(m\) edges.

Parameters

- **G** (*NetworkX graph*) – Edges of the graph are expected to have an attribute called ‘capacity’.  
  If this attribute is not present, the edge is considered to have infinite capacity.
- **s** (*node*) – Source node for the flow.
- **t** (*node*) – Sink node for the flow.
- **capacity** (*string*) – Edges of the graph G are expected to have an attribute capacity that indicates how much flow the edge can support.  
  If this attribute is not present, the edge is considered to have infinite capacity. Default value: ‘capacity’.
- **residual** (*NetworkX graph*) – Residual network on which the algorithm is to be executed. If None, a new residual network is created. Default value: None.
- **value_only** (*bool*) – If True compute only the value of the maximum flow. This parameter will be ignored by this algorithm because it is not applicable.
- **cutoff** (*integer, float*) – If specified, the algorithm will terminate when the flow value reaches or exceeds the cutoff. In this case, it may be unable to immediately determine a minimum cut. Default value: None.

Returns **R** – Residual network after computing the maximum flow.

Return type  
NetworkX DiGraph

Raises

- **NetworkXError** – The algorithm does not support MultiGraph and MultiDiGraph. If the input graph is an instance of one of these two classes, a NetworkXError is raised.
- **NetworkXUnbounded** – If the graph has a path of infinite capacity, the value of a feasible flow on the graph is unbounded above and the function raises a NetworkXUnbounded.

See also:

maximum_flow(), minimum_cut(), preflow_push(), shortest_augmenting_path()

Notes

The residual network \(R\) from an input graph \(G\) has the same nodes as \(G\). \(R\) is a DiGraph that contains a pair of edges \((u, v)\) and \((v, u)\) iff \((u, v)\) is not a self-loop, and at least one of \((u, v)\) and \((v, u)\) exists in \(G\).

For each edge \((u, v)\) in \(R, R[u][v]['capacity']\) is equal to the capacity of \((u, v)\) in \(G\) if it exists in \(G\) or zero otherwise. If the capacity is infinite, \(R[u][v]['capacity']\) will have a high arbitrary finite value that does not affect the solution of the problem. This value is stored in \(R.graph['inf']\). For each edge \((u,
in $R, R[u][v][\text{\textquoteleft flow\textquoteright}]$ represents the flow function of $(u, v)$ and satisfies $R[u][v][\text{\textquoteleft flow\textquoteright}] == -R[v][u][\text{\textquoteleft flow\textquoteright}]$.

The flow value, defined as the total flow into $t$, the sink, is stored in $R\text{.graph}[\text{\textquoteleft flow\_value\textquoteright}]$. If cutoff is not specified, reachability to $t$ using only edges $(u, v)$ such that $R[u][v][\text{\textquoteleft flow\textquoteright}] < R[u][v][\text{\textquoteleft capacity\textquoteright}]$ induces a minimum $s$-$t$ cut.

**Examples**

```python
>>> import networkx as nx
>>> from networkx.algorithms.flow import edmonds_karp

>>> G = nx.DiGraph()
>>> G.add_edge('x','a', capacity=3.0)
>>> G.add_edge('x','b', capacity=1.0)
>>> G.add_edge('a','c', capacity=3.0)
>>> G.add_edge('b','c', capacity=5.0)
>>> G.add_edge('b','d', capacity=4.0)
>>> G.add_edge('d','e', capacity=2.0)
>>> G.add_edge('c','y', capacity=2.0)
>>> G.add_edge('e','y', capacity=3.0)
>>> R = edmonds_karp(G, 'x', 'y')
>>> flow_value = nx.maximum_flow_value(G, 'x', 'y')
>>> flow_value
3.0
>>> flow_value == R.graph['flow_value']
True
```

### 3.28.3 Shortest Augmenting Path

**shortest_augmenting_path**(G, $s$, $t$[, ...]) Find a maximum single-commodity flow using the shortest augmenting path algorithm.

**networkx.algorithms.flow.shortest_augmenting_path**

**shortest_augmenting_path**(G, $s$, $t$, $capacity$='capacity', residual=None, value_only=False, two_phase=False, cutoff=None)

Find a maximum single-commodity flow using the shortest augmenting path algorithm.

This function returns the residual network resulting after computing the maximum flow. See below for details about the conventions NetworkX uses for defining residual networks.

This algorithm has a running time of $O(n^2m)$ for $n$ nodes and $m$ edges.

**Parameters**

- **G (NetworkX graph)** – Edges of the graph are expected to have an attribute called ‘capacity’. If this attribute is not present, the edge is considered to have infinite capacity.
- **s (node)** – Source node for the flow.
- **t (node)** – Sink node for the flow.
• **capacity** *(string)* – Edges of the graph G are expected to have an attribute capacity that indicates how much flow the edge can support. If this attribute is not present, the edge is considered to have infinite capacity. Default value: 'capacity'.

• **residual** *(NetworkX graph)* – Residual network on which the algorithm is to be executed. If None, a new residual network is created. Default value: None.

• **value_only** *(bool)* – If True compute only the value of the maximum flow. This parameter will be ignored by this algorithm because it is not applicable.

• **two_phase** *(bool)* – If True, a two-phase variant is used. The two-phase variant improves the running time on unit-capacity networks from $O(nm)$ to $O(\min(n^{2/3}, m^{1/2})m)$. Default value: False.

• **cutoff** *(integer, float)* – If specified, the algorithm will terminate when the flow value reaches or exceeds the cutoff. In this case, it may be unable to immediately determine a minimum cut. Default value: None.

**Returns**  
**R** – Residual network after computing the maximum flow.

**Return type**  
NetworkX DiGraph

**Raises**

- **NetworkXError** – The algorithm does not support MultiGraph and MultiDiGraph. If the input graph is an instance of one of these two classes, a NetworkXError is raised.

- **NetworkXUnbounded** – If the graph has a path of infinite capacity, the value of a feasible flow on the graph is unbounded above and the function raises a NetworkXUnbounded.

**See also:**

maximum_flow(), minimum_cut(), edmonds_karp(), preflow_push()

**Notes**

The residual network R from an input graph G has the same nodes as G. R is a DiGraph that contains a pair of edges (u, v) and (v, u) iff (u, v) is not a self-loop, and at least one of (u, v) and (v, u) exists in G.

For each edge (u, v) in R,R[u][v]["capacity"] is equal to the capacity of (u, v) in G if it exists in G or zero otherwise. If the capacity is infinite, R[u][v]["capacity"] will have a high arbitrary finite value that does not affect the solution of the problem. This value is stored in R.graph["inf"]. For each edge (u, v) in R,R[u][v]["flow"] represents the flow function of (u, v) and satisfies R[u][v]["flow"] == -R[v][u]["flow"].

The flow value, defined as the total flow into t, the sink, is stored in R.graph["flow_value"]. If cutoff is not specified, reachability to t using only edges (u, v) such that R[u][v]["flow"] < R[u][v]["capacity"] induces a minimum s-t cut.

**Examples**

```python
>>> import networkx as nx
>>> from networkx.algorithms.flow import shortest_augmenting_path
```

The functions that implement flow algorithms and output a residual network, such as this one, are not imported to the base NetworkX namespace, so you have to explicitly import them from the flow package.
>>> G = nx.DiGraph()
>>> G.add_edge('x','a', capacity=3.0)
>>> G.add_edge('x','b', capacity=1.0)
>>> G.add_edge('a','c', capacity=3.0)
>>> G.add_edge('b','c', capacity=5.0)
>>> G.add_edge('b','d', capacity=4.0)
>>> G.add_edge('d','e', capacity=2.0)
>>> G.add_edge('c','y', capacity=2.0)
>>> G.add_edge('e','y', capacity=3.0)
>>> R = shortest_augmenting_path(G, 'x', 'y')
>>> flow_value = nx.maximum_flow_value(G, 'x', 'y')
>>> flow_value
3.0
>>> flow_value == R.graph['flow_value']
True

3.28.4 Preflow-Push

`preflow_push(G, s, t[, capacity, residual, ...])` Find a maximum single-commodity flow using the highest-label preflow-push algorithm.

`networkx.algorithms.flow.preflow_push`

`preflow_push(G, s, t, capacity='capacity', residual=None, global_relabel_freq=1, value_only=False)` Find a maximum single-commodity flow using the highest-label preflow-push algorithm.

This function returns the residual network resulting after computing the maximum flow. See below for details about the conventions NetworkX uses for defining residual networks.

This algorithm has a running time of $O(n^2 \sqrt{m})$ for $n$ nodes and $m$ edges.

**Parameters**

- **G** *(NetworkX graph)* – Edges of the graph are expected to have an attribute called ‘capacity’. If this attribute is not present, the edge is considered to have infinite capacity.
- **s** *(node)* – Source node for the flow.
- **t** *(node)* – Sink node for the flow.
- **capacity** *(string)* – Edges of the graph G are expected to have an attribute capacity that indicates how much flow the edge can support. If this attribute is not present, the edge is considered to have infinite capacity. Default value: ‘capacity’.
- **residual** *(NetworkX graph)* – Residual network on which the algorithm is to be executed. If None, a new residual network is created. Default value: None.
- **global_relabel_freq** *(integer, float)* – Relative frequency of applying the global relabeling heuristic to speed up the algorithm. If it is None, the heuristic is disabled. Default value: 1.
- **value_only** *(bool)* – If False, compute a maximum flow; otherwise, compute a maximum preflow which is enough for computing the maximum flow value. Default value: False.

**Returns** **R** – Residual network after computing the maximum flow.

**Return type** NetworkX DiGraph

**Raises**
• **NetworkXError** – The algorithm does not support MultiGraph and MultiDiGraph. If the input graph is an instance of one of these two classes, a NetworkXError is raised.

• **NetworkXUnbounded** – If the graph has a path of infinite capacity, the value of a feasible flow on the graph is unbounded above and the function raises a NetworkXUnbounded.

**See also:**

*maximum_flow()*, *minimum_cut()*, *edmonds_karp()*, *shortest_augmenting_path()*

**Notes**

The residual network \( R \) from an input graph \( G \) has the same nodes as \( G \). \( R \) is a DiGraph that contains a pair of edges \((u, v)\) and \((v, u)\) if \((u, v)\) is not a self-loop, and at least one of \((u, v)\) and \((v, u)\) exists in \( G \). For each node \( u \) in \( R \), \( R.n[u]['excess'] \) represents the difference between flow into \( u \) and flow out of \( u \).

For each edge \((u, v)\) in \( R\), \( R[u][v]['capacity'] \) is equal to the capacity of \((u, v)\) in \( G \) if it exists in \( G \) or zero otherwise. If the capacity is infinite, \( R[u][v]['capacity'] \) will have a high arbitrary finite value that does not affect the solution of the problem. This value is stored in \( R.graph['inf'] \). For each edge \((u, v)\) in \( R \), \( R[u][v]['flow'] \) represents the flow function of \((u, v)\) and satisfies \( R[u][v]['flow'] == -R[v][u]['flow'] \).

The flow value, defined as the total flow into \( t \), the sink, is stored in \( R.graph['flow_value'] \). Reachability to \( t \) using only edges \((u, v)\) such that \( R[u][v]['flow'] < R[u][v]['capacity'] \) induces a minimum \( s \)-\( t \) cut.

**Examples**

```python
click$results_index=0
\n>>> import networkx as nx
>>> from networkx.algorithms.flow import preflow_push

The functions that implement flow algorithms and output a residual network, such as this one, are not imported to the base NetworkX namespace, so you have to explicitly import them from the flow package.

```python
>>> G = nx.DiGraph()
>>> G.add_edge('x', 'a', capacity=3.0)
>>> G.add_edge('x', 'b', capacity=1.0)
>>> G.add_edge('a', 'c', capacity=3.0)
>>> G.add_edge('b', 'c', capacity=5.0)
>>> G.add_edge('b', 'd', capacity=4.0)
>>> G.add_edge('d', 'e', capacity=2.0)
>>> G.add_edge('c', 'y', capacity=2.0)
>>> G.add_edge('e', 'y', capacity=3.0)
>>> R = preflow_push(G, 'x', 'y')
>>> flow_value = nx.maximum_flow_value(G, 'x', 'y')
>>> flow_value == R.graph['flow_value']
True
>>> # preflow_push also stores the maximum flow value
>>> # in the excess attribute of the sink node t
>>> flow_value == R.nodes['y']['excess']
True
>>> # For some problems, you might only want to compute a
>>> # maximum preflow.
>>> R = preflow_push(G, 'x', 'y', value_only=True)
```

(continues on next page)
>>> flow_value == R.graph['flow_value']
True
>>> flow_value == R.nodes['y']['excess']
True

3.28.5 Dinitz

\texttt{dinitz}(G, s, t[, capacity, residual, \ldots]) \quad \text{Find a maximum single-commodity flow using Dinitz' algorithm.}

\texttt{networkx.algorithms.flow.dinitz}

dinitz \quad (G, s, t, capacity='capacity', residual=None, value_only=False, cutoff=None)

Find a maximum single-commodity flow using Dinitz’ algorithm.

This function returns the residual network resulting after computing the maximum flow. See below for details about the conventions NetworkX uses for defining residual networks.

This algorithm has a running time of $O(n^2m)$ for $n$ nodes and $m$ edges\footnote{Dinitz’ Algorithm: The Original Version and Even’s Version. 2006. Yefim Dinitz. In Theoretical Computer Science. Lecture Notes in Computer Science. Volume 3895. pp 218-240. \url{http://www.cs.bgu.ac.il/~dinitz/Papers/Dinitz_alg.pdf}}.

Parameters

- \texttt{G} (\text{NetworkX graph}) – Edges of the graph are expected to have an attribute called ‘capacity’. If this attribute is not present, the edge is considered to have infinite capacity.
- \texttt{s} (\text{node}) – Source node for the flow.
- \texttt{t} (\text{node}) – Sink node for the flow.
- \texttt{capacity} (\text{string}) – Edges of the graph G are expected to have an attribute capacity that indicates how much flow the edge can support. If this attribute is not present, the edge is considered to have infinite capacity. Default value: ‘capacity’.
- \texttt{residual} (\text{NetworkX graph}) – Residual network on which the algorithm is to be executed. If None, a new residual network is created. Default value: None.
- \texttt{value_only} (\text{bool}) – If True compute only the value of the maximum flow. This parameter will be ignored by this algorithm because it is not applicable.
- \texttt{cutoff} (\text{integer, float}) – If specified, the algorithm will terminate when the flow value reaches or exceeds the cutoff. In this case, it may be unable to immediately determine a minimum cut. Default value: None.

Returns \texttt{R} – Residual network after computing the maximum flow.

Return type NetworkX DiGraph

Raises

- \texttt{NetworkXError} – The algorithm does not support MultiGraph and MultiDiGraph. If the input graph is an instance of one of these two classes, a NetworkXError is raised.
- \texttt{NetworkXUnbounded} – If the graph has a path of infinite capacity, the value of a feasible flow on the graph is unbounded above and the function raises a NetworkXUnbounded.
See also:

maximum_flow(), minimum_cut(), preflow_push(), shortest_augmenting_path()

Notes

The residual network $R$ from an input graph $G$ has the same nodes as $G$. $R$ is a DiGraph that contains a pair of edges $(u, v)$ and $(v, u)$ iff $(u, v)$ is not a self-loop, and at least one of $(u, v)$ and $(v, u)$ exists in $G$.

For each edge $(u, v)$ in $R$, $R[u][v]['capacity']$ is equal to the capacity of $(u, v)$ in $G$ if it exists in $G$ or zero otherwise. If the capacity is infinite, $R[u][v]['capacity']$ will have a high arbitrary finite value that does not affect the solution of the problem. This value is stored in $R$.graph['inf']. For each edge $(u, v)$ in $R$, $R[u][v]['flow']$ represents the flow function of $(u, v)$ and satisfies $R[u][v]['flow'] == -R[v][u]['flow']$.

The flow value, defined as the total flow into $t$, the sink, is stored in $R$.graph['flow_value']. If cutoff is not specified, reachability to $t$ using only edges $(u, v)$ such that $R[u][v]['flow'] < R[u][v]['capacity']$ induces a minimum $s$-$t$ cut.

Examples

```python
>>> import networkx as nx
>>> from networkx.algorithms.flow import dinitz

>>> G = nx.DiGraph()
>>> G.add_edge('x','a', capacity=3.0)
>>> G.add_edge('x','b', capacity=1.0)
>>> G.add_edge('a','c', capacity=3.0)
>>> G.add_edge('b','c', capacity=5.0)
>>> G.add_edge('b','d', capacity=4.0)
>>> G.add_edge('d','e', capacity=2.0)
>>> G.add_edge('c','y', capacity=2.0)
>>> G.add_edge('e','y', capacity=3.0)
>>> R = dinitz(G, 'x', 'y')
>>> flow_value = nx.maximum_flow_value(G, 'x', 'y')
>>> flow_value
3.0
>>> flow_value == R.graph['flow_value']
True
```

References

3.28.6 Boykov-Kolmogorov

`boykov_kolmogorov(G, s, t[, capacity, ...])` Find a maximum single-commodity flow using Boykov-Kolmogorov algorithm.
networkx.algorithms.flow.boykov_kolmogorov

boykov_kolmogorov(G, s, t, capacity='capacity', residual=None, value_only=False, cutoff=None)

Find a maximum single-commodity flow using Boykov-Kolmogorov algorithm.

This function returns the residual network resulting after computing the maximum flow. See below for details about the conventions NetworkX uses for defining residual networks.

This algorithm has worse case complexity $O(n^2 m |C|)$ for $n$ nodes, $m$ edges, and $|C|$ the cost of the minimum cut\(^1\). This implementation uses the marking heuristic defined in\(^2\) which improves its running time in many practical problems.

**Parameters**

- **G** (NetworkX graph) – Edges of the graph are expected to have an attribute called ‘capacity’. If this attribute is not present, the edge is considered to have infinite capacity.
- **s** (node) – Source node for the flow.
- **t** (node) – Sink node for the flow.
- **capacity** (string) – Edges of the graph G are expected to have an attribute capacity that indicates how much flow the edge can support. If this attribute is not present, the edge is considered to have infinite capacity. Default value: ‘capacity’.
- **residual** (NetworkX graph) – Residual network on which the algorithm is to be executed. If None, a new residual network is created. Default value: None.
- **value_only** (bool) – If True compute only the value of the maximum flow. This parameter will be ignored by this algorithm because it is not applicable.
- **cutoff** (integer, float) – If specified, the algorithm will terminate when the flow value reaches or exceeds the cutoff. In this case, it may be unable to immediately determine a minimum cut. Default value: None.

**Returns**

- **R** – Residual network after computing the maximum flow.

**Return type** NetworkX DiGraph

**Raises**

- **NetworkXError** – The algorithm does not support MultiGraph and MultiDiGraph. If the input graph is an instance of one of these two classes, a NetworkXError is raised.
- **NetworkXUnbounded** – If the graph has a path of infinite capacity, the value of a feasible flow on the graph is unbounded above and the function raises a NetworkXUnbounded.

**See also:**

maximum_flow(), minimum_cut(), preflow_push(), shortest_augmenting_path()

**Notes**

The residual network $R$ from an input graph $G$ has the same nodes as $G$. $R$ is a DiGraph that contains a pair of edges $(u, v)$ and $(v, u)$ iff $(u, v)$ is not a self-loop, and at least one of $(u, v)$ and $(v, u)$ exists in $G$.


For each edge \((u, v)\) in \(R, R[u][v][\text{\textquoteleft capacity\textquoteright}]\) is equal to the capacity of \((u, v)\) in \(G\) if it exists in \(G\) or zero otherwise. If the capacity is infinite, \(R[u][v][\text{\textquoteleft capacity\textquoteright}]\) will have a high arbitrary finite value that does not affect the solution of the problem. This value is stored in \(R\.\text{graph}[\text{\textquoteleft inf\textquoteright}]\). For each edge \((u, v)\) in \(R, R[u][v][\text{\textquoteleft flow\textquoteright}]\) represents the flow function of \((u, v)\) and satisfies \(R[u][v][\text{\textquoteleft flow\textquoteright}] == -R[v][u][\text{\textquoteleft flow\textquoteright}]\).

The flow value, defined as the total flow into \(t\), the sink, is stored in \(R\.\text{graph}[\text{\textquoteleft flow\_value\textquoteright}]\). If cutoff is not specified, reachability to \(t\) using only edges \((u, v)\) such that \(R[u][v][\text{\textquoteleft flow\textquoteright}] < R[u][v][\text{\textquoteleft capacity\textquoteright}]\) induces a minimum \(s\)-\(t\) cut.

**Examples**

```python
>>> import networkx as nx
>>> from networkx.algorithms.flow import boykov_kolmogorov
```

The functions that implement flow algorithms and output a residual network, such as this one, are not imported to the base NetworkX namespace, so you have to explicitly import them from the flow package.

```python
>>> G = nx.DiGraph()
>>> G.add_edge('x','a', capacity=3.0)
>>> G.add_edge('x','b', capacity=1.0)
>>> G.add_edge('a','c', capacity=3.0)
>>> G.add_edge('b','c', capacity=5.0)
>>> G.add_edge('b','d', capacity=4.0)
>>> G.add_edge('d','e', capacity=2.0)
>>> G.add_edge('c','y', capacity=2.0)
>>> G.add_edge('e','y', capacity=3.0)
>>> R = boykov_kolmogorov(G, 'x', 'y')
>>> flow_value = nx.maximum_flow_value(G, 'x', 'y')
>>> flow_value
3.0
>>> flow_value == R.graph[\text{\textquoteleft flow\_value\textquoteright}]
True
```

A nice feature of the Boykov-Kolmogorov algorithm is that a partition of the nodes that defines a minimum cut can be easily computed based on the search trees used during the algorithm. These trees are stored in the graph attribute \(trees\) of the residual network.

```python
>>> source_tree, target_tree = R.graph[\text{\textquoteleft trees\textquoteright}]
>>> partition = (set(source_tree), set(G) - set(source_tree))
```

Or equivalently:

```python
>>> partition = (set(G) - set(target_tree), set(target_tree))
```

**References**

3.28.7 Gomory-Hu Tree

\(\text{gomory\_hu\_tree}(G, [\text{capacity, flow\_func}])\) Returns the Gomory-Hu tree of an undirected graph \(G\).
networkx.algorithms.flow.gomory_hu_tree

gomory_hu_tree (G, capacity='capacity', flow_func=None)

Returns the Gomory-Hu tree of an undirected graph G.

A Gomory-Hu tree of an undirected graph with capacities is a weighted tree that represents the minimum s-t cuts for all s-t pairs in the graph.

It only requires $n-1$ minimum cut computations instead of the obvious $n(n-1)/2$. The tree represents all s-t cuts as the minimum cut value among any pair of nodes is the minimum edge weight in the shortest path between the two nodes in the Gomory-Hu tree.

The Gomory-Hu tree also has the property that removing the edge with the minimum weight in the shortest path between any two nodes leaves two connected components that form a partition of the nodes in G that defines the minimum s-t cut.

See Examples section below for details.

Parameters

- **G** *(NetworkX graph)* – Undirected graph
- **capacity** *(string)* – Edges of the graph G are expected to have an attribute capacity that indicates how much flow the edge can support. If this attribute is not present, the edge is considered to have infinite capacity. Default value: ‘capacity’.
- **flow_func** *(function)* – Function to perform the underlying flow computations. Default value `edmonds_karp()`. This function performs better in sparse graphs with right tailed degree distributions. `shortest_augmenting_path()` will perform better in denser graphs.

Returns **Tree** – A NetworkX graph representing the Gomory-Hu tree of the input graph.

Return type **NetworkX graph**

Raises

- **NetworkXNotImplemented : Exception** – Raised if the input graph is directed.
- **NetworkXError: Exception** – Raised if the input graph is an empty Graph.

Examples

```python
>>> G = nx.karate_club_graph()
>>> nx.set_edge_attributes(G, 1, 'capacity')
>>> T = nx.gomory_hu_tree(G)
>>> # The value of the minimum cut between any pair of nodes in G is the minimum edge weight in the shortest path between the two nodes in the Gomory-Hu tree.
... def minimum_edge_weight_in_shortest_path(T, u, v):
...     path = nx.shortest_path(T, u, v, weight='weight')
...     return min((T[u][v]['weight'], (u,v)) for (u, v) in zip(path, path[1:]))
>>> u, v = 0, 33
>>> cut_value, edge = minimum_edge_weight_in_shortest_path(T, u, v)
>>> cut_value
10
>>> nx.minimum_cut_value(G, u, v)
10
>>> # The Gomory-Hu tree also has the property that removing the edge with the minimum weight in the shortest path between
... # two nodes leaves two connected components that form a partition of the nodes in G that defines the minimum s-t cut.
```
... # any two nodes leaves two connected components that form
... # a partition of the nodes in G that defines the minimum s-t
... # cut.
... cut_value, edge = minimum_edge_weight_in_shortest_path(T, u, v)
>>> T.remove_edge(*edge)
>>> U, V = list(nx.connected_components(T))
>>> # Thus U and V form a partition that defines a minimum cut
... # between u and v in G. You can compute the edge cut set,
... # that is, the set of edges that if removed from G will
... # disconnect u from v in G, with this information:
... cutset = set()
>>> for x, nbrs in ((n, G[n]) for n in U):
...     cutset.update((x, y) for y in nbrs if y in V)
>>> # Because we have set the capacities of all edges to 1
... # the cutset contains ten edges
... len(cutset)
10
>>> # You can use any maximum flow algorithm for the underlying
... # flow computations using the argument flow_func
... from networkx.algorithms import flow
>>> T = nx.gomory_hu_tree(G, flow_func=flow.boykov_kolmogorov)
>>> cut_value, edge = minimum_edge_weight_in_shortest_path(T, u, v)
>>> cut_value
10
>>> nx.minimum_cut_value(G, u, v, flow_func=flow.boykov_kolmogorov)
10

Notes

This implementation is based on Gusfield approach\(^1\) to compute Comory-Hu trees, which does not require node
contractions and has the same computational complexity than the original method.

See also:

minimum_cut(), maximum_flow()

References

3.28.8 Utils

build_residual_network(G, capacity)  Build a residual network and initialize a zero flow.

networkx.algorithms.flow.build_residual_network

build_residual_network(G, capacity)

Build a residual network and initialize a zero flow.

The residual network \( R \) from an input graph \( G \) has the same nodes as \( G \). \( R \) is a DiGraph that contains a pair of
edges \( (u, v) \) and \( (v, u) \) iff \( (u, v) \) is not a self-loop, and at least one of \( (u, v) \) and \( (v, u) \) exists in
\( G \).

For each edge \( (u, v) \) in \( R[R[u][v]['capacity']] \) is equal to the capacity of \( (u, v) \) in \( G \) if it exists in

---

If the capacity is infinite, R[u][v]['capacity'] will have a high arbitrary finite value that does not affect the solution of the problem. This value is stored in R.graph['inf']. For each edge (u, v) in R, R[u][v]['flow'] represents the flow function of (u, v) and satisfies R[u][v]['flow'] == -R[v][u]['flow'].

The flow value, defined as the total flow into t, the sink, is stored in R.graph['flow_value']. If cutoff is not specified, reachability to t using only edges (u, v) such that R[u][v]['flow'] < R[u][v]['capacity'] induces a minimum s-t cut.

### 3.28.9 Network Simplex

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>network_simplex(G, demand, capacity, weight)</td>
<td>Find a minimum cost flow satisfying all demands in digraph G.</td>
</tr>
<tr>
<td>min_cost_flow_cost(G, demand, capacity, weight)</td>
<td>Find the cost of a minimum cost flow satisfying all demands in digraph G.</td>
</tr>
<tr>
<td>min_cost_flow(G, demand, capacity, weight)</td>
<td>Return a minimum cost flow satisfying all demands in digraph G.</td>
</tr>
<tr>
<td>cost_of_flow(G, flowDict, weight)</td>
<td>Compute the cost of the flow given by flowDict on graph G.</td>
</tr>
<tr>
<td>max_flow_min_cost(G, s, t, capacity, weight)</td>
<td>Return a maximum (s, t)-flow of minimum cost.</td>
</tr>
</tbody>
</table>

**networkx.algorithms.flow.network_simplex**

`network_simplex(G, demand='demand', capacity='capacity', weight='weight')`

Find a minimum cost flow satisfying all demands in digraph G.

This is a primal network simplex algorithm that uses the leaving arc rule to prevent cycling.

G is a digraph with edge costs and capacities and in which nodes have demand, i.e., they want to send or receive some amount of flow. A negative demand means that the node wants to send flow, a positive demand means that the node want to receive flow. A flow on the digraph G satisfies all demand if the net flow into each node is equal to the demand of that node.

**Parameters**

- G (NetworkX graph) – DiGraph on which a minimum cost flow satisfying all demands is to be found.
- demand (string) – Nodes of the graph G are expected to have an attribute demand that indicates how much flow a node wants to send (negative demand) or receive (positive demand). Note that the sum of the demands should be 0 otherwise the problem in not feasible. If this attribute is not present, a node is considered to have 0 demand. Default value: ‘demand’.
- capacity (string) – Edges of the graph G are expected to have an attribute capacity that indicates how much flow the edge can support. If this attribute is not present, the edge is considered to have infinite capacity. Default value: ‘capacity’.
- weight (string) – Edges of the graph G are expected to have an attribute weight that indicates the cost incurred by sending one unit of flow on that edge. If not present, the weight is considered to be 0. Default value: ‘weight’.

**Returns**

- flowCost (integer, float) – Cost of a minimum cost flow satisfying all demands.
- flowDict (dictionary) – Dictionary of dictionaries keyed by nodes such that flowDict[u][v] is the flow edge (u, v).
Raises

- **NetworkXError** – This exception is raised if the input graph is not directed, not connected or is a multigraph.
- **NetworkXUnfeasible** – This exception is raised in the following situations:
  - The sum of the demands is not zero. Then, there is no flow satisfying all demands.
  - There is no flow satisfying all demand.
- **NetworkXUnbounded** – This exception is raised if the digraph G has a cycle of negative cost and infinite capacity. Then, the cost of a flow satisfying all demands is unbounded below.

Notes

This algorithm is not guaranteed to work if edge weights or demands are floating point numbers (overflows and roundoff errors can cause problems). As a workaround you can use integer numbers by multiplying the relevant edge attributes by a convenient constant factor (eg 100).

See also:

- `cost_of_flow()`, `max_flow_min_cost()`, `min_cost_flow()`, `min_cost_flow_cost()`

Examples

A simple example of a min cost flow problem.

```
>>> import networkx as nx
>>> G = nx.DiGraph()
>>> G.add_node('a', demand=-5)
>>> G.add_node('d', demand=5)
>>> G.add_edge('a', 'b', weight=3, capacity=4)
>>> G.add_edge('a', 'c', weight=6, capacity=10)
>>> G.add_edge('b', 'd', weight=1, capacity=9)
>>> G.add_edge('c', 'd', weight=2, capacity=5)
>>> flowCost, flowDict = nx.network_simplex(G)
>>> flowCost
24
>>> flowDict
{'a': {'c': 1, 'b': 4}, 'c': {'d': 1}, 'b': {'d': 4}, 'd': {}}
```

The mincost flow algorithm can also be used to solve shortest path problems. To find the shortest path between two nodes u and v, give all edges an infinite capacity, give node u a demand of -1 and node v a demand a 1. Then run the network simplex. The value of a min cost flow will be the distance between u and v and edges carrying positive flow will indicate the path.

```
>>> G=nx.DiGraph()
>>> G.add_weighted_edges_from([('s', 'u', 10), ('s', 'x', 5),
... ('u', 'v', 1), ('u', 'x', 2),
... ('v', 'y', 1), ('x', 'u', 3),
... ('x', 'v', 5), ('x', 'y', 2),
... ('y', 's', 7), ('y', 'v', 6)])
>>> G.add_node('s', demand = -1)
>>> G.add_node('v', demand = 1)
>>> flowCost, flowDict = nx.network_simplex(G)
```

(continues on next page)
>>> flowCost == nx.shortest_path_length(G, 's', 'v', weight='weight')
True
>>> sorted(((u, v) for u in flowDict for v in flowDict[u] if flowDict[u][v] > 0))
[('s', 'x'), ('u', 'v'), ('x', 'u')]
>>> nx.shortest_path(G, 's', 'v', weight = 'weight')
['s', 'x', 'u', 'v']

It is possible to change the name of the attributes used for the algorithm.

>>> G = nx.DiGraph()
>>> G.add_node('p', spam=-4)
>>> G.add_node('q', spam=2)
>>> G.add_node('a', spam=-2)
>>> G.add_node('d', spam=-1)
>>> G.add_node('t', spam=2)
>>> G.add_node('w', spam=3)
>>> G.add_edge('p', 'q', cost=7, vacancies=5)
>>> G.add_edge('p', 'a', cost=1, vacancies=4)
>>> G.add_edge('q', 'd', cost=2, vacancies=3)
>>> G.add_edge('t', 'q', cost=1, vacancies=2)
>>> G.add_edge('a', 't', cost=2, vacancies=4)
>>> G.add_edge('d', 'w', cost=3, vacancies=4)
>>> G.add_edge('t', 'w', cost=4, vacancies=1)
>>> flowCost, flowDict = nx.network_simplex(G, demand='spam',
.. capacity='vacancies',
.. weight='cost')
>>> flowCost
37
>>> flowDict
{'a': {'t': 4}, 'd': {'w': 2}, 'q': {'d': 1}, 'p': {'q': 2, 'a': 2}, 't': {'q': 1, 'w': 1}, 'w': {}}

References

networkx.algorithms.flow.min_cost_flow_cost

min_cost_flow_cost (G, demand='demand', capacity='capacity', weight='weight')

Find the cost of a minimum cost flow satisfying all demands in digraph G.

G is a digraph with edge costs and capacities and in which nodes have demand, i.e., they want to send or receive some amount of flow. A negative demand means that the node wants to send flow, a positive demand means that the node want to receive flow. A flow on the digraph G satisfies all demand if the net flow into each node is equal to the demand of that node.

Parameters

- G (NetworkX graph) – DiGraph on which a minimum cost flow satisfying all demands is to be found.
- demand (string) – Nodes of the graph G are expected to have an attribute demand that indicates how much flow a node wants to send (negative demand) or receive (positive demand). Note that the sum of the demands should be 0 otherwise the problem in not feasible. If this attribute is not present, a node is considered to have 0 demand. Default value: ‘demand’.
- capacity (string) – Edges of the graph G are expected to have an attribute capacity that indicates how much flow the edge can support. If this attribute is not present, the edge is
considered to have infinite capacity. Default value: ‘capacity’.

- **weight** *(string)* – Edges of the graph G are expected to have an attribute weight that indicates the cost incurred by sending one unit of flow on that edge. If not present, the weight is considered to be 0. Default value: ‘weight’.

**Returns** flowCost – Cost of a minimum cost flow satisfying all demands.

**Return type** integer, float

** Raises **

- NetworkXError – This exception is raised if the input graph is not directed or not connected.

- NetworkXUnfeasible – This exception is raised in the following situations:
  - The sum of the demands is not zero. Then, there is no flow satisfying all demands.
  - There is no flow satisfying all demand.

- NetworkXUnbounded – This exception is raised if the digraph G has a cycle of negative cost and infinite capacity. Then, the cost of a flow satisfying all demands is unbounded below.

**See also:**

cost_of_flow(), max_flow_min_cost(), min_cost_flow(), network_simplex()

**Notes**

This algorithm is not guaranteed to work if edge weights or demands are floating point numbers (overflows and roundoff errors can cause problems). As a workaround you can use integer numbers by multiplying the relevant edge attributes by a convenient constant factor (eg 100).

**Examples**

A simple example of a min cost flow problem.

```python
>>> import networkx as nx
>>> G = nx.DiGraph()
>>> G.add_node('a', demand = -5)
>>> G.add_node('d', demand = 5)
>>> G.add_edge('a', 'b', weight = 3, capacity = 4)
>>> G.add_edge('a', 'c', weight = 6, capacity = 10)
>>> G.add_edge('b', 'd', weight = 1, capacity = 9)
>>> G.add_edge('c', 'd', weight = 2, capacity = 5)
>>> flowCost = nx.min_cost_flow_cost(G)
>>> flowCost
24
```

**networkx.algorithms.flow.min_cost_flow**

min_cost_flow *(G, demand='demand', capacity='capacity', weight='weight')*

Return a minimum cost flow satisfying all demands in digraph G.

G is a digraph with edge costs and capacities and in which nodes have demand, i.e., they want to send or receive some amount of flow. A negative demand means that the node wants to send flow, a positive demand means
that the node want to receive flow. A flow on the digraph $G$ satisfies all demand if the net flow into each node is equal to the demand of that node.

**Parameters**

- $G$ (**NetworkX graph**) – DiGraph on which a minimum cost flow satisfying all demands is to be found.
- `demand` (**string**) – Nodes of the graph $G$ are expected to have an attribute `demand` that indicates how much flow a node wants to send (negative demand) or receive (positive demand). Note that the sum of the demands should be 0 otherwise the problem in not feasible. If this attribute is not present, a node is considered to have 0 demand. Default value: ‘demand’.
- `capacity` (**string**) – Edges of the graph $G$ are expected to have an attribute `capacity` that indicates how much flow the edge can support. If this attribute is not present, the edge is considered to have infinite capacity. Default value: ‘capacity’.
- `weight` (**string**) – Edges of the graph $G$ are expected to have an attribute `weight` that indicates the cost incurred by sending one unit of flow on that edge. If not present, the weight is considered to be 0. Default value: ‘weight’.

**Returns**

`flowDict` – Dictionary of dictionaries keyed by nodes such that `flowDict[u][v]` is the flow edge $(u, v)$.

**Return type** dictionary

**Raises**

- `NetworkXError` – This exception is raised if the input graph is not directed or not connected.
- `NetworkXUnfeasible` – This exception is raised in the following situations:
  - The sum of the demands is not zero. Then, there is no flow satisfying all demands.
  - There is no flow satisfying all demand.
- `NetworkXUnbounded` – This exception is raised if the digraph $G$ has a cycle of negative cost and infinite capacity. Then, the cost of a flow satisfying all demands is unbounded below.

**See also:**

`cost_of_flow()`, `max_flow_min_cost()`, `min_cost_flow_cost()`, `network_simplex()`

**Notes**

This algorithm is not guaranteed to work if edge weights or demands are floating point numbers (overflows and roundoff errors can cause problems). As a workaround you can use integer numbers by multiplying the relevant edge attributes by a convenient constant factor (eg 100).

**Examples**

A simple example of a min cost flow problem.

```python
>>> import networkx as nx
>>> G = nx.DiGraph()
>>> G.add_node('a', demand = -5)
>>> G.add_node('d', demand = 5)
>>> G.add_node('b', demand = 0)
>>> G.add_node('c', demand = 0)
>>> G.add_edge('a', 'b', weight = 1, capacity = 10)
>>> G.add_edge('a', 'c', weight = 2, capacity = 20)
>>> G.add_edge('b', 'c', weight = 1, capacity = 10)
>>> min_cost_flow(G, demand = 'demand')
```

(continues on next page)
networkx.algorithms.flow.cost_of_flow

cost_of_flow(G, flowDict, weight=’weight’)  
Compute the cost of the flow given by flowDict on graph G.

Note that this function does not check for the validity of the flow flowDict. This function will fail if the graph G and the flow don’t have the same edge set.

Parameters

• G (NetworkX graph) – DiGraph on which a minimum cost flow satisfying all demands is to be found.

• weight (string) – Edges of the graph G are expected to have an attribute weight that indicates the cost incurred by sending one unit of flow on that edge. If not present, the weight is considered to be 0. Default value: ‘weight’.

• flowDict (dictionary) – Dictionary of dictionaries keyed by nodes such that flowDict[u][v] is the flow edge (u, v).

Returns cost – The total cost of the flow. This is given by the sum over all edges of the product of the edge’s flow and the edge’s weight.

Return type Integer, float

See also:

max_flow_min_cost(), min_cost_flow(), min_cost_flow_cost(), network_simplex()

Notes

This algorithm is not guaranteed to work if edge weights or demands are floating point numbers (overflows and roundoff errors can cause problems). As a workaround you can use integer numbers by multiplying the relevant edge attributes by a convenient constant factor (eg 100).

networkx.algorithms.flow.max_flow_min_cost

max_flow_min_cost(G, s, t, capacity=’capacity’, weight=’weight’)  
Return a maximum (s, t)-flow of minimum cost.

G is a digraph with edge costs and capacities. There is a source node s and a sink node t. This function finds a maximum flow from s to t whose total cost is minimized.

Parameters

• G (NetworkX graph) – DiGraph on which a minimum cost flow satisfying all demands is to be found.

• s (node label) – Source of the flow.

• t (node label) – Destination of the flow.
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• **capacity** (*string*) – Edges of the graph G are expected to have an attribute capacity that indicates how much flow the edge can support. If this attribute is not present, the edge is considered to have infinite capacity. Default value: ‘capacity’.

• **weight** (*string*) – Edges of the graph G are expected to have an attribute weight that indicates the cost incurred by sending one unit of flow on that edge. If not present, the weight is considered to be 0. Default value: ‘weight’.

**Returns** flowDict – Dictionary of dictionaries keyed by nodes such that flowDict[u][v] is the flow edge (u, v).

**Return type** dictionary

**Raises**

- **NetworkXError** – This exception is raised if the input graph is not directed or not connected.

- **NetworkXUnbounded** – This exception is raised if there is an infinite capacity path from s to t in G. In this case there is no maximum flow. This exception is also raised if the digraph G has a cycle of negative cost and infinite capacity. Then, the cost of a flow is unbounded below.

**See also:**

cost_of_flow(), min_cost_flow(), min_cost_flow_cost(), network_simplex()

**Notes**

This algorithm is not guaranteed to work if edge weights or demands are floating point numbers (overflows and roundoff errors can cause problems). As a workaround you can use integer numbers by multiplying the relevant edge attributes by a convenient constant factor (eg 100).

**Examples**

```python
>>> G = nx.DiGraph()
>>> G.add_edges_from([(1, 2, {'capacity': 12, 'weight': 4}),
...                   (1, 3, {'capacity': 20, 'weight': 6}),
...                   (2, 3, {'capacity': 6, 'weight': -3}),
...                   (2, 6, {'capacity': 14, 'weight': 1}),
...                   (3, 4, {'weight': 9}),
...                   (3, 5, {'capacity': 10, 'weight': 5}),
...                   (4, 2, {'capacity': 19, 'weight': 13}),
...                   (4, 5, {'capacity': 4, 'weight': 0}),
...                   (5, 7, {'capacity': 28, 'weight': 2}),
...                   (6, 5, {'capacity': 11, 'weight': 1}),
...                   (6, 7, {'weight': 8}),
...                   (7, 4, {'capacity': 6, 'weight': 6})])
>>> mincostFlow = nx.max_flow_min_cost(G, 1, 7)
>>> mincost = nx.cost_of_flow(G, mincostFlow)
>>> mincost
373
>>> from networkx.algorithms.flow import maximum_flow
>>> maxFlow = maximum_flow(G, 1, 7)[1]
>>> nx.cost_of_flow(G, maxFlow) >= mincost
True
>>> mincostFlowValue = (sum((mincostFlow[u][7] for u in G.predecessors(7)))
```

(continues on next page)
... - sum((mincostFlow[7][v] for v in G.successors(7)))
>>> mincostFlowValue == nx.maximum_flow_value(G, 1, 7)
True

### 3.28.10 Capacity Scaling Minimum Cost Flow

<table>
<thead>
<tr>
<th>capacity_scaling(G, demand, capacity, ...)</th>
<th>Find a minimum cost flow satisfying all demands in digraph G.</th>
</tr>
</thead>
</table>

`networkx.algorithms.flow.capacity_scaling`

**capacity_scaling**

(\(G, \text{ demand='demand'}, \text{ capacity='capacity'}, \text{ weight='weight'}, \text{ heap=<class \textit{networkx.utils.heaps.BinaryHeap}>})\)

Find a minimum cost flow satisfying all demands in digraph \(G\).

This is a capacity scaling successive shortest augmenting path algorithm.

\(G\) is a digraph with edge costs and capacities and in which nodes have demand, i.e., they want to send or receive some amount of flow. A negative demand means that the node wants to send flow, a positive demand means that the node want to receive flow. A flow on the digraph \(G\) satisfies all demand if the net flow into each node is equal to the demand of that node.

**Parameters**

- \(G\) (\textit{NetworkX graph}) – DiGraph or MultiDiGraph on which a minimum cost flow satisfying all demands is to be found.
- \texttt{demand} (\textit{string}) – Nodes of the graph \(G\) are expected to have an attribute demand that indicates how much flow a node wants to send (negative demand) or receive (positive demand). Note that the sum of the demands should be 0 otherwise the problem in not feasible. If this attribute is not present, a node is considered to have 0 demand. Default value: ‘demand’.
- \texttt{capacity} (\textit{string}) – Edges of the graph \(G\) are expected to have an attribute capacity that indicates how much flow the edge can support. If this attribute is not present, the edge is considered to have infinite capacity. Default value: ‘capacity’.
- \texttt{weight} (\textit{string}) – Edges of the graph \(G\) are expected to have an attribute weight that indicates the cost incurred by sending one unit of flow on that edge. If not present, the weight is considered to be 0. Default value: ‘weight’.
- \texttt{heap} (\textit{class}) – Type of heap to be used in the algorithm. It should be a subclass of \textit{MinHeap} or implement a compatible interface.

If a stock heap implementation is to be used, \textit{BinaryHeap} is recommended over \textit{PairingHeap} for Python implementations without optimized attribute accesses (e.g., CPython) despite a slower asymptotic running time. For Python implementations with optimized attribute accesses (e.g., PyPy), \textit{PairingHeap} provides better performance. Default value: \textit{BinaryHeap}.

**Returns**

- \texttt{flowCost} (integer) – Cost of a minimum cost flow satisfying all demands.
- \texttt{flowDict} (dictionary) – If \(G\) is a digraph, a dict-of-dicts keyed by nodes such that \texttt{flowDict}[u][v] is the flow on edge \((u, v)\). If \(G\) is a MultiDiGraph, a dict-of-dicts-of-dicts keyed by nodes so that \texttt{flowDict}[u][v][key] is the flow on edge \((u, v, key)\).
Raises

- **NetworkXError** – This exception is raised if the input graph is not directed, not connected.
- **NetworkXUnfeasible** – This exception is raised in the following situations:
  - The sum of the demands is not zero. Then, there is no flow satisfying all demands.
  - There is no flow satisfying all demand.
- **NetworkXUnbounded** – This exception is raised if the digraph G has a cycle of negative cost and infinite capacity. Then, the cost of a flow satisfying all demands is unbounded below.

Notes

This algorithm does not work if edge weights are floating-point numbers.

See also:

`network_simplex()`

Examples

A simple example of a min cost flow problem.

```python
>>> import networkx as nx
>>> G = nx.DiGraph()
>>> G.add_node('a', demand = -5)
>>> G.add_node('d', demand = 5)
>>> G.add_edge('a', 'b', weight = 3, capacity = 4)
>>> G.add_edge('a', 'c', weight = 6, capacity = 10)
>>> G.add_edge('b', 'd', weight = 1, capacity = 9)
>>> G.add_edge('c', 'd', weight = 2, capacity = 5)
>>> flowCost, flowDict = nx.capacity_scaling(G)
>>> flowCost
24
>>> flowDict
{'a': {'c': 1, 'b': 4}, 'c': {'d': 1}, 'b': {'d': 4}, 'd': {}}
```

It is possible to change the name of the attributes used for the algorithm.

```python
>>> G = nx.DiGraph()
>>> G.add_node('p', spam = -4)
>>> G.add_node('q', spam = 2)
>>> G.add_node('a', spam = -2)
>>> G.add_node('d', spam = -1)
>>> G.add_node('t', spam = 2)
>>> G.add_node('w', spam = 3)
>>> G.add_edge('p', 'q', cost = 7, vacancies = 5)
>>> G.add_edge('p', 'a', cost = 1, vacancies = 4)
>>> G.add_edge('q', 'd', cost = 2, vacancies = 3)
>>> G.add_edge('t', 'q', cost = 1, vacancies = 2)
>>> G.add_edge('a', 't', cost = 2, vacancies = 4)
>>> G.add_edge('d', 'w', cost = 3, vacancies = 4)
>>> G.add_edge('t', 'w', cost = 4, vacancies = 1)
```

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NetworkX Reference, Release 2.2rc1.dev20180319181321

>>> flowCost, flowDict = nx.capacity_scaling(G, demand = 'spam',
... capacity = 'vacancies',
... weight = 'cost')

>>> flowCost
37

>>> flowDict
{'a': {'t': 4}, 'd': {'w': 2}, 'q': {'d': 1}, 'p': {'q': 2, 'a': 2}, 't': {'q': 1,
... 'w': 1}, 'w': {}}

3.29 Graphical degree sequence

Test sequences for graphiness.

<table>
<thead>
<tr>
<th>is_graphical(sequence[, method])</th>
<th>Returns True if sequence is a valid degree sequence.</th>
</tr>
</thead>
<tbody>
<tr>
<td>is_digraphical(in_sequence, out_sequence)</td>
<td>Returns True if some directed graph can realize the in- and out-degree sequences.</td>
</tr>
<tr>
<td>is_multigraphical(sequence)</td>
<td>Returns True if some multigraph can realize the sequence.</td>
</tr>
<tr>
<td>is_pseudographical(sequence)</td>
<td>Returns True if some pseudograph can realize the sequence.</td>
</tr>
<tr>
<td>is_valid_degree_sequence_havel_hakimi(...)</td>
<td>Returns True if deg_sequence can be realized by a simple graph.</td>
</tr>
<tr>
<td>is_valid_degree_sequence_erdos_gallai(...)</td>
<td>Returns True if deg_sequence can be realized by a simple graph.</td>
</tr>
</tbody>
</table>

3.29.1 networkx.algorithms.graphical.is_graphical

is_graphical(sequence[, method='eg'])
Returns True if sequence is a valid degree sequence.

A degree sequence is valid if some graph can realize it.

Parameters

- sequence (list or iterable container) – A sequence of integer node degrees
- method (“eg” | “hh”) – The method used to validate the degree sequence. “eg” corresponds to the Erdős-Gallai algorithm, and “hh” to the Havel-Hakimi algorithm.

Returns  valid – True if the sequence is a valid degree sequence and False if not.

Return type  bool

Examples

>>> G = nx.path_graph(4)
>>> sequence = (d for n, d in G.degree())
>>> nx.is_graphical(sequence)
True
References

Erdős-Gallai [EG1960], [choudum1986]
Havel-Hakimi [havel1955], [hakimi1962], [CL1996]

3.29.2 networkx.algorithms.graphical.is_digraphical

is_digraphical(in_sequence, out_sequence)
Returns True if some directed graph can realize the in- and out-degree sequences.

Parameters

• in_sequence (list or iterable container) – A sequence of integer node in-degrees
• out_sequence (list or iterable container) – A sequence of integer node out-degrees

Returns valid – True if in and out-sequences are digraphic False if not.
Return type bool

Notes

This algorithm is from Kleitman and Wang\(^1\). The worst case runtime is \(O(s \times \log n)\) where \(s\) and \(n\) are the sum and length of the sequences respectively.

References

3.29.3 networkx.algorithms.graphical.is_multigraphical

is_multigraphical(sequence)
Returns True if some multigraph can realize the sequence.

Parameters sequence (list) – A list of integers

Returns valid – True if deg_sequence is a multigraphic degree sequence and False if not.
Return type bool

Notes

The worst-case run time is \(O(n)\) where \(n\) is the length of the sequence.

References

3.29.4 networkx.algorithms.graphical.is_pseudographical

is_pseudographical(sequence)
Returns True if some pseudograph can realize the sequence.

Every nonnegative integer sequence with an even sum is pseudographical (see\(^1\)).

**Parameters** sequence *(list or iterable container)* – A sequence of integer node degrees

**Returns** valid – True if the sequence is a pseudographic degree sequence and False if not.

**Return type** bool

**Notes**

The worst-case run time is \(O(n)\) where \(n\) is the length of the sequence.

**References**

3.29.5 `networkx.algorithms.graphical.is_valid_degree_sequence_havel_hakimi`

`is_valid_degree_sequence_havel_hakimi`(deg_sequence)

Returns True if deg_sequence can be realized by a simple graph.

The validation proceeds using the Havel-Hakimi theorem. Worst-case run time is \(O(s)\) where \(s\) is the sum of the sequence.

**Parameters** deg_sequence *(list)* – A list of integers where each element specifies the degree of a node in a graph.

**Returns** valid – True if deg_sequence is graphical and False if not.

**Return type** bool

**Notes**

The ZZ condition says that for the sequence \(d\) if

\[
|d| \geq \frac{(\max(d) + \min(d) + 1)^2}{4 \cdot \min(d)}
\]

then \(d\) is graphical. This was shown in Theorem 6 in\(^1\).

**References**

[havel1955], [hakimi1962], [CL1996]

3.29.6 `networkx.algorithms.graphical.is_valid_degree_sequence_erdos_gallai`

`is_valid_degree_sequence_erdos_gallai`(deg_sequence)

Returns True if deg_sequence can be realized by a simple graph.

The validation is done using the Erdős-Gallai theorem [EG1960].

**Parameters** deg_sequence *(list)* – A list of integers

---


Returns valid – True if deg_sequence is graphical and False if not.

Return type bool

Notes

This implementation uses an equivalent form of the Erdős-Gallai criterion. Worst-case run time is $O(n)$ where $n$ is the length of the sequence.

Specifically, a sequence $d$ is graphical if and only if the sum of the sequence is even and for all strong indices $k$ in the sequence,

$$\sum_{i=1}^{k} d_i \leq k(k - 1) + \sum_{j=k+1}^{n} \min(d_i, k) = k(n - 1) - \left( k \sum_{j=0}^{k-1} n_j - \sum_{j=0}^{k-1} jn_j \right)$$

A strong index $k$ is any index where $d_k \geq k$ and the value $n_j$ is the number of occurrences of $j$ in $d$. The maximal strong index is called the Durfee index.

This particular rearrangement comes from the proof of Theorem 3 in\(^2\).

The ZZ condition says that for the sequence $d$ if

$$|d| \geq \frac{(\max(d) + \min(d) + 1)^2}{4 \times \min(d)}$$

then $d$ is graphical. This was shown in Theorem 6 in \(^2\).

References

[EG1960], [choudum1986]

---

**3.30 Hierarchy**

Flow Hierarchy.

```python
flow_hierarchy(G[, weight])
```

Returns the flow hierarchy of a directed network.

---

**3.30.1 networkx.algorithms.hierarchy.flow_hierarchy**

```python
flow_hierarchy(G, weight=None)
```

Returns the flow hierarchy of a directed network.

Flow hierarchy is defined as the fraction of edges not participating in cycles in a directed graph\(^1\).

Parameters

- **G** (*DiGraph or MultiDiGraph*) – A directed graph

---


• **weight** *(key, optional (default=None)) – Attribute to use for node weights. If None the weight defaults to 1.\n
**Returns** \ h – Flow hierarchy value

**Return type** \ float

**Notes**

The algorithm described in \(^1\) computes the flow hierarchy through exponentiation of the adjacency matrix. This function implements an alternative approach that finds strongly connected components. An edge is in a cycle if and only if it is in a strongly connected component, which can be found in \(O(m)\) time using Tarjan’s algorithm.

**References**

### 3.31 Hybrid

Provides functions for finding and testing for locally \((k, l)\)-connected graphs.

| \(\text{kl_connected_subgraph}(G, k, l, \text{low_memory}, \ldots)\) | Returns the maximum locally \((k, l)\)-connected subgraph of \(G\). |
| \(\text{is_kl_connected}(G, k, l, \text{low_memory})\) | Returns True if and only if \(G\) is locally \((k, l)\)-connected. |

#### 3.31.1 networkx.algorithms.hybrid.kl_connected_subgraph

**\(\text{kl_connected_subgraph}(G, k, l, \text{low_memory}=False, \text{same_as_graph}=False)\)**

Returns the maximum locally \((k, l)\)-connected subgraph of \(G\).

A graph is locally \((k, l)\)-connected if for each edge \((u, v)\) in the graph there are at least \(l\) edge-disjoint paths of length at most \(k\) joining \(u\) to \(v\).

**Parameters**

- **G** *(NetworkX graph)* – The graph in which to find a maximum locally \((k, l)\)-connected subgraph.
- **k** *(integer)* – The maximum length of paths to consider. A higher number means a looser connectivity requirement.
- **l** *(integer)* – The number of edge-disjoint paths. A higher number means a stricter connectivity requirement.
- **low_memory** *(bool)* – If this is True, this function uses an algorithm that uses slightly more time but less memory.
- **same_as_graph** *(bool)* – If True then return a tuple of the form \((H, is_same)\), where \(H\) is the maximum locally \((k, l)\)-connected subgraph and \(is_same\) is a Boolean representing whether \(G\) is locally \((k, l)\)-connected (and hence, whether \(H\) is simply a copy of the input graph \(G\)).

**Returns** If **same_as_graph** is True, then this function returns a two-tuple as described above. Otherwise, it returns only the maximum locally \((k, l)\)-connected subgraph.

**Return type** NetworkX graph or two-tuple
See also:

\texttt{is_kl_connected()}

References

3.31.2 \texttt{networkx.algorithms.hybrid.is_kl_connected}

\texttt{is_kl_connected(G, k, l, low_memory=False)}

Returns True if and only if $G$ is locally $(k, l)$-connected.

A graph is locally $(k, l)$-connected if for each edge $(u, v)$ in the graph there are at least $l$ edge-disjoint paths of length at most $k$ joining $u$ to $v$.

Parameters

- \texttt{G} (NetworkX graph) – The graph to test for local $(k, l)$-connectedness.
- \texttt{k} (integer) – The maximum length of paths to consider. A higher number means a looser connectivity requirement.
- \texttt{l} (integer) – The number of edge-disjoint paths. A higher number means a stricter connectivity requirement.
- \texttt{low_memory} (bool) – If this is True, this function uses an algorithm that uses slightly more time but less memory.

Returns Whether the graph is locally $(k, l)$-connected subgraph.

Return type \texttt{bool}

See also: \texttt{kl_connected_subgraph()}

References

3.32 Isolates

Functions for identifying isolate (degree zero) nodes.

| \texttt{is_isolate(G, n)} | Determines whether a node is an isolate. |
| \texttt{isolates(G)} | Iterator over isolates in the graph. |

3.32.1 \texttt{networkx.algorithms.isolate.is_isolate}

\texttt{is_isolate(G, n)}

Determines whether a node is an isolate.

An isolate is a node with no neighbors (that is, with degree zero). For directed graphs, this means no in-neighbors and no out-neighbors.

Parameters

- \texttt{G} (NetworkX graph)
- \texttt{n} (node) – A node in $G$. 

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Returns **isolate** – True if and only if \( n \) has no neighbors.

Return type **bool**

### Examples

```python
>>> G = nx.Graph()
>>> G.add_edge(1, 2)
>>> G.add_node(3)
>>> nx.is_isolate(G, 2)
False
>>> nx.is_isolate(G, 3)
True
```

#### 3.32.2 networkx.algorithms.isolate.isolates

**isolates** *(G)*

Iterator over isolates in the graph.

An isolate is a node with no neighbors (that is, with degree zero). For directed graphs, this means no in-neighbors and no out-neighbors.

**Parameters**

- **G** *(NetworkX graph)*

**Returns**

An iterator over the isolates of \( G \).

**Return type** **iterator**

### Examples

To get a list of all isolates of a graph, use the `list` constructor:

```python
>>> G = nx.Graph()
>>> G.add_edge(1, 2)
>>> G.add_node(3)
>>> list(nx.isolates(G))
[3]
```

To remove all isolates in the graph, first create a list of the isolates, then use `Graph.remove_nodes_from()`:

```python
>>> G.remove_nodes_from(list(nx.isolates(G)))
>>> list(G)
[1, 2]
```

For digraphs, isolates have zero in-degree and zero out_degree:

```python
>>> G = nx.DiGraph([(0, 1), (1, 2)])
>>> G.add_node(3)
>>> list(nx.isolates(G))
[3]
```
### 3.33 Isomorphism

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
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<tbody>
<tr>
<td><code>is_isomorphic(G1, G2[, node_match, edge_match])</code></td>
<td>Returns True if the graphs G1 and G2 are isomorphic and False otherwise.</td>
</tr>
<tr>
<td><code>could_be_isomorphic(G1, G2)</code></td>
<td>Returns False if graphs are definitely not isomorphic.</td>
</tr>
<tr>
<td><code>fast_could_be_isomorphic(G1, G2)</code></td>
<td>Returns False if graphs are definitely not isomorphic.</td>
</tr>
<tr>
<td><code>faster_could_be_isomorphic(G1, G2)</code></td>
<td>Returns False if graphs are definitely not isomorphic.</td>
</tr>
</tbody>
</table>

#### 3.33.1 networkx.algorithms.isomorphism.is_isomorphic

`is_isomorphic(G1, G2, node_match=None, edge_match=None)`

Returns True if the graphs G1 and G2 are isomorphic and False otherwise.

**Parameters**

- **G1, G2 (graphs)** – The two graphs G1 and G2 must be the same type.
- **node_match (callable)** – A function that returns True if node n1 in G1 and n2 in G2 should be considered equal during the isomorphism test. If node_match is not specified then node attributes are not considered.
  
  The function will be called like
  
  `node_match(G1.nodes[n1], G2.nodes[n2])`.

  That is, the function will receive the node attribute dictionaries for n1 and n2 as inputs.
- **edge_match (callable)** – A function that returns True if the edge attribute dictionary for the pair of nodes (u1, v1) in G1 and (u2, v2) in G2 should be considered equal during the isomorphism test. If edge_match is not specified then edge attributes are not considered.
  
  The function will be called like
  
  `edge_match(G1[u1][v1], G2[u2][v2])`.

  That is, the function will receive the edge attribute dictionaries of the edges under consideration.

**Notes**

Uses the vf2 algorithm\(^1\).

**Examples**

```python
>>> import networkx.algorithms.isomorphism as iso
```

For digraphs G1 and G2, using ‘weight’ edge attribute (default: 1)

```python
>>> G1 = nx.DiGraph()  
>>> G2 = nx.DiGraph()  
>>> nx.add_path(G1, [1, 2, 3, 4], weight=1)  
>>> nx.add_path(G2, [10, 20, 30, 40], weight=2)
```

---

```python
>>> em = iso.numerical_edge_match('weight', 1)
>>> nx.is_isomorphic(G1, G2)  # no weights considered
True
>>> nx.is_isomorphic(G1, G2, edge_match=em)  # match weights
False
```

For multidigraphs G1 and G2, using ‘fill’ node attribute (default: ‘’)
```python
>>> G1 = nx.MultiDiGraph()
>>> G2 = nx.MultiDiGraph()
>>> G1.add_nodes_from([1,2,3], fill='red')
>>> G2.add_nodes_from([10,20,30,40], fill='red')
>>> nx.add_path(G1, [1,2,3,4], weight=3, linewidth=2.5)
>>> nx.add_path(G2, [10,20,30,40], weight=3)
>>> nm = iso.categorical_node_match('fill', 'red')
>>> nx.is_isomorphic(G1, G2, node_match=nm)
True
```

For multidigraphs G1 and G2, using ‘weight’ edge attribute (default: 7)
```python
>>> G1.add_edge(1,2, weight=7)
1
>>> G2.add_edge(10,20)
1
>>> em = iso.numerical_multiedge_match('weight', 7, rtol=1e-6)
>>> nx.is_isomorphic(G1, G2, edge_match=em)
True
```

For multigraphs G1 and G2, using ‘weight’ and ‘linewidth’ edge attributes with default values 7 and 2.5. Also using ‘fill’ node attribute with default value ‘red’.
```python
>>> em = iso.numerical_multiedge_match(['weight', 'linewidth'], [7, 2.5])
>>> nm = iso.categorical_node_match('fill', 'red')
>>> nx.is_isomorphic(G1, G2, edge_match=em, node_match=nm)
True
```

See also:
- `numerical_node_match()`, `numerical_edge_match()`, `numerical_multiedge_match()`
- `categorical_node_match()`, `categorical_edge_match()`, `categorical_multiedge_match()`

References

3.33.2 `networkx.algorithms.isomorphism.could_be_isomorphic`

could_be_isomorphic(G1, G2)
Returns False if graphs are definitely not isomorphic. True does NOT guarantee isomorphism.

Parameters  
G1, G2 (graphs) – The two graphs G1 and G2 must be the same type.

Notes

Checks for matching degree, triangle, and number of cliques sequences.
3.33.3 networkx.algorithms.isomorphism.fast_could_be_isomorphic

**fast_could_be_isomorphic**(*G1, G2*)

Returns False if graphs are definitely not isomorphic.

True does NOT guarantee isomorphism.

**Parameters** G1, G2 (*graphs*) – The two graphs G1 and G2 must be the same type.

**Notes**

Checks for matching degree and triangle sequences.

3.33.4 networkx.algorithms.isomorphism.faster_could_be_isomorphic

**faster_could_be_isomorphic**(*G1, G2*)

Returns False if graphs are definitely not isomorphic.

True does NOT guarantee isomorphism.

**Parameters** G1, G2 (*graphs*) – The two graphs G1 and G2 must be the same type.

**Notes**

Checks for matching degree sequences.

3.33.5 Advanced Interface to VF2 Algorithm

**VF2 Algorithm**

An implementation of VF2 algorithm for graph isomorphism testing.

The simplest interface to use this module is to call networkx.is_isomorphic().

**Introduction**

The GraphMatcher and DiGraphMatcher are responsible for matching graphs or directed graphs in a predetermined manner. This usually means a check for an isomorphism, though other checks are also possible. For example, a subgraph of one graph can be checked for isomorphism to a second graph.

Matching is done via syntactic feasibility. It is also possible to check for semantic feasibility. Feasibility, then, is defined as the logical AND of the two functions.

To include a semantic check, the (Di)GraphMatcher class should be subclassed, and the semantic_feasibility() function should be redefined. By default, the semantic feasibility function always returns True. The effect of this is that semantics are not considered in the matching of G1 and G2.
Examples

Suppose G1 and G2 are isomorphic graphs. Verification is as follows:

```
>>> from networkx.algorithms import isomorphism
>>> G1 = nx.path_graph(4)
>>> G2 = nx.path_graph(4)
>>> GM = isomorphism.GraphMatcher(G1,G2)
>>> GM.is_isomorphic()
True
```

GM.mapping stores the isomorphism mapping from G1 to G2.

```
>>> GM.mapping
{0: 0, 1: 1, 2: 2, 3: 3}
```

Suppose G1 and G2 are isomorphic directed graphs graphs. Verification is as follows:

```
>>> G1 = nx.path_graph(4, create_using=nx.DiGraph())
>>> G2 = nx.path_graph(4, create_using=nx.DiGraph())
>>> DiGM = isomorphism.DiGraphMatcher(G1,G2)
>>> DiGM.is_isomorphic()
True
```

DiGM.mapping stores the isomorphism mapping from G1 to G2.

```
>>> DiGM.mapping
{0: 0, 1: 1, 2: 2, 3: 3}
```

Subgraph Isomorphism

Graph theory literature can be ambiguous about the meaning of the above statement, and we seek to clarify it now.

In the VF2 literature, a mapping M is said to be a graph-subgraph isomorphism iff M is an isomorphism between G2 and a subgraph of G1. Thus, to say that G1 and G2 are graph-subgraph isomorphic is to say that a subgraph of G1 is isomorphic to G2.

Other literature uses the phrase ‘subgraph isomorphic’ as in ‘G1 does not have a subgraph isomorphic to G2’. Another use is as an adverb for isomorphic. Thus, to say that G1 and G2 are subgraph isomorphic is to say that a subgraph of G1 is isomorphic to G2.

Finally, the term ‘subgraph’ can have multiple meanings. In this context, ‘subgraph’ always means a ‘node-induced subgraph’. Edge-induced subgraph isomorphisms are not directly supported, but one should be able to perform the check by making use of nx.line_graph(). For subgraphs which are not induced, the term ‘monomorphism’ is preferred over ‘isomorphism’. Currently, it is not possible to check for monomorphisms.

Let G=(N,E) be a graph with a set of nodes N and set of edges E.

- If G’=(N’,E’) is a subgraph, then: N’ is a subset of N E’ is a subset of E
- If G’=(N’,E’) is a node-induced subgraph, then: N’ is a subset of N E’ is the subset of edges in E relating nodes in N’
- If G’=(N’,E’) is an edge-induced subgraph, then: N’ is the subset of nodes in N related by edges in E’ E’ is a subset of E
References


See also:

syntactic_feasibility, semantic_feasibility

Notes

The implementation handles both directed and undirected graphs as well as multigraphs. However, it does require that nodes in the graph are orderable (in addition to the general NetworkX requirement that nodes are hashable). If the nodes in your graph are not orderable, you can convert them to an orderable type (int, for example) by using the networkx.relabel() function. You can store the dictionary of old-to-new node labels to retrieve the original node labels after running the isomorphism algorithm:

```python
>>> G = nx.Graph()
>>> node1, node2 = object(), object()
>>> G.add_nodes_from([node1, node2])
>>> mapping = {k: v for v, k in enumerate(G)}
>>> G = nx.relabel_nodes(G, mapping)
```

In general, the subgraph isomorphism problem is NP-complete whereas the graph isomorphism problem is most likely not NP-complete (although no polynomial-time algorithm is known to exist).

Graph Matcher

```python
GraphMatcher.__init__(G1, G2[, node_match, ...])
Initialize graph matcher.
```

```
GraphMatcher.initialize()
Reinitializes the state of the algorithm.
```

```
GraphMatcher.is_isomorphic()
Returns True if G1 and G2 are isomorphic graphs.
```

```
GraphMatcher.subgraph_is_isomorphic()
Returns True if a subgraph of G1 is isomorphic to G2.
```

```
GraphMatcher.isomorphisms_iter()
Generator over isomorphisms between G1 and G2.
```

```
GraphMatcher.subgraph_isomorphisms_iter()
Generator over isomorphisms between a subgraph of G1 and G2.
```

```
GraphMatcher.candidate_pairs_iter()
Iterator over candidate pairs of nodes in G1 and G2.
```

```
GraphMatcher.match()
Extends the isomorphism mapping.
```

```
GraphMatcher.semantic_feasibility(G1_node, ...)
Returns True if mapping G1_node to G2_node is semantically feasible.
```

```
GraphMatcher.syntactic_feasibility(G1_node, Returns True if adding (G1_node, G2_node) is syntactically feasible.
```

networkx.algorithms.isomorphism.GraphMatcher.__init__

GraphMatcher.__init__(G1, G2, node_match=None, edge_match=None)
Initialize graph matcher.
Parameters

- **G1, G2** (*graph*) – The graphs to be tested.
- **node_match** (*callable*) – A function that returns True iff node \( n1 \) in \( G1 \) and \( n2 \) in \( G2 \) should be considered equal during the isomorphism test. The function will be called like:

```python
def node_match(G1.nodes[n1], G2.nodes[n2])
```

That is, the function will receive the node attribute dictionaries of the nodes under consideration. If None, then no attributes are considered when testing for an isomorphism.

- **edge_match** (*callable*) – A function that returns True iff the edge attribute dictionary for the pair of nodes \( (u1, v1) \) in \( G1 \) and \( (u2, v2) \) in \( G2 \) should be considered equal during the isomorphism test. The function will be called like:

```python
def edge_match(G1[u1][v1], G2[u2][v2])
```

That is, the function will receive the edge attribute dictionaries of the edges under consideration. If None, then no attributes are considered when testing for an isomorphism.

**networkx.algorithms.isomorphism.GraphMatcher.initialize**

```python
GraphMatcher.initialize()
```

Reinitializes the state of the algorithm.

This method should be redefined if using something other than GMState. If only subclassing GraphMatcher, a redefinition is not necessary.

**networkx.algorithms.isomorphism.GraphMatcher.is_isomorphic**

```python
GraphMatcher.is_isomorphic()
```

Returns True if \( G1 \) and \( G2 \) are isomorphic graphs.

**networkx.algorithms.isomorphism.GraphMatcher.subgraph_is_isomorphic**

```python
GraphMatcher.subgraph_is_isomorphic()
```

Returns True if a subgraph of \( G1 \) is isomorphic to \( G2 \).

**networkx.algorithms.isomorphism.GraphMatcher.isomorphisms_iter**

```python
GraphMatcher.isomorphisms_iter()
```

Generator over isomorphisms between \( G1 \) and \( G2 \).

**networkx.algorithms.isomorphism.GraphMatcher.subgraph_isomorphisms_iter**

```python
GraphMatcher.subgraph_isomorphisms_iter()
```

Generator over isomorphisms between a subgraph of \( G1 \) and \( G2 \).
**networkx.algorithms.isomorphism.GraphMatcher.candidate_pairs_iter**

GraphMatcher.candidate_pairs_iter()

Iterator over candidate pairs of nodes in G1 and G2.

**networkx.algorithms.isomorphism.GraphMatcher.match**

GraphMatcher.match()

Extends the isomorphism mapping.

This function is called recursively to determine if a complete isomorphism can be found between G1 and G2. It cleans up the class variables after each recursive call. If an isomorphism is found, we yield the mapping.

**networkx.algorithms.isomorphism.GraphMatcher.semantic_feasibility**

GraphMatcher.semantic_feasibility(G1_node, G2_node)

Returns True if mapping G1_node to G2_node is semantically feasible.

**networkx.algorithms.isomorphism.GraphMatcher.syntactic_feasibility**

GraphMatcher.syntactic_feasibility(G1_node, G2_node)

Returns True if adding (G1_node, G2_node) is syntactically feasible.

This function returns True if it is adding the candidate pair to the current partial isomorphism mapping is allowable. The addition is allowable if the inclusion of the candidate pair does not make it impossible for an isomorphism to be found.

**DiGraph Matcher**

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
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<tbody>
<tr>
<td>DiGraphMatcher.<strong>init</strong>(G1, G2,...)</td>
<td>Initialize graph matcher.</td>
</tr>
<tr>
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<td>Reinitializes the state of the algorithm.</td>
</tr>
<tr>
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<td>Returns True if a subgraph of G1 is isomorphic to G2.</td>
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<tr>
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<td>Iterator over candidate pairs of nodes in G1 and G2.</td>
</tr>
<tr>
<td>DiGraphMatcher.match()</td>
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<tr>
<td>DiGraphMatcher.semantic_feasibility(G1_node,...,)</td>
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</tr>
<tr>
<td>DiGraphMatcher.syntactic_feasibility(...)</td>
<td>Returns True if adding (G1_node, G2_node) is syntactically feasible.</td>
</tr>
</tbody>
</table>

**networkx.algorithms.isomorphism.DiGraphMatcher.__init__**

DiGraphMatcher.__init__(G1, G2, node_match=None, edge_match=None)

Initialize graph matcher.

Parameters
NetworkX Reference, Release 2.2rc1.dev20180319181321

• **G1, G2** *(graph)* – The graphs to be tested.

• **node_match** *(callable)* – A function that returns True iff node n1 in G1 and n2 in G2 should be considered equal during the isomorphism test. The function will be called like:

  ```python
  node_match(G1.nodes[n1], G2.nodes[n2])
  ```

  That is, the function will receive the node attribute dictionaries of the nodes under consideration. If None, then no attributes are considered when testing for an isomorphism.

• **edge_match** *(callable)* – A function that returns True iff the edge attribute dictionary for the pair of nodes (u1, v1) in G1 and (u2, v2) in G2 should be considered equal during the isomorphism test. The function will be called like:

  ```python
  edge_match(G1[u1][v1], G2[u2][v2])
  ```

  That is, the function will receive the edge attribute dictionaries of the edges under consideration. If None, then no attributes are considered when testing for an isomorphism.

**networkx.algorithms.isomorphism.DiGraphMatcher.initialize**

`DiGraphMatcher.initialize()`  
Reinitializes the state of the algorithm.

  This method should be redefined if using something other than DiGMState. If only subclassing GraphMatcher, a redefinition is not necessary.

**networkx.algorithms.isomorphism.DiGraphMatcher.is_isomorphic**

`DiGraphMatcher.is_isomorphic()`  
Returns True if G1 and G2 are isomorphic graphs.

**networkx.algorithms.isomorphism.DiGraphMatcher.subgraph_is_isomorphic**

`DiGraphMatcher.subgraph_is_isomorphic()`  
Returns True if a subgraph of G1 is isomorphic to G2.

**networkx.algorithms.isomorphism.DiGraphMatcher.isomorphisms_iter**

`DiGraphMatcher.isomorphisms_iter()`  
Generator over isomorphisms between G1 and G2.

**networkx.algorithms.isomorphism.DiGraphMatcher.subgraph_isomorphisms_iter**

`DiGraphMatcher.subgraph_isomorphisms_iter()`  
Generator over isomorphisms between a subgraph of G1 and G2.

3.33. Isomorphism
networkx.algorithms.isomorphism.DiGraphMatcher.candidate_pairs_iter

DiGraphMatcher\_.candidate_pairs_iter()  
Iterator over candidate pairs of nodes in G1 and G2.

networkx.algorithms.isomorphism.DiGraphMatcher.match

DiGraphMatcher\_.match()  
Extends the isomorphism mapping.  
This function is called recursively to determine if a complete isomorphism can be found between G1 and G2. It  
cleans up the class variables after each recursive call. If an isomorphism is found, we yield the mapping.

networkx.algorithms.isomorphism.DiGraphMatcher.semantic_feasibility

DiGraphMatcher\_.semantic_feasibility(G1_node, G2_node)  
Returns True if mapping G1_node to G2_node is semantically feasible.

networkx.algorithms.isomorphism.DiGraphMatcher.syntactic_feasibility

DiGraphMatcher\_.syntactic_feasibility(G1_node, G2_node)  
Returns True if adding (G1_node, G2_node) is syntactically feasible.  
This function returns True if it is adding the candidate pair to the current partial isomorphism mapping is  
allowable. The addition is allowable if the inclusion of the candidate pair does not make it impossible for an  
isomorphism to be found.

Match helpers

<table>
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<td>categorical_node_match(attr, default)</td>
<td>Returns a comparison function for a categorical node attribute.</td>
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<td>categorical_edge_match(attr, default)</td>
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<tr>
<td>numerical_node_match(attr, default[, rtol, atol])</td>
<td>Returns a comparison function for a numerical node attribute.</td>
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<td>Returns a comparison function for a numerical edge attribute.</td>
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<tr>
<td>numerical_multiedge_match(attr, default[, ...])</td>
<td>Returns a comparison function for a numerical edge attribute.</td>
</tr>
<tr>
<td>generic_node_match(attr, default, op)</td>
<td>Returns a comparison function for a generic attribute.</td>
</tr>
<tr>
<td>generic_edge_match(attr, default, op)</td>
<td>Returns a comparison function for a generic attribute.</td>
</tr>
<tr>
<td>generic_multiedge_match(attr, default, op)</td>
<td>Returns a comparison function for a generic attribute.</td>
</tr>
</tbody>
</table>

networkx.algorithms.isomorphism.categorical_node_match

categorical_node_match(attr, default)  
Returns a comparison function for a categorical node attribute.
The value(s) of the attr(s) must be hashable and comparable via the == operator since they are placed into a set([]) object. If the sets from G1 and G2 are the same, then the constructed function returns True.

Parameters

- **attr** *(string | list)* – The categorical node attribute to compare, or a list of categorical node attributes to compare.
- **default** *(value | list)* – The default value for the categorical node attribute, or a list of default values for the categorical node attributes.

**Returns** match – The customized, categorical node_match function.

**Return type** function

**Examples**

```python
>>> import networkx.algorithms.isomorphism as iso
>>> nm = iso.categorical_node_match('size', 1)
>>> nm = iso.categorical_node_match(['color', 'size'], ['red', 2])
```

**networkx.algorithms.isomorphism.categorical_edge_match**

categorical_edge_match *(attr, default)*

Returns a comparison function for a categorical edge attribute.

The value(s) of the attr(s) must be hashable and comparable via the == operator since they are placed into a set([]) object. If the sets from G1 and G2 are the same, then the constructed function returns True.

Parameters

- **attr** *(string | list)* – The categorical edge attribute to compare, or a list of categorical edge attributes to compare.
- **default** *(value | list)* – The default value for the categorical edge attribute, or a list of default values for the categorical edge attributes.

**Returns** match – The customized, categorical edge_match function.

**Return type** function

**Examples**

```python
>>> import networkx.algorithms.isomorphism as iso
>>> nm = iso.categorical_edge_match('size', 1)
>>> nm = iso.categorical_edge_match(['color', 'size'], ['red', 2])
```

**networkx.algorithms.isomorphism.categorical_multiedge_match**

categorical_multiedge_match *(attr, default)*

Returns a comparison function for a categorical edge attribute.

The value(s) of the attr(s) must be hashable and comparable via the == operator since they are placed into a set([]) object. If the sets from G1 and G2 are the same, then the constructed function returns True.
Parameters

- **attr (string | list)** – The categorical edge attribute to compare, or a list of categorical edge attributes to compare.
- **default (value | list)** – The default value for the categorical edge attribute, or a list of default values for the categorical edge attributes.

Returns **match** – The customized, categorical `edge_match` function.

Return type **function**

Examples

```python
>>> import networkx.algorithms.isomorphism as iso
>>> nm = iso.categorical_multiedge_match('size', 1)
>>> nm = iso.categorical_multiedge_match(['color', 'size'], ['red', 2])
```

`networkx.algorithms.isomorphism.numerical_node_match`

**numerical_node_match (attr, default, rtol=1e-05, atol=1e-08)**

Returns a comparison function for a numerical node attribute.

The value(s) of the attr(s) must be numerical and sortable. If the sorted list of values from G1 and G2 are the same within some tolerance, then the constructed function returns True.

Parameters

- **attr (string | list)** – The numerical node attribute to compare, or a list of numerical node attributes to compare.
- **default (value | list)** – The default value for the numerical node attribute, or a list of default values for the numerical node attributes.
- **rtol (float)** – The relative error tolerance.
- **atol (float)** – The absolute error tolerance.

Returns **match** – The customized, numerical `node_match` function.

Return type **function**

Examples

```python
>>> import networkx.algorithms.isomorphism as iso
>>> nm = iso.numerical_node_match('weight', 1.0)
>>> nm = iso.numerical_node_match(['weight', 'linewidth'], [.25, .5])
```

`networkx.algorithms.isomorphism.numerical_edge_match`

**numerical_edge_match (attr, default, rtol=1e-05, atol=1e-08)**

Returns a comparison function for a numerical edge attribute.

The value(s) of the attr(s) must be numerical and sortable. If the sorted list of values from G1 and G2 are the same within some tolerance, then the constructed function returns True.

```python
>>> import networkx.algorithms.isomorphism as iso
>>> nm = iso.numerical_edge_match('weight', 1.0)
>>> nm = iso.numerical_edge_match(['weight', 'linewidth'], [.25, .5])
```
Parameters

- **attr** *(string | list)* – The numerical edge attribute to compare, or a list of numerical edge attributes to compare.
- **default** *(value | list)* – The default value for the numerical edge attribute, or a list of default values for the numerical edge attributes.
- **rtol** *(float)* – The relative error tolerance.
- **atol** *(float)* – The absolute error tolerance.

**Returns**  
match – The customized, numerical edge_match function.

**Return type**  
function

**Examples**

```python
>>> import networkx.algorithms.isomorphism as iso
>>> nm = iso.numerical_edge_match('weight', 1.0)
>>> nm = iso.numerical_edge_match(['weight', 'linewidth'], [.25, .5])
```

**networkx.algorithms.isomorphism.numerical_multiedge_match**

**numerical_multiedge_match** *(attr, default, rtol=1e-05, atol=1e-08)*

Returns a comparison function for a numerical edge attribute.

The value(s) of the attr(s) must be numerical and sortable. If the sorted list of values from G1 and G2 are the same within some tolerance, then the constructed function returns True.

**Parameters**

- **attr** *(string | list)* – The numerical edge attribute to compare, or a list of numerical edge attributes to compare.
- **default** *(value | list)* – The default value for the numerical edge attribute, or a list of default values for the numerical edge attributes.
- **rtol** *(float)* – The relative error tolerance.
- **atol** *(float)* – The absolute error tolerance.

**Returns**  
match – The customized, numerical edge_match function.

**Return type**  
function

**Examples**

```python
>>> import networkx.algorithms.isomorphism as iso
>>> nm = iso.numerical_multiedge_match('weight', 1.0)
>>> nm = iso.numerical_multiedge_match(['weight', 'linewidth'], [.25, .5])
```

**networkx.algorithms.isomorphism.generic_node_match**

**generic_node_match** *(attr, default, op)*

Returns a comparison function for a generic attribute.
The value(s) of the attr(s) are compared using the specified operators. If all the attributes are equal, then the constructed function returns True.

**Parameters**

- **attr** *(string | list)* – The node attribute to compare, or a list of node attributes to compare.
- **default** *(value | list)* – The default value for the node attribute, or a list of default values for the node attributes.
- **op** *(callable | list)* – The operator to use when comparing attribute values, or a list of operators to use when comparing values for each attribute.

**Returns** *match* – The customized, generic *node_match* function.

**Return type** *function*

**Examples**

```python
>>> from operator import eq
>>> from networkx.algorithms.isomorphism.matchhelpers import close
>>> from networkx.algorithms.isomorphism import generic_node_match
>>> nm = generic_node_match('weight', 1.0, close)
>>> nm = generic_node_match('color', 'red', eq)
>>> nm = generic_node_match(['weight', 'color'], [1.0, 'red'], [close, eq])
```

**networkx.algorithms.isomorphism.generic_edge_match**

*generic_edge_match* *(attr, default, op)*

Returns a comparison function for a generic attribute.

The value(s) of the attr(s) are compared using the specified operators. If all the attributes are equal, then the constructed function returns True.

**Parameters**

- **attr** *(string | list)* – The edge attribute to compare, or a list of edge attributes to compare.
- **default** *(value | list)* – The default value for the edge attribute, or a list of default values for the edge attributes.
- **op** *(callable | list)* – The operator to use when comparing attribute values, or a list of operators to use when comparing values for each attribute.

**Returns** *match* – The customized, generic *edge_match* function.

**Return type** *function*

**Examples**

```python
>>> from operator import eq
>>> from networkx.algorithms.isomorphism.matchhelpers import close
>>> from networkx.algorithms.isomorphism import generic_edge_match
>>> nm = generic_edge_match('weight', 1.0, close)
>>> nm = generic_edge_match('color', 'red', eq)
>>> nm = generic_edge_match(['weight', 'color'], [1.0, 'red'], [close, eq])
```
networkx.algorithms.isomorphism.generic_multiedge_match

generic_multiedge_match(attr, default, op)

Returns a comparison function for a generic attribute.

The value(s) of the attr(s) are compared using the specified operators. If all the attributes are equal, then the constructed function returns True. Potentially, the constructed edge_match function can be slow since it must verify that no isomorphism exists between the multiedges before it returns False.

Parameters

- **attr** *(string | list)* – The edge attribute to compare, or a list of node attributes to compare.
- **default** *(value | list)* – The default value for the edge attribute, or a list of default values for the edge attributes.
- **op** *(callable | list)* – The operator to use when comparing attribute values, or a list of operators to use when comparing values for each attribute.

Returns **match** – The customized, generic edge_match function.

Return type **function**

Examples

```python
>>> from operator import eq
>>> from networkx.algorithms.isomorphism.matchhelpers import close
>>> from networkx.algorithms.isomorphism import generic_node_match

>>> nm = generic_node_match('weight', 1.0, close)
>>> nm = generic_node_match('color', 'red', eq)
>>> nm = generic_node_match(['weight', 'color'], [1.0, 'red'], [close, eq])
```

3.34 Link Analysis

3.34.1 PageRank

PageRank analysis of graph structure.

```python
pagerank(G[, alpha, personalization, ...])

Return the PageRank of the nodes in the graph.
```

```python
pagerank_numpy(G[, alpha, personalization, ...])

Return the PageRank of the nodes in the graph.
```

```python
pagerank_scipy(G[, alpha, personalization, ...])

Return the PageRank of the nodes in the graph.
```

```python
google_matrix(G[, alpha, personalization, ...])

Return the Google matrix of the graph.
```

networkx.algorithms.link_analysis.pagerank_alg.pagerank

```python
pagerank(G, alpha=0.85, personalization=None, max_iter=100, tol=1e-06, nstart=None, weight='weight', dangling=None)

Return the PageRank of the nodes in the graph.
```

PageRank computes a ranking of the nodes in the graph G based on the structure of the incoming links. It was
originally designed as an algorithm to rank web pages.

Parameters

- **G (graph)** – A NetworkX graph. Undirected graphs will be converted to a directed graph with two directed edges for each undirected edge.
- **alpha (float, optional)** – Damping parameter for PageRank, default=0.85.
- **personalization (dict, optional)** – The “personalization vector” consisting of a dictionary with a key some subset of graph nodes and personalization value each of those. At least one personalization value must be non-zero. If not specified, a nodes personalization value will be zero. By default, a uniform distribution is used.
- **max_iter (integer, optional)** – Maximum number of iterations in power method eigenvalue solver.
- **tol (float, optional)** – Error tolerance used to check convergence in power method solver.
- **nstart (dictionary, optional)** – Starting value of PageRank iteration for each node.
- **weight (key, optional)** – Edge data key to use as weight. If None weights are set to 1.
- **dangling (dict, optional)** – The outedges to be assigned to any “dangling” nodes, i.e., nodes without any outedges. The dict key is the node the outedge points to and the dict value is the weight of that outedge. By default, dangling nodes are given outedges according to the personalization vector (uniform if not specified). This must be selected to result in an irreducible transition matrix (see notes under google_matrix). It may be common to have the dangling dict to be the same as the personalization dict.

**Returns** pagerank – Dictionary of nodes with PageRank as value

**Return type** dictionary

Examples

```python
>>> G = nx.DiGraph(nx.path_graph(4))
>>> pr = nx.pagerank(G, alpha=0.9)
```

Notes

The eigenvector calculation is done by the power iteration method and has no guarantee of convergence. The iteration will stop after an error tolerance of len(G) * tol has been reached. If the number of iterations exceed max_iter, a `networkx.exception.PowerIterationFailedConvergence` exception is raised.

The PageRank algorithm was designed for directed graphs but this algorithm does not check if the input graph is directed and will execute on undirected graphs by converting each edge in the directed graph to two edges.

See also:

`pagerank_numpy()`, `pagerank_scipy()`, `google_matrix()`

**Raises** `PowerIterationFailedConvergence` – If the algorithm fails to converge to the specified tolerance within the specified number of iterations of the power iteration method.
References

networkx.algorithms.link_analysis pagerank Alg pagerank_numpy

**pagerank_numpy** *(G, alpha=0.85, personalization=None, weight='weight', dangling=None)*

Return the PageRank of the nodes in the graph.

PageRank computes a ranking of the nodes in the graph G based on the structure of the incoming links. It was originally designed as an algorithm to rank web pages.

**Parameters**

- **G** *(graph)* – A NetworkX graph. Undirected graphs will be converted to a directed graph with two directed edges for each undirected edge.
- **alpha** *(float, optional)* – Damping parameter for PageRank, default=0.85.
- **personalization** *(dict, optional)* – The “personalization vector” consisting of a dictionary with a key some subset of graph nodes and personalization value each of those. At least one personalization value must be non-zero. If not specified, a nodes personalization value will be zero. By default, a uniform distribution is used.
- **weight** *(key, optional)* – Edge data key to use as weight. If None weights are set to 1.
- **dangling** *(dict, optional)* – The outedges to be assigned to any “dangling” nodes, i.e., nodes without any outedges. The dict key is the node the outedge points to and the dict value is the weight of that outedge. By default, dangling nodes are given outedges according to the personalization vector (uniform if not specified) This must be selected to result in an irreducible transition matrix (see notes under google_matrix). It may be common to have the dangling dict to be the same as the personalization dict.

**Returns** pagerank – Dictionary of nodes with PageRank as value.

**Return type** dictionary

**Examples**

```
>>> G = nx.DiGraph(nx.path_graph(4))
>>> pr = nx.pagerank_numpy(G, alpha=0.9)
```

**Notes**

The eigenvector calculation uses NumPy’s interface to the LAPACK eigenvalue solvers. This will be the fastest and most accurate for small graphs.

This implementation works with Multi(Di)Graphs. For multigraphs the weight between two nodes is set to be the sum of all edge weights between those nodes.

**See also:**

```
pagerank(), pagerank_scipy(), google_matrix()
```
References

networkx.algorithms.link_analysis.pagerank_alg.pagerank_scipy

\textbf{pagerank_scipy} \( (G, \alpha=0.85, \text{personalization=None, max} \_\text{iter}=100, \text{tol}=1e-06, \text{weight}='\text{weight'}, \text{dangling=None}) \)

Return the PageRank of the nodes in the graph.

PageRank computes a ranking of the nodes in the graph \( G \) based on the structure of the incoming links. It was originally designed as an algorithm to rank web pages.

\textbf{Parameters}

- \( G \) (graph) – A NetworkX graph. Undirected graphs will be converted to a directed graph with two directed edges for each undirected edge.
- \( \alpha \) (float, optional) – Damping parameter for PageRank, default=0.85.
- \text{personalization} (dict, optional) – The “personalization vector” consisting of a dictionary with a key some subset of graph nodes and personalization value each of those. At least one personalization value must be non-zero. If not specified, a nodes personalization value will be zero. By default, a uniform distribution is used.
- \text{max} \_\text{iter} (integer, optional) – Maximum number of iterations in power method eigenvalue solver.
- \( \text{tol} \) (float, optional) – Error tolerance used to check convergence in power method solver.
- \text{weight} (key, optional) – Edge data key to use as weight. If None weights are set to 1.
- \text{dangling} (dict, optional) – The outedges to be assigned to any “dangling” nodes, i.e., nodes without any outedges. The dict key is the node the outedge points to and the dict value is the weight of that outedge. By default, dangling nodes are given outedges according to the personalization vector (uniform if not specified) This must be selected to result in an irreducible transition matrix (see notes under google_matrix). It may be common to have the dangling dict to be the same as the personalization dict.

\textbf{Returns} pagerank – Dictionary of nodes with PageRank as value

\textbf{Return type} dictionary

\textbf{Examples}

\begin{verbatim}
>>> G = nx.DiGraph(nx.path_graph(4))
>>> pr = nx.pagerank_scipy(G, alpha=0.9)
\end{verbatim}

\textbf{Notes}

The eigenvector calculation uses power iteration with a SciPy sparse matrix representation.

This implementation works with Multi(Di)Graphs. For multigraphs the weight between two nodes is set to be the sum of all edge weights between those nodes.

\textbf{See also:}

- pagerank()
- pagerank_numpy()
- google_matrix()
Raises `PowerIterationFailedConvergence` – If the algorithm fails to converge to the specified tolerance within the specified number of iterations of the power iteration method.

References

`networkx.algorithms.link_analysis.pagerank_alg.google_matrix`

```python
google_matrix(G, alpha=0.85, personalization=None, nodelist=None, weight='weight', dangling=None)
```

Return the Google matrix of the graph.

Parameters

- \( G \) (graph) – A NetworkX graph. Undirected graphs will be converted to a directed graph with two directed edges for each undirected edge.
- \( \alpha \) (float) – The damping factor.
- `personalization` (dict, optional) – The “personalization vector” consisting of a dictionary with a key some subset of graph nodes and personalization value each of those. At least one personalization value must be non-zero. If not specified, a nodes personalization value will be zero. By default, a uniform distribution is used.
- `nodelist` (list, optional) – The rows and columns are ordered according to the nodes in nodelist. If nodelist is None, then the ordering is produced by G.nodes().
- `weight` (key, optional) – Edge data key to use as weight. If None weights are set to 1.
- `dangling` (dict, optional) – The outedges to be assigned to any “dangling” nodes, i.e., nodes without any outedges. The dict key is the node the outedge points to and the dict value is the weight of that outedge. By default, dangling nodes are given outedges according to the personalization vector (uniform if not specified) This must be selected to result in an irreducible transition matrix (see notes below). It may be common to have the dangling dict to be the same as the personalization dict.

Returns \( A \) – Google matrix of the graph

Return type NumPy matrix

Notes

The matrix returned represents the transition matrix that describes the Markov chain used in PageRank. For PageRank to converge to a unique solution (i.e., a unique stationary distribution in a Markov chain), the transition matrix must be irreducible. In other words, it must be that there exists a path between every pair of nodes in the graph, or else there is the potential of “rank sinks."

This implementation works with Multi(Di)Graphs. For multigraphs the weight between two nodes is set to be the sum of all edge weights between those nodes.

See also:

`pagerank()`, `pagerank_numpy()`, `pagerank_scipy()`

3.34.2 Hits

Hubs and authorities analysis of graph structure.
networkx.algorithms.link_analysis.hits_alg.hits

**hits** *(G, max_iter=100, tol=1e-08, nstart=None, normalized=True)*

Return HITS hubs and authorities values for nodes.

The HITS algorithm computes two numbers for a node. Authorities estimates the node value based on the incoming links. Hubs estimates the node value based on outgoing links.

**Parameters**

- *G* *(graph)* – A NetworkX graph
- *max_iter* *(integer, optional)* – Maximum number of iterations in power method.
- *tol* *(float, optional)* – Error tolerance used to check convergence in power method iteration.
- *nstart* *(dictionary, optional)* – Starting value of each node for power method iteration.
- *normalized* *(bool (default=True))* – Normalize results by the sum of all of the values.

**Returns** *(hubs, authorities)* – Two dictionaries keyed by node containing the hub and authority values.

**Return type** two-tuple of dictionaries

**Raises** PowerIterationFailedConvergence – If the algorithm fails to converge to the specified tolerance within the specified number of iterations of the power iteration method.

**Examples**

```python
>>> G=nx.path_graph(4)
>>> h,a=nx.hits(G)
```

**Notes**

The eigenvector calculation is done by the power iteration method and has no guarantee of convergence. The iteration will stop after max_iter iterations or an error tolerance of number_of_nodes(G)*tol has been reached.

The HITS algorithm was designed for directed graphs but this algorithm does not check if the input graph is directed and will execute on undirected graphs.

**References**

networkx.algorithms.link_analysis.hits_alg.hits_numpy

**hits_numpy** *(G, normalized=True)*

Return HITS hubs and authorities values for nodes.
The HITS algorithm computes two numbers for a node. Authorities estimates the node value based on the incoming links. Hubs estimates the node value based on outgoing links.

**Parameters**

- G (graph) – A NetworkX graph
- normalized (bool (default=True)) – Normalize results by the sum of all of the values.

**Returns** (hubs,authorities) – Two dictionaries keyed by node containing the hub and authority values.

**Return type** two-tuple of dictionaries

**Examples**

```python
>>> G=nx.path_graph(4)
>>> h,a=nx.hits(G)
```

**Notes**

The eigenvector calculation uses NumPy’s interface to LAPACK.

The HITS algorithm was designed for directed graphs but this algorithm does not check if the input graph is directed and will execute on undirected graphs.

**References**

networkx.algorithms.link_analysis.hits_alg.hits_scipy

**hits_scipy** (G, max_iter=100, tol=1e-06, normalized=True)
Return HITS hubs and authorities values for nodes.

The HITS algorithm computes two numbers for a node. Authorities estimates the node value based on the incoming links. Hubs estimates the node value based on outgoing links.

**Parameters**

- G (graph) – A NetworkX graph
- max_iter (integer, optional) – Maximum number of iterations in power method.
- tol (float, optional) – Error tolerance used to check convergence in power method iteration.
- nstart (dictionary, optional) – Starting value of each node for power method iteration.
- normalized (bool (default=True)) – Normalize results by the sum of all of the values.

**Returns** (hubs,authorities) – Two dictionaries keyed by node containing the hub and authority values.

**Return type** two-tuple of dictionaries

**Examples**
Notes

This implementation uses SciPy sparse matrices.

The eigenvector calculation is done by the power iteration method and has no guarantee of convergence. The iteration will stop after max_iter iterations or an error tolerance of number_of_nodes(G)*tol has been reached.

The HITS algorithm was designed for directed graphs but this algorithm does not check if the input graph is directed and will execute on undirected graphs.

Raises: PowerIterationFailedConvergence – If the algorithm fails to converge to the specified tolerance within the specified number of iterations of the power iteration method.

References

networkx.algorithms.link_analysis.hits_alg.hub_matrix

hub_matrix(G, nodelist=None)
Return the HITS hub matrix.

networkx.algorithms.link_analysis.hits_alg.authority_matrix

authority_matrix(G, nodelist=None)
Return the HITS authority matrix.

3.35 Link Prediction

Link prediction algorithms.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>resource_allocation_index(G[, ebunch])</td>
<td>Compute the resource allocation index of all node pairs in ebunch.</td>
</tr>
<tr>
<td>jaccard_coefficient(G[, ebunch])</td>
<td>Compute the Jaccard coefficient of all node pairs in ebunch.</td>
</tr>
<tr>
<td>adamic_adar_index(G[, ebunch])</td>
<td>Compute the Adamic-Adar index of all node pairs in ebunch.</td>
</tr>
<tr>
<td>preferential_attachment(G[, ebunch])</td>
<td>Compute the preferential attachment score of all node pairs in ebunch.</td>
</tr>
<tr>
<td>cn_soundarajan_hopcroft(G[, ebunch, community])</td>
<td>Count the number of common neighbors of all node pairs in ebunch using community information.</td>
</tr>
<tr>
<td>ra_index_soundarajan_hopcroft(G[, ebunch, ...])</td>
<td>Compute the resource allocation index of all node pairs in ebunch using community information.</td>
</tr>
<tr>
<td>within_inter_cluster(G[, ebunch, delta, ...])</td>
<td>Compute the ratio of within- and inter-cluster common neighbors of all node pairs in ebunch.</td>
</tr>
</tbody>
</table>
3.35.1 networkx.algorithms.link_prediction.resource_allocation_index

resource_allocation_index \( (G, \text{ebunch=}=\text{None}) \)
Compute the resource allocation index of all node pairs in ebunch.

Resource allocation index of \( u \) and \( v \) is defined as

\[
\sum_{w \in \Gamma(u) \cap \Gamma(v)} \frac{1}{|\Gamma(w)|}
\]

where \( \Gamma(u) \) denotes the set of neighbors of \( u \).

Parameters

- \( G \) (*graph*) -- A NetworkX undirected graph.
- \( \text{ebunch} \) (*iterable of node pairs, optional (default = None)*) -- Resource allocation index will be computed for each pair of nodes given in the iterable. The pairs must be given as 2-tuples \((u, v)\) where \( u \) and \( v \) are nodes in the graph. If \( \text{ebunch} \) is None then all non-existent edges in the graph will be used. Default value: None.

Returns \( \text{piter} \) -- An iterator of 3-tuples in the form \((u, v, p)\) where \((u, v)\) is a pair of nodes and \( p \) is their resource allocation index.

Return type \( \text{iterator} \)

Examples

```python
>>> import networkx as nx
>>> G = nx.complete_graph(5)
>>> preds = nx.resource_allocation_index(G, [(0, 1), (2, 3)])
>>> for u, v, p in preds:
...     print('%d, %d -> %.8f' % (u, v, p))
... '(0, 1) -> 0.75000000'
... '(2, 3) -> 0.75000000'
```

References

3.35.2 networkx.algorithms.link_prediction.jaccard_coefficient

jaccard_coefficient \( (G, \text{ebunch=}=\text{None}) \)
Compute the Jaccard coefficient of all node pairs in ebunch.

Jaccard coefficient of nodes \( u \) and \( v \) is defined as

\[
\frac{|\Gamma(u) \cap \Gamma(v)|}{|\Gamma(u) \cup \Gamma(v)|}
\]

where \( \Gamma(u) \) denotes the set of neighbors of \( u \).

Parameters

- \( G \) (*graph*) -- A NetworkX undirected graph.
- \( \text{ebunch} \) (*iterable of node pairs, optional (default = None)*) -- Jaccard coefficient will be computed for each pair of nodes given in the iterable. The pairs must be given as 2-tuples \((u, v)\) where \( u \) and \( v \) are nodes in the graph. If \( \text{ebunch} \) is None then all non-existent edges in the graph will be used. Default value: None.
NetworkX Reference, Release 2.2rc1.dev20180319181321

Returns piter – An iterator of 3-tuples in the form \((u, v, p)\) where \((u, v)\) is a pair of nodes and \(p\) is their Jaccard coefficient.

Return type iterator

Examples

```python
>>> import networkx as nx
>>> G = nx.complete_graph(5)
>>> preds = nx.jaccard_coefficient(G, [(0, 1), (2, 3)])
>>> for u, v, p in preds:
...     print('(%.d, %.d) -> %.8f' % (u, v, p))
...(0, 1) -> 0.60000000
...(2, 3) -> 0.60000000
```

References

3.35.3 networkx.algorithms.link_prediction.adamic_adar_index

adamic_adar_index \((G, ebunch=None)\)

Compute the Adamic-Adar index of all node pairs in ebunch.

Adamic-Adar index of \(u\) and \(v\) is defined as

\[
\sum_{w \in \Gamma(u) \cap \Gamma(v)} \frac{1}{\log |\Gamma(w)|}
\]

where \(\Gamma(u)\) denotes the set of neighbors of \(u\).

Parameters

- \(G\) (graph) – NetworkX undirected graph.
- \(ebunch\) (iterable of node pairs, optional (default = None)) – Adamic-Adar index will be computed for each pair of nodes given in the iterable. The pairs must be given as 2-tuples \((u, v)\) where \(u\) and \(v\) are nodes in the graph. If ebunch is None then all non-existent edges in the graph will be used. Default value: None.

Returns piter – An iterator of 3-tuples in the form \((u, v, p)\) where \((u, v)\) is a pair of nodes and \(p\) is their Adamic-Adar index.

Return type iterator

Examples

```python
>>> import networkx as nx
>>> G = nx.complete_graph(5)
>>> preds = nx.adamic_adar_index(G, [(0, 1), (2, 3)])
>>> for u, v, p in preds:
...     print('(%.d, %.d) -> %.8f' % (u, v, p))
...(0, 1) -> 2.16404256
...(2, 3) -> 2.16404256
```
References

3.35.4 networkx.algorithms.link_prediction.preferential_attachment

preferential_attachment \((G, ebunch=None)\)

Compute the preferential attachment score of all node pairs in ebunch.

Preferential attachment score of \(u\) and \(v\) is defined as

\[ |\Gamma(u)||\Gamma(v)| \]

where \(\Gamma(u)\) denotes the set of neighbors of \(u\).

Parameters

- \(G\) (graph) – NetworkX undirected graph.
- \(ebunch\) (iterable of node pairs, optional (default = None)) – Preferential attachment score will be computed for each pair of nodes given in the iterable. The pairs must be given as 2-tuples \((u, v)\) where \(u\) and \(v\) are nodes in the graph. If \(ebunch\) is None then all non-existent edges in the graph will be used. Default value: None.

Returns \(piter\) – An iterator of 3-tuples in the form \((u, v, p)\) where \((u, v)\) is a pair of nodes and \(p\) is their preferential attachment score.

Return type iterator

Examples

```python
>>> import networkx as nx
>>> G = nx.complete_graph(5)
>>> preds = nx.preferential_attachment(G, [(0, 1), (2, 3)])
>>> for u, v, p in preds:
...     print('(%d, %d) -> %d' % (u, v, p))
...     ...
'(0, 1) -> 16'
'(2, 3) -> 16'
```

References

3.35.5 networkx.algorithms.link_prediction.cn_soundarajan_hopcroft

cn_soundarajan_hopcroft \((G, ebunch=None, community='community')\)

Count the number of common neighbors of all node pairs in ebunch using community information.

For two nodes \(u\) and \(v\), this function computes the number of common neighbors and bonus one for each common neighbor belonging to the same community as \(u\) and \(v\). Mathematically,

\[ |\Gamma(u) \cap \Gamma(v)| + \sum_{w \in \Gamma(u) \cap \Gamma(v)} f(w) \]

where \(f(w)\) equals 1 if \(w\) belongs to the same community as \(u\) and \(v\) or 0 otherwise and \(\Gamma(u)\) denotes the set of neighbors of \(u\).

Parameters
• **G (graph)** – A NetworkX undirected graph.

• **ebunch (iterable of node pairs, optional (default = None))** – The score will be computed for each pair of nodes given in the iterable. The pairs must be given as 2-tuples (u, v) where u and v are nodes in the graph. If ebunch is None then all non-existent edges in the graph will be used. Default value: None.

• **community (string, optional (default = ‘community’))** – Nodes attribute name containing the community information. G[u][community] identifies which community u belongs to. Each node belongs to at most one community. Default value: ‘community’.

**Returns piter** – An iterator of 3-tuples in the form (u, v, p) where (u, v) is a pair of nodes and p is their score.

**Return type** iterator

**Examples**

```python
>>> import networkx as nx
>>> G = nx.path_graph(3)
>>> G.nodes[0]['community'] = 0
>>> G.nodes[1]['community'] = 0
>>> G.nodes[2]['community'] = 0
>>> preds = nx.cn_soundarajan_hopcroft(G, [(0, 2)])
>>> for u, v, p in preds:
...     print('(%d, %d) -> %d' % (u, v, p))
'0, 2 -> 2'
```

**References**

3.35.6 networkx.algorithms.link_prediction.ra_index_soundarajan_hopcroft

ra_index_soundarajan_hopcroft (G, ebunch=None, community='community')

Compute the resource allocation index of all node pairs in ebunch using community information.

For two nodes u and v, this function computes the resource allocation index considering only common neighbors belonging to the same community as u and v. Mathematically,

\[
\sum_{w \in \Gamma(u) \cap \Gamma(v)} \frac{f(w)}{\Gamma(w)}
\]

where \(f(w)\) equals 1 if w belongs to the same community as u and v or 0 otherwise and \(\Gamma(u)\) denotes the set of neighbors of u.

**Parameters**

• **G (graph)** – A NetworkX undirected graph.

• **ebunch (iterable of node pairs, optional (default = None))** – The score will be computed for each pair of nodes given in the iterable. The pairs must be given as 2-tuples (u, v) where u and v are nodes in the graph. If ebunch is None then all non-existent edges in the graph will be used. Default value: None.

• **community (string, optional (default = ‘community’))** – Nodes attribute name containing the community information. G[u][community] identifies which community u belongs to. Each node belongs to at most one community. Default value: ‘community’.
Returns `piter` – An iterator of 3-tuples in the form (u, v, p) where (u, v) is a pair of nodes and p is their score.

Return type  iterator

Examples

```python
>>> import networkx as nx
>>> G = nx.Graph()
>>> G.add_edges_from([(0, 1), (0, 2), (1, 3), (2, 3)])
>>> G.nodes[0]['community'] = 0
>>> G.nodes[1]['community'] = 0
>>> G.nodes[2]['community'] = 1
>>> G.nodes[3]['community'] = 0
>>> preds = nx.ra_index_soundarajan_hopcroft(G, [(0, 3)])
>>> for u, v, p in preds:
...     '(%d, %d) -> %.8f' % (u, v, p)
'(0, 3) -> 0.50000000'
```

References

3.35.7 `networkx.algorithms.link_prediction.within_inter_cluster`

`within_inter_cluster(G, ebunch=None, delta=0.001, community='community')`

Compute the ratio of within- and inter-cluster common neighbors of all node pairs in ebunch.

For two nodes u and v, if a common neighbor w belongs to the same community as them, w is considered as within-cluster common neighbor of u and v. Otherwise, it is considered as inter-cluster common neighbor of u and v. The ratio between the size of the set of within- and inter-cluster common neighbors is defined as the WIC measure.¹

Parameters

- `G (graph)` – A NetworkX undirected graph.
- `ebunch (iterable of node pairs, optional (default = None))` – The WIC measure will be computed for each pair of nodes given in the iterable. The pairs must be given as 2-tuples (u, v) where u and v are nodes in the graph. If ebunch is None then all non-existent edges in the graph will be used. Default value: None.
- `delta (float, optional (default = 0.001))` – Value to prevent division by zero in case there is no inter-cluster common neighbor between two nodes. See¹ for details. Default value: 0.001.
- `community (string, optional (default = ‘community’))` – Nodes attribute name containing the community information. G[u][community] identifies which community u belongs to. Each node belongs to at most one community. Default value: ‘community’.

Returns `piter` – An iterator of 3-tuples in the form (u, v, p) where (u, v) is a pair of nodes and p is their WIC measure.

Return type  iterator

Examples

```python
>>> import networkx as nx
>>> G = nx.Graph()
>>> G.add_edges_from([(0, 1), (0, 2), (0, 3), (1, 4), (2, 4), (3, 4)])
>>> G.nodes[0]['community'] = 0
>>> G.nodes[1]['community'] = 1
>>> G.nodes[2]['community'] = 0
>>> G.nodes[3]['community'] = 0
>>> G.nodes[4]['community'] = 0
>>> preds = nx.within_inter_cluster(G, [(0, 4)])
>>> for u, v, p in preds:
...     print('(%d, %d) -> %.8f' % (u, v, p))
...     print('(0, 4) -> 1.99800200')
>>> preds = nx.within_inter_cluster(G, [(0, 4)], delta=0.5)
>>> for u, v, p in preds:
...     print('(%d, %d) -> %.8f' % (u, v, p))
...     print('(0, 4) -> 1.33333333')
```

References

### 3.36 Matching

Functions for computing and verifying matchings in a graph.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
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<tr>
<td><code>is_matching(G, matching)</code></td>
<td>Decides whether the given set or dictionary represents a valid matching in G.</td>
</tr>
<tr>
<td><code>is_maximal_matching(G, matching)</code></td>
<td>Decides whether the given set or dictionary represents a valid maximal matching in G.</td>
</tr>
<tr>
<td><code>maximal_matching(G)</code></td>
<td>Find a maximal matching in the graph.</td>
</tr>
<tr>
<td><code>max_weight_matching(G[, maxcardinality, weight])</code></td>
<td>Compute a maximum-weighted matching of G.</td>
</tr>
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#### 3.36.1 networkx.algorithms.matching.is_matching

`is_matching(G, matching)`

Decides whether the given set or dictionary represents a valid matching in G.

A matching in a graph is a set of edges in which no two distinct edges share a common endpoint.

**Parameters**

- **G** (*NetworkX graph*)
- **matching** (*dict or set*) – A dictionary or set representing a matching. If a dictionary, it must have `matching[u] == v` and `matching[v] == u` for each edge `(u, v)` in the matching. If a set, it must have elements of the form `(u, v)`, where `(u, v)` is an edge in the matching.

**Returns**  Whether the given set or dictionary represents a valid matching in the graph.

**Return type**  `bool`
### 3.36.2 networkx.algorithms.matching.is_maximal_matching

**is_maximal_matching** *(G, matching)*

Decides whether the given set or dictionary represents a valid maximal matching in G.

A maximal matching in a graph is a matching in which adding any edge would cause the set to no longer be a valid matching.

**Parameters**

- **G** *(NetworkX graph)*
- **matching** *(dict or set)* – A dictionary or set representing a matching. If a dictionary, it must have `matching[u] == v` and `matching[v] == u` for each edge `(u, v)` in the matching. If a set, it must have elements of the form `(u, v)`, where `(u, v)` is an edge in the matching.

**Returns** Whether the given set or dictionary represents a valid maximal matching in the graph.

**Return type** bool

### 3.36.3 networkx.algorithms.matching.maximal_matching

**maximal_matching** *(G)*

Find a maximal matching in the graph.

A matching is a subset of edges in which no node occurs more than once. A maximal matching cannot add more edges and still be a matching.

**Parameters**

- **G** *(NetworkX graph)* – Undirected graph

**Returns** matching – A maximal matching of the graph.

**Return type** set

**Notes**

The algorithm greedily selects a maximal matching M of the graph G (i.e. no superset of M exists). It runs in $O(|E|)$ time.

### 3.36.4 networkx.algorithms.matching.max_weight_matching

**max_weight_matching** *(G, maxcardinality=False, weight='weight')*

Compute a maximum-weighted matching of G.

A matching is a subset of edges in which no node occurs more than once. The weight of a matching is the sum of the weights of its edges. A maximal matching cannot add more edges and still be a matching. The cardinality of a matching is the number of matched edges.

**Parameters**

- **G** *(NetworkX graph)* – Undirected graph
- **maxcardinality** *(bool, optional (default=False))* – If maxcardinality is True, compute the maximum-cardinality matching with maximum weight among all maximum-cardinality matchings.
- **weight** *(string, optional (default='weight'))* – Edge data key corresponding to the edge weight. If key not found, uses 1 as weight.
Returns matching – A maximal matching of the graph.

Return type set

Notes

If G has edges with weight attributes the edge data are used as weight values else the weights are assumed to be 1.

This function takes time \(O(\text{number_of_nodes}^3)\).

If all edge weights are integers, the algorithm uses only integer computations. If floating point weights are used, the algorithm could return a slightly suboptimal matching due to numeric precision errors.

This method is based on the “blossom” method for finding augmenting paths and the “primal-dual” method for finding a matching of maximum weight, both methods invented by Jack Edmonds\(^1\).

Bipartite graphs can also be matched using the functions present in networkx.algorithms.bipartite.matching.

References

3.37 Minors

Provides functions for computing minors of a graph.

| contracted_edge(G, edge[, self_loops]) | Returns the graph that results from contracting the specified edge. |
| contracted_nodes(G, u, v[, self_loops]) | Returns the graph that results from contracting \(u\) and \(v\). |
| identified_nodes(G, u, v[, self_loops]) | Returns the graph that results from contracting \(u\) and \(v\). |
| quotient_graph(G, partition[, …]) | Returns the quotient graph of \(G\) under the specified equivalence relation on nodes. |

3.37.1 networkx.algorithms.minors.contracted_edge

contracted_edge \((G, \text{edge}, \text{self_loops}=\text{True})\)

Returns the graph that results from contracting the specified edge.

Edge contraction identifies the two endpoints of the edge as a single node incident to any edge that was incident to the original two nodes. A graph that results from edge contraction is called a minor of the original graph.

Parameters

- \(G\) (NetworkX graph) – The graph whose edge will be contracted.
- \(\text{edge}\) (tuple) – Must be a pair of nodes in \(G\).
- \(\text{self_loops}\) (Boolean) – If this is True, any edges (including \(\text{edge}\)) joining the endpoints of \(\text{edge}\) in \(G\) become self-loops on the new node in the returned graph.

Returns A new graph object of the same type as \(G\) (leaving \(G\) unmodified) with endpoints of \(\text{edge}\) identified in a single node. The right node of \(\text{edge}\) will be merged into the left one, so only the left one will appear in the returned graph.

Return type  Networkx graph

Raises  ValueError – If edge is not an edge in G.

Examples

Attempting to contract two nonadjacent nodes yields an error:

```python
>>> import networkx as nx
>>> G = nx.cycle_graph(4)
>>> nx.contracted_edge(G, (1, 3))
Traceback (most recent call last):
  ...
ValueError: Edge (1, 3) does not exist in graph G; cannot contract it
```

Contracting two adjacent nodes in the cycle graph on $n$ nodes yields the cycle graph on $n - 1$ nodes:

```python
>>> import networkx as nx
>>> C5 = nx.cycle_graph(5)
>>> C4 = nx.cycle_graph(4)
>>> M = nx.contracted_edge(C5, (0, 1), self_loops=False)
>>> nx.is_isomorphic(M, C4)
True
```

See also:

`contracted_nodes()`, `quotient_graph()`

## 3.37.2 networkx.algorithms.minors.contracted_nodes

`contracted_nodes(G, u, v, self_loops=True)`

Returns the graph that results from contracting $u$ and $v$.

Node contraction identifies the two nodes as a single node incident to any edge that was incident to the original two nodes.

**Parameters**

- $G$ (*NetworkX graph*) – The graph whose nodes will be contracted.
- $u, v$ (*nodes*) – Must be nodes in $G$.
- `self_loops` (*Boolean*) – If this is True, any edges joining $u$ and $v$ in $G$ become self-loops on the new node in the returned graph.

**Returns**  A new graph object of the same type as $G$ (leaving $G$ unmodified) with $u$ and $v$ identified in a single node. The right node $v$ will be merged into the node $u$, so only $u$ will appear in the returned graph.

**Return type**  Networkx graph

**Notes**

For multigraphs, the edge keys for the realigned edges may not be the same as the edge keys for the old edges. This is natural because edge keys are unique only within each pair of nodes.
Examples

Contracting two nonadjacent nodes of the cycle graph on four nodes \( C_4 \) yields the path graph (ignoring parallel edges):

```python
>>> G = nx.cycle_graph(4)
>>> M = nx.contracted_nodes(G, 1, 3)
>>> P3 = nx.path_graph(3)
>>> nx.is_isomorphic(M, P3)
True

>>> G = nx.MultiGraph(P3)
>>> M = nx.contracted_nodes(G, 0, 2)
>>> M.edges
MultiEdgeView([(0, 1, 0), (0, 1, 1)])

>>> G = nx.Graph([(1,2), (2,2)])
>>> H = nx.contracted_nodes(G, 1, 2, self_loops=False)
>>> list(H.nodes())
[1]
>>> list(H.edges())
[(1, 1)]
```

See also:

`contracted_edge()`, `quotient_graph()`

Notes

This function is also available as `identified_nodes`.

3.37.3 `networkx.algorithms.minors.identified_nodes`

`identified_nodes(G, u, v, self_loops=True)`

Returns the graph that results from contracting \( u \) and \( v \).

Node contraction identifies the two nodes as a single node incident to any edge that was incident to the original two nodes.

Parameters

- \( G \) (NetworkX graph) – The graph whose nodes will be contracted.
- \( u, v \) (nodes) – Must be nodes in \( G \).
- `self_loops` (Boolean) – If this is True, any edges joining \( u \) and \( v \) in \( G \) become self-loops on the new node in the returned graph.

Returns A new graph object of the same type as \( G \) (leaving \( G \) unmodified) with \( u \) and \( v \) identified in a single node. The right node \( v \) will be merged into the node \( u \), so only \( u \) will appear in the returned graph.

Return type Networkx graph
Notes

For multigraphs, the edge keys for the realigned edges may not be the same as the edge keys for the old edges. This is natural because edge keys are unique only within each pair of nodes.

Examples

Contracting two nonadjacent nodes of the cycle graph on four nodes $C_4$ yields the path graph (ignoring parallel edges):

```python
>>> G = nx.cycle_graph(4)
>>> M = nx.contracted_nodes(G, 1, 3)
>>> P3 = nx.path_graph(3)
>>> nx.is_isomorphic(M, P3)
True

>>> G = nx.MultiGraph(P3)
>>> M = nx.contracted_nodes(G, 0, 2)
>>> M.edges
MultiEdgeView([(0, 1, 0), (0, 1, 1)])

>>> G = nx.Graph([(1,2), (2,2)])
>>> H = nx.contracted_nodes(G, 1, 2, self_loops=False)
>>> list(H.nodes())
[1]
>>> list(H.edges())
[(1, 1)]
```

See also:

`contracted_edge()`, `quotient_graph()`

Notes

This function is also available as `identified_nodes`.

3.37.4 `networkx.algorithms.minors.quotient_graph`

`quotient_graph(G, partition, edge_relation=None, node_data=None, edge_data=None, relabel=False, create_using=None)`

Returns the quotient graph of $G$ under the specified equivalence relation on nodes.

Parameters

- **G** (*NetworkX graph*) – The graph for which to return the quotient graph with the specified node relation.

- **partition** (*function or list of sets*) – If a function, this function must represent an equivalence relation on the nodes of $G$. It must take two arguments $u$ and $v$ and return True exactly when $u$ and $v$ are in the same equivalence class. The equivalence classes form the nodes in the returned graph.

  If a list of sets, the list must form a valid partition of the nodes of the graph. That is, each node must be in exactly one block of the partition.

- **edge_relation** (*function*) – A two-argument function that takes two edges $(u, v)$ and $(x, y)$ and returns True if they are related by the specified relation. This relation must be an equivalence relation.

- **node_data** (*dictionary*) – If specified, this dictionary is attached as a “node_data” attribute to the returned graph.

- **edge_data** (*dictionary*) – If specified, this dictionary is attached as an “edge_data” attribute to the returned graph.

- **relabel** (*Boolean*) – If True, returned graph’s node labels are relabeled to be unique integers ranging from 0 to $|V(G)| - 1$, where $V(G)$ is the set of nodes in $G$.

- **create_using** (*NetworkX graph class*) – If specified, returns a graph of this class, instead of a `NetworkX` graph object.


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• **edge_relation** *(Boolean function with two arguments)* – This function must represent an edge relation on the blocks of \( G \) in the partition induced by \( \text{node_relation} \). It must take two arguments, \( B \) and \( C \), each one a set of nodes, and return True exactly when there should be an edge joining block \( B \) to block \( C \) in the returned graph.

If \( \text{edge_relation} \) is not specified, it is assumed to be the following relation. Block \( B \) is related to block \( C \) if and only if some node in \( B \) is adjacent to some node in \( C \), according to the edge set of \( G \).

• **edge_data** *(function)* – This function takes two arguments, \( B \) and \( C \), each one a set of nodes, and must return a dictionary representing the edge data attributes to set on the edge joining \( B \) and \( C \), should there be an edge joining \( B \) and \( C \) in the quotient graph (if no such edge occurs in the quotient graph as determined by \( \text{edge_relation} \), then the output of this function is ignored).

If the quotient graph would be a multigraph, this function is not applied, since the edge data from each edge in the graph \( G \) appears in the edges of the quotient graph.

• **node_data** *(function)* – This function takes one argument, \( B \), a set of nodes in \( G \), and must return a dictionary representing the node data attributes to set on the node representing \( B \) in the quotient graph. If None, the following node attributes will be set:

  – ‘graph’, the subgraph of the graph \( G \) that this block represents,
  – ‘nnodes’, the number of nodes in this block,
  – ‘nedges’, the number of edges within this block,
  – ‘density’, the density of the subgraph of \( G \) that this block represents.

• **relabel** *(bool)* – If True, relabel the nodes of the quotient graph to be nonnegative integers. Otherwise, the nodes are identified with \text{frozenset} \ instances representing the blocks given in \( \text{partition} \).

• **create_using** *(NetworkX graph)* – If specified, this must be an instance of a NetworkX graph class. The nodes and edges of the quotient graph will be added to this graph and returned. If not specified, the returned graph will have the same type as the input graph.

**Returns** The quotient graph of \( G \) under the equivalence relation specified by \( \text{partition} \). If the partition were given as a list of \text{set} \ instances and \( \text{relabel} \) is False, each node will be a \text{frozenset} corresponding to the same \text{set}.

**Return type** NetworkX graph

**Raises** NetworkXException – If the given partition is not a valid partition of the nodes of \( G \).

### Examples

The quotient graph of the complete bipartite graph under the “same neighbors” equivalence relation is \( K_2 \). Under this relation, two nodes are equivalent if they are not adjacent but have the same neighbor set:

```python
>>> import networkx as nx
>>> G = nx.complete_bipartite_graph(2, 3)
>>> same_neighbors = lambda u, v: (u not in G[v] and v not in G[u] and G[u] == G[v])
... >>> Q = nx.quotient_graph(G, same_neighbors)
>>> K2 = nx.complete_graph(2)
>>> nx.is_isomorphic(Q, K2)
True
```
The quotient graph of a directed graph under the “same strongly connected component” equivalence relation is the condensation of the graph (see condensation()). This example comes from the Wikipedia article ‘Strongly connected component’:

```python
>>> import networkx as nx
>>> G = nx.DiGraph()
>>> edges = ['ab', 'be', 'bf', 'bc', 'cg', 'cd', 'dc', 'dh', 'ea',
... 'ef', 'fg', 'gf', 'hd', 'hf']
>>> G.add_edges_from(tuple(x) for x in edges)
>>> components = list(nx.strongly_connected_components(G))
>>> sorted(sorted(component) for component in components)
[['a', 'b', 'e'], ['c', 'd', 'h'], ['f', 'g']]

>>> C = nx.condensation(G, components)
>>> component_of = C.graph['mapping']
>>> same_component = lambda u, v: component_of[u] == component_of[v]
>>> Q = nx.quotient_graph(G, same_component)
>>> nx.is_isomorphic(C, Q)
True

Node identification can be represented as the quotient of a graph under the equivalence relation that places the two nodes in one block and each other node in its own singleton block:

```python
>>> import networkx as nx
>>> K24 = nx.complete_bipartite_graph(2, 4)
>>> K34 = nx.complete_bipartite_graph(3, 4)
>>> C = nx.contracted_nodes(K34, 1, 2)
>>> nodes = {1, 2}
>>> is_contracted = lambda u, v: u in nodes and v in nodes
>>> Q = nx.quotient_graph(K34, is_contracted)
>>> nx.is_isomorphic(Q, C)
True
>>> nx.is_isomorphic(Q, K24)
True

The blockmodeling technique described in\(^1\) can be implemented as a quotient graph:

```python
>>> G = nx.path_graph(6)
>>> partition = [{0, 1}, {2, 3}, {4, 5}]
>>> M = nx.quotient_graph(G, partition, relabel=True)
>>> list(M.edges())
[(0, 1), (1, 2)]
```

References

3.38 Maximal independent set

Algorithm to find a maximal (not maximum) independent set.

\[
\text{maximal\_independent\_set}(G[, \text{nodes}])
\]

Return a random maximal independent set guaranteed to contain a given set of nodes.

3.38.1 `networkx.algorithms.mis.maximal_independent_set`

`maximal_independent_set(G, nodes=None)`

Return a random maximal independent set guaranteed to contain a given set of nodes.

An independent set is a set of nodes such that the subgraph of G induced by these nodes contains no edges. A maximal independent set is an independent set such that it is not possible to add a new node and still get an independent set.

**Parameters**

- `G` *(NetworkX graph)*
- `nodes` *(list or iterable)* – Nodes that must be part of the independent set. This set of nodes must be independent.

**Returns** `indep_nodes` – List of nodes that are part of a maximal independent set.

**Return type** list

**Raises**

- `NetworkXUnfeasible` – If the nodes in the provided list are not part of the graph or do not form an independent set, an exception is raised.
- `NetworkXNotImplemented` – If `G` is directed.

**Examples**

```python
>>> G = nx.path_graph(5)
>>> nx.maximal_independent_set(G)
[4, 0, 2]
>>> nx.maximal_independent_set(G, [1])
[1, 3]
```

**Notes**

This algorithm does not solve the maximum independent set problem.

3.39 Operators

Unary operations on graphs

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<th><code>complement(G)</code></th>
<th>Return the graph complement of G.</th>
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<tr>
<td><code>reverse(G[, copy])</code></td>
<td>Return the reverse directed graph of G.</td>
</tr>
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</table>

3.39.1 `networkx.algorithms.operators.unary.complement`

`complement(G)`

Return the graph complement of G.

**Parameters** `G` *(graph)* – A NetworkX graph

**Returns** `GC`
Return type A new graph.

Notes

Note that complement() does not create self-loops and also does not produce parallel edges for MultiGraphs. Graph, node, and edge data are not propagated to the new graph.

3.39.2 networkx.algorithms.operators.unary.reverse

reverse(G, copy=True)

Return the reverse directed graph of G.

Parameters

• G (directed graph) – A NetworkX directed graph

• copy (bool) – If True, then a new graph is returned. If False, then the graph is reversed in place.

Returns H – The reversed G.

Return type directed graph

Operations on graphs including union, intersection, difference.

<table>
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<th>Description</th>
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<td>compose(G, H)</td>
<td>Return a new graph of G composed with H.</td>
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<td>union(G, H[, rename, name])</td>
<td>Return the union of graphs G and H.</td>
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<tr>
<td>disjoint_union(G, H)</td>
<td>Return the disjoint union of graphs G and H.</td>
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<tr>
<td>intersection(G, H)</td>
<td>Return a new graph that contains only the edges that exist in both G and H.</td>
</tr>
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<td>difference(G, H)</td>
<td>Return a new graph that contains the edges that exist in G but not in H.</td>
</tr>
<tr>
<td>symmetric_difference(G, H)</td>
<td>Return new graph with edges that exist in either G or H but not both.</td>
</tr>
</tbody>
</table>

3.39.3 networkx.algorithms.operators.binary.compose

compose(G, H)

Return a new graph of G composed with H.

Composition is the simple union of the node sets and edge sets. The node sets of G and H do not need to be disjoint.

Parameters G, H (graph) – A NetworkX graph

Returns C

Return type A new graph with the same type as G

Notes

It is recommended that G and H be either both directed or both undirected. Attributes from H take precedent over attributes from G.
For MultiGraphs, the edges are identified by incident nodes AND edge-key. This can cause surprises (i.e., edge (1, 2) may or may not be the same in two graphs) if you use MultiGraph without keeping track of edge keys.

### 3.39.4 networkx.algorithms.operators.binary.union

#### union(G, H, rename=None, None), name=None)

Return the union of graphs G and H.

Graphs G and H must be disjoint, otherwise an exception is raised.

**Parameters**

- **G, H (graph)** – A NetworkX graph
- **rename (bool, default=(None, None))** – Node names of G and H can be changed by specifying the tuple rename=('G-','H-') (for example). Node “u” in G is then renamed “G-u” and “v” in H is renamed “H-v”.
- **name (string)** – Specify the name for the union graph

**Returns** U

**Return type** A union graph with the same type as G.

#### Notes

To force a disjoint union with node relabeling, use disjoint_union(G,H) or convert_node_labels_to_integers().

Graph, edge, and node attributes are propagated from G and H to the union graph. If a graph attribute is present in both G and H the value from H is used.

**See also:**

disjoint_union()

### 3.39.5 networkx.algorithms.operators.binary.disjoint_union

#### disjoint_union(G, H)

Return the disjoint union of graphs G and H.

This algorithm forces distinct integer node labels.

**Parameters** G, H (graph) – A NetworkX graph

**Returns** U

**Return type** A union graph with the same type as G.

#### Notes

A new graph is created, of the same class as G. It is recommended that G and H be either both directed or both undirected.

The nodes of G are relabeled 0 to len(G)-1, and the nodes of H are relabeled len(G) to len(G)+len(H)-1.

Graph, edge, and node attributes are propagated from G and H to the union graph. If a graph attribute is present in both G and H the value from H is used.
3.39.6 `networkx.algorithms.operators.binary.intersection`

**intersection** \((G, H)\)

Return a new graph that contains only the edges that exist in both \(G\) and \(H\).

The node sets of \(H\) and \(G\) must be the same.

**Parameters**
\(G, H\) (graph) – A NetworkX graph. \(G\) and \(H\) must have the same node sets.

**Returns**
\(G, H\)

**Return type**
A new graph with the same type as \(G\).

**Notes**

Attributes from the graph, nodes, and edges are not copied to the new graph. If you want a new graph of the intersection of \(G\) and \(H\) with the attributes (including edge data) from \(G\) use `remove_nodes_from()` as follows:

```python
>>> G = nx.path_graph(3)
>>> H = nx.path_graph(5)
>>> R = G.copy()
>>> R.remove_nodes_from(n for n in G if n not in H)
```

3.39.7 `networkx.algorithms.operators.binary.difference`

**difference** \((G, H)\)

Return a new graph that contains the edges that exist in \(G\) but not in \(H\).

The node sets of \(H\) and \(G\) must be the same.

**Parameters**
\(G, H\) (graph) – A NetworkX graph. \(G\) and \(H\) must have the same node sets.

**Returns**
\(D\)

**Return type**
A new graph with the same type as \(G\).

**Notes**

Attributes from the graph, nodes, and edges are not copied to the new graph. If you want a new graph of the difference of \(G\) and \(H\) with with the attributes (including edge data) from \(G\) use `remove_nodes_from()` as follows:

```python
>>> G = nx.path_graph(3)
>>> H = nx.path_graph(5)
>>> R = G.copy()
>>> R.remove_nodes_from(n for n in G if n in H)
```

3.39.8 `networkx.algorithms.operators.binary.symmetric_difference`

**symmetric_difference** \((G, H)\)

Return new graph with edges that exist in either \(G\) or \(H\) but not both.

The node sets of \(H\) and \(G\) must be the same.

**Parameters**
\(G, H\) (graph) – A NetworkX graph. \(G\) and \(H\) must have the same node sets.
Returns D

**Return type** A new graph with the same type as G.

**Notes**

Attributes from the graph, nodes, and edges are not copied to the new graph.

Operations on many graphs.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
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<td>Return the composition of all graphs.</td>
</tr>
<tr>
<td><code>union_all(graphs[, rename])</code></td>
<td>Return the union of all graphs.</td>
</tr>
<tr>
<td><code>disjoint_union_all(graphs)</code></td>
<td>Return the disjoint union of all graphs.</td>
</tr>
<tr>
<td><code>intersection_all(graphs)</code></td>
<td>Return a new graph that contains only the edges that exist in all graphs.</td>
</tr>
</tbody>
</table>

### 3.39.9 networkx.algorithms.operators.all.compose_all

**compose_all** *(graphs)*

Return the composition of all graphs.

Composition is the simple union of the node sets and edge sets. The node sets of the supplied graphs need not be disjoint.

**Parameters**

- **graphs** *(list)* – List of NetworkX graphs

**Returns** C

**Return type** A graph with the same type as the first graph in list

**Notes**

It is recommended that the supplied graphs be either all directed or all undirected.

Graph, edge, and node attributes are propagated to the union graph. If a graph attribute is present in multiple graphs, then the value from the last graph in the list with that attribute is used.

### 3.39.10 networkx.algorithms.operators.all.union_all

**union_all**(graphs, rename=(None, None))

Return the union of all graphs.

The graphs must be disjoint, otherwise an exception is raised.

**Parameters**

- **graphs** *(list of graphs)* – List of NetworkX graphs
- **rename** *(bool, default=(None, None))* – Node names of G and H can be changed by specifying the tuple rename=('G-','H-') (for example). Node “u” in G is then renamed “G-u” and “v” in H is renamed “H-v”.

**Returns** U

**Return type** a graph with the same type as the first graph in list
Notes

To force a disjoint union with node relabeling, use `disjoint_union_all(G,H)` or `convert_node_labels_to_integers()`. Graph, edge, and node attributes are propagated to the union graph. If a graph attribute is present in multiple graphs, then the value from the last graph in the list with that attribute is used.

See also:

`union()`, `disjoint_union_all()`

### 3.39.11 networkx.algorithms.operators.all.disjoint_union_all

`disjoint_union_all(graphs)`

Return the disjoint union of all graphs.

This operation forces distinct integer node labels starting with 0 for the first graph in the list and numbering consecutively.

**Parameters**

`graphs (list)` – List of NetworkX graphs

**Returns**

`U`

**Return type**

A graph with the same type as the first graph in list

Notes

It is recommended that the graphs be either all directed or all undirected.

Graph, edge, and node attributes are propagated to the union graph. If a graph attribute is present in multiple graphs, then the value from the last graph in the list with that attribute is used.

### 3.39.12 networkx.algorithms.operators.all.intersection_all

`intersection_all(graphs)`

Return a new graph that contains only the edges that exist in all graphs.

All supplied graphs must have the same node set.

**Parameters**

`graphs (list)` – List of NetworkX graphs

**Returns**

`R`

**Return type**

A new graph with the same type as the first graph in list

Notes

Attributes from the graph, nodes, and edges are not copied to the new graph.

Graph products.

<table>
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<th>Function</th>
<th>Description</th>
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<tbody>
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<td><code>cartesian_product(G, H)</code></td>
<td>Return the Cartesian product of G and H.</td>
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<tr>
<td><code>lexicographic_product(G, H)</code></td>
<td>Return the lexicographic product of G and H.</td>
</tr>
<tr>
<td><code>strong_product(G, H)</code></td>
<td>Return the strong product of G and H.</td>
</tr>
<tr>
<td><code>tensor_product(G, H)</code></td>
<td>Return the tensor product of G and H.</td>
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</table>
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<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
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<tbody>
<tr>
<td>$\text{power}(G, k)$</td>
<td>Returns the specified power of a graph.</td>
</tr>
</tbody>
</table>

### 3.39.13 networkx.algorithms.operators.product.cartesian_product

#### cartesian_product $(G, H)$

Return the Cartesian product of $G$ and $H$.

The Cartesian product $P$ of the graphs $G$ and $H$ has a node set that is the Cartesian product of the node sets, $V(P) = V(G) \times V(H)$. $P$ has an edge $((u, v), (x, y))$ if and only if either $u$ is equal to $x$ and both $v$ and $y$ are adjacent in $H$ or if $v$ is equal to $y$ and both $u$ and $x$ are adjacent in $G$.

**Parameters**

$G, H$ (graphs) – Networkx graphs.

**Returns**

$P$ – The Cartesian product of $G$ and $H$. $P$ will be a multi-graph if either $G$ or $H$ is a multi-graph. Will be a directed if $G$ and $H$ are directed, and undirected if $G$ and $H$ are undirected.

**Return type**

NetworkX graph

**Raises**

NetworkXError – If $G$ and $H$ are not both directed or both undirected.

### Notes

Node attributes in $P$ are two-tuple of the $G$ and $H$ node attributes. Missing attributes are assigned None.

### Examples

```python
>>> G = nx.Graph()
>>> H = nx.Graph()
>>> G.add_node(0, a1=True)
>>> H.add_node('a', a2='Spam')
>>> P = nx.cartesian_product(G, H)
>>> list(P)
[(0, 'a')]
```

Edge attributes and edge keys (for multigraphs) are also copied to the new product graph.

### 3.39.14 networkx.algorithms.operators.product.lexicographic_product

#### lexicographic_product $(G, H)$

Return the lexicographic product of $G$ and $H$.

The lexicographical product $P$ of the graphs $G$ and $H$ has a node set that is the Cartesian product of the node sets, $V(P) = V(G) \times V(H)$. $P$ has an edge $((u, v), (x, y))$ if and only if $(u, v)$ is an edge in $G$ or $u == v$ and $(x, y)$ is an edge in $H$.

**Parameters**

$G, H$ (graphs) – Networkx graphs.

**Returns**

$P$ – The Cartesian product of $G$ and $H$. $P$ will be a multi-graph if either $G$ or $H$ is a multi-graph. Will be a directed if $G$ and $H$ are directed, and undirected if $G$ and $H$ are undirected.

**Return type**

NetworkX graph

**Raises**

NetworkXError – If $G$ and $H$ are not both directed or both undirected.
Notes

Node attributes in P are two-tuple of the G and H node attributes. Missing attributes are assigned None.

Examples

```python
>>> G = nx.Graph()
>>> H = nx.Graph()
>>> G.add_node(0, a1=True)
>>> H.add_node('a', a2='Spam')
>>> P = nx.lexicographic_product(G, H)
>>> list(P)
[(0, 'a')]
```

Edge attributes and edge keys (for multigraphs) are also copied to the new product graph.

3.39.15 networkx.algorithms.operators.product.strong_product

**strong_product** *(G, H)*

Return the strong product of G and H.

The strong product \( P \) of the graphs \( G \) and \( H \) has a node set that is the Cartesian product of the node sets, \( V(P) = V(G) \times V(H) \). \( P \) has an edge \((u, v), (x, y)\) if and only if \( u == v \) and \((x, y)\) is an edge in \( H \), or \( x == y \) and \((u, v)\) is an edge in \( G \), or \((u, v)\) is an edge in \( G \) and \((x, y)\) is an edge in \( H \).

**Parameters**  
\( G, H \) *(graphs)* – NetworkX graphs.

**Returns**  
\( P \) – The Cartesian product of \( G \) and \( H \). \( P \) will be a multi-graph if either \( G \) or \( H \) is a multi-graph. Will be a directed if \( G \) and \( H \) are directed, and undirected if \( G \) and \( H \) are undirected.

**Return type**  
NetworkX graph

**Raises**  
NetworkXError – If \( G \) and \( H \) are not both directed or both undirected.

Notes

Node attributes in P are two-tuple of the G and H node attributes. Missing attributes are assigned None.

Examples

```python
>>> G = nx.Graph()
>>> H = nx.Graph()
>>> G.add_node(0, a1=True)
>>> H.add_node('a', a2='Spam')
>>> P = nx.strong_product(G, H)
>>> list(P)
[(0, 'a')]
```

Edge attributes and edge keys (for multigraphs) are also copied to the new product graph.
3.39.16 networkx.algorithms.operators.product.tensor_product

tensor_product (G, H)
Return the tensor product of G and H.

The tensor product $P$ of the graphs $G$ and $H$ has a node set that is the tensor product of the node sets, $V(P) = V(G) \times V(H)$. $P$ has an edge $((u, v), (x, y))$ if and only if $(u, x)$ is an edge in $G$ and $(v, y)$ is an edge in $H$.

Tensor product is sometimes also referred to as the categorical product, direct product, cardinal product or conjunction.


Returns  P – The tensor product of G and H. P will be a multi-graph if either G or H is a multi-graph, will be a directed if G and H are directed, and undirected if G and H are undirected.

Return type  NetworkX graph

Raises  NetworkXError – If G and H are not both directed or both undirected.

Notes

Node attributes in P are two-tuple of the G and H node attributes. Missing attributes are assigned None.

Examples

```python
>>> G = nx.Graph()
>>> H = nx.Graph()
>>> G.add_node(0, a1=True)
>>> H.add_node('a', a2='Spam')
>>> P = nx.tensor_product(G, H)
>>> list(P)
[(0, 'a')]
```

Edge attributes and edge keys (for multigraphs) are also copied to the new product graph

3.39.17 networkx.algorithms.operators.product.power

power (G, k)
Returns the specified power of a graph.

The $k$th power of a simple graph : $G^k$, is a graph on the same set of nodes in which two distinct nodes $u$ and $v$ are adjacent in $G^k$ if and only if the shortest path distance between $u$ and $v$ in $G$ is at most $k$.

Parameters

- G (graph) – A NetworkX simple graph object.
- k (positive integer) – The power to which to raise the graph G.

Returns  G to the power k.

Return type  NetworkX simple graph

Raises  • ValueError – If the exponent k is not positive.
• NetworkXNotImplemented – If G is not a simple graph.

Examples

The number of edges will never decrease when taking successive powers:

```python
>>> G = nx.path_graph(4)
>>> list(nx.power(G, 2).edges)
[(0, 1), (0, 2), (1, 2), (1, 3), (2, 3)]
>>> list(nx.power(G, 3).edges)
[(0, 1), (0, 2), (0, 3), (1, 2), (1, 3), (2, 3)]
```

The $k$'th power of a cycle graph on $n$ nodes is the complete graph on $n$ nodes, if $k$ is at least $n // 2$:

```python
>>> G = nx.cycle_graph(5)
>>> H = nx.complete_graph(5)
>>> nx.is_isomorphic(nx.power(G, 2), H)
True
>>> G = nx.cycle_graph(8)
>>> H = nx.complete_graph(8)
>>> nx.is_isomorphic(nx.power(G, 4), H)
True
```

References

Notes

This definition of “power graph” comes from Exercise 3.1.6 of *Graph Theory* by Bondy and Murty\(^1\).

3.40 Reciprocity

Algorithms to calculate reciprocity in a directed graph.

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<tr>
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<tbody>
<tr>
<td><code>reciprocity(G[, nodes])</code></td>
<td>Compute the reciprocity in a directed graph.</td>
</tr>
<tr>
<td><code>overall_reciprocity(G)</code></td>
<td>Compute the reciprocity for the whole graph.</td>
</tr>
</tbody>
</table>

3.40.1 networkx.algorithms.reciprocity.reciprocity

`reciprocity(G, nodes=None)`

Compute the reciprocity in a directed graph.

The reciprocity of a directed graph is defined as the ratio of the number of edges pointing in both directions to the total number of edges in the graph. Formally, $r = |(u, v) \in G|(v, u) \in G|/|(u, v) \in G|$.

The reciprocity of a single node $u$ is defined similarly, it is the ratio of the number of edges in both directions to the total number of edges attached to node $u$.

Parameters

- **G** (graph) – A networkx directed graph
- **nodes** (container of nodes, optional (default=whole graph)) – Compute reciprocity for
  nodes in this container.

Returns **out** – Reciprocity keyed by node label.

Return type dictionary

Notes

The reciprocity is not defined for isolated nodes. In such cases this function will return None.

3.40.2 networkx.algorithms.reciprocity.overall_reciprocity

**overall_reciprocity** *(G)*

Compute the reciprocity for the whole graph.

See the doc of reciprocity for the definition.

Parameters **G** (graph) – A networkx graph

3.41 Rich Club

Functions for computing rich-club coefficients.

---

**rich_club_coefficient** *(G[, normalized, Q])* Returns the rich-club coefficient of the graph G.

3.41.1 networkx.algorithms.richclub.rich_club_coefficient

**rich_club_coefficient** *(G, normalized=True, Q=100)*

Returns the rich-club coefficient of the graph G.

For each degree *k*, the rich-club coefficient is the ratio of the number of actual to the number of potential edges for nodes with degree greater than *k*:

\[
\phi(k) = \frac{2E_k}{N_k(N_k - 1)}
\]

where \(N_k\) is the number of nodes with degree larger than *k*, and \(E_k\) is the number of edges among those
nodes.

Parameters

- **G** *(NetworkX graph)* – Undirected graph with neither parallel edges nor self-loops.
- **normalized** *(bool (optional))* – Normalize using randomized network as in
  
Returns \( rc \) – A dictionary, keyed by degree, with rich-club coefficient values.

Return type dictionary

**Examples**

```python
g = nx.Graph([(0, 1), (0, 2), (1, 2), (1, 3), (1, 4), (4, 5)])
rc = nx.rich_club_coefficient(g, normalized=False)
rc[0]
```

**Notes**

The rich club definition and algorithm are found in\(^1\). This algorithm ignores any edge weights and is not defined for directed graphs or graphs with parallel edges or self loops.

Estimates for appropriate values of \( Q \) are found in\(^2\).

**References**

### 3.42 Shortest Paths

Compute the shortest paths and path lengths between nodes in the graph.

These algorithms work with undirected and directed graphs.

---

**shortest_path**\((G, \text{source}=\text{None}, \text{target}=\text{None}, \text{weight}=\text{None})\)

Compute shortest paths in the graph.

**all_shortest_paths**\((G, \text{source}=\text{None}, \text{target}=\text{None}, \text{weight}=\text{None})\)

Compute all shortest paths in the graph.

**shortest_path_length**\((G, \text{source}=\text{None}, \text{target}=\text{None}, \text{weight}=\text{None})\)

Compute shortest path lengths in the graph.

**average_shortest_path_length**\((G, \text{weight}=\text{None})\)

Return the average shortest path length.

**has_path**\((G, \text{source}=\text{None}, \text{target}=\text{None})\)

Return True if \( G \) has a path from source to target.

---

### 3.42.1 networkx.algorithms.shortest_paths.generic.shortest_path

**shortest_path**\((G, \text{source}=\text{None}, \text{target}=\text{None}, \text{weight}=\text{None})\)

Compute shortest paths in the graph.

**Parameters**

- \( G \) (NetworkX graph)
- \( \text{source} \) (node, optional) – Starting node for path. If not specified, compute shortest paths for each possible starting node.
- \( \text{target} \) (node, optional) – Ending node for path. If not specified, compute shortest paths to all possible nodes.
- \( \text{weight} \) (None or string, optional (default = None)) – If None, every edge has weight/distance/cost 1. If a string, use this edge attribute as the edge weight. Any edge attribute not present defaults to 1.

---


Returns

`path` – All returned paths include both the source and target in the path.

If the source and target are both specified, return a single list of nodes in a shortest path from the source to the target.

If only the source is specified, return a dictionary keyed by targets with a list of nodes in a shortest path from the source to one of the targets.

If only the target is specified, return a dictionary keyed by sources with a list of nodes in a shortest path from one of the sources to the target.

If neither the source nor target are specified return a dictionary of dictionaries with `path[source][target]=[list of nodes in path]`.

**Return type** list or dictionary

**Examples**

```python
g = nx.path_graph(5)
p = nx.shortest_path(g, source=0)
p[4]  # target not specified
p = nx.shortest_path(g, target=4)  # source not specified
p[0]  # source, target not specified
p = nx.shortest_path(g)
p[0][4]  # source, target not specified
```

**Notes**

There may be more than one shortest path between a source and target. This returns only one of them.

**See also:**

`all_pairs_shortest_path()`, `all_pairs_dijkstra_path()`, `single_source_shortest_path()`, `single_source_dijkstra_path()`

### 3.42.2 networkx.algorithms.shortest_paths.generic.all_shortest_paths

`all_shortest_paths(G, source, target, weight=None)`

Compute all shortest paths in the graph.

**Parameters**

- **G** (NetworkX graph)
- **source** (node) – Starting node for path.
- **target** (node) – Ending node for path.
- **weight** (None or string, optional (default = None)) – If None, every edge has weight/distance/cost 1. If a string, use this edge attribute as the edge weight. Any edge attribute not present defaults to 1.
Returns paths – A generator of all paths between source and target.

Return type generator of lists

Examples

```python
>>> G = nx.Graph()
>>> nx.add_path(G, [0, 1, 2])
>>> nx.add_path(G, [0, 10, 2])
>>> print([p for p in nx.all_shortest_paths(G, source=0, target=2)])
[[0, 1, 2], [0, 10, 2]]
```

Notes

There may be many shortest paths between the source and target.

See also:

`shortest_path()`, `single_source_shortest_path()`, `all_pairs_shortest_path()`

3.42.3 `networkx.algorithms.shortest_paths.generic.shortest_path_length`

`shortest_path_length(G, source=None, target=None, weight=None)`

Compute shortest path lengths in the graph.

Parameters

- G (NetworkX graph)
- source (node, optional) – Starting node for path. If not specified, compute shortest path
  lengths using all nodes as source nodes.
- target (node, optional) – Ending node for path. If not specified, compute shortest path
  lengths using all nodes as target nodes.
- weight (None or string, optional (default = None)) – If None, every edge has
  weight/distance/cost 1. If a string, use this edge attribute as the edge weight. Any edge
  attribute not present defaults to 1.

Returns

length – If the source and target are both specified, return the length of the shortest path from
the source to the target.

If only the source is specified, return a dict keyed by target to the shortest path length from the
source to that target.

If only the target is specified, return a dict keyed by source to the shortest path length from that
source to the target.

If neither the source nor target are specified, return an iterator over (source, dictionary) where
dictionary is keyed by target to shortest path length from source to that target.

Return type int or iterator

Raises NetworkXNoPath – If no path exists between source and target.
**Examples**

```python
>>> G = nx.path_graph(5)
>>> nx.shortest_path_length(G, source=0, target=4)
4
>>> p = nx.shortest_path_length(G, source=0)  # target not specified
>>> p[4]
4
>>> p = nx.shortest_path_length(G, target=4)  # source not specified
>>> p[0]
4
>>> p = dict(nx.shortest_path_length(G))  # source, target not specified
>>> p[0][4]
4
```

**Notes**

The length of the path is always 1 less than the number of nodes involved in the path since the length measures
the number of edges followed.

For digraphs this returns the shortest directed path length. To find path lengths in the reverse direction use
G.reverse(copy=False) first to flip the edge orientation.

**See also:**

- `all_pairs_shortest_path_length()`, `all_pairs_dijkstra_path_length()`,
- `single_source_shortest_path_length()`, `single_source_dijkstra_path_length()`

### 3.42.4 `networkx.algorithms.shortest_paths.generic.average_shortest_path_length`

**average_shortest_path_length** *(G, weight=None)*

Return the average shortest path length.

The average shortest path length is

\[
a = \sum_{s,t \in V} \frac{d(s, t)}{n(n-1)}
\]

where \( V \) is the set of nodes in \( G \), \( d(s, t) \) is the shortest path from \( s \) to \( t \), and \( n \) is the number of nodes in \( G \).

**Parameters**

- `G` *(NetworkX graph)*
- `weight` *(None or string, optional (default = None)) – If None, every edge has weight/distance/cost 1. If a string, use this edge attribute as the edge weight. Any edge attribute not present defaults to 1.*

**Raises**

- `NetworkXPointlessConcept` – If \( G \) is the null graph (that is, the graph on zero nodes).
- `NetworkXError` – If \( G \) is not connected (or not weakly connected, in the case of a directed graph).
Examples

```python
>>> G = nx.path_graph(5)
>>> nx.average_shortest_path_length(G)
2.0
```

For disconnected graphs, you can compute the average shortest path length for each component

```python
>>> G = nx.Graph([(1, 2), (3, 4)])
>>> for C in nx.connected_component_subgraphs(G):
...     print(nx.average_shortest_path_length(C))
1.0
1.0
```

3.42.5 networkx.algorithms.shortest_paths.generic.has_path

**has_path** *(G, source, target)*

Return `True` if `G` has a path from `source` to `target`.

**Parameters**

- `G` (*NetworkX graph*)
- `source` (*node*) – Starting node for path
- `target` (*node*) – Ending node for path

3.42.6 Advanced Interface

Shortest path algorithms for unweighted graphs.

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<td>Compute shortest path between source and all other nodes reachable from source.</td>
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<td><code>single_source_shortest_path_length(G, source)</code></td>
<td>Compute the shortest path lengths from source to all reachable nodes.</td>
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<tr>
<td><code>all_pairs_shortest_path(G[, cutoff])</code></td>
<td>Compute shortest paths between all nodes.</td>
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<tr>
<td><code>all_pairs_shortest_path_length(G[, cutoff])</code></td>
<td>Computes the shortest path lengths between all nodes in <code>G</code>.</td>
</tr>
<tr>
<td><code>predecessor(G, source[, target, cutoff, ...])</code></td>
<td>Returns dict of predecessors for the path from source to all nodes in <code>G</code>.</td>
</tr>
</tbody>
</table>

3.42. Shortest Paths

**single_source_shortest_path** *(G, source, cutoff=None)*

Compute shortest path between source and all other nodes reachable from source.

**Parameters**

- `G` (*NetworkX graph*)
- `source` (*node label*) – Starting node for path
- `cutoff` (*integer, optional*) – Depth to stop the search. Only paths of length <= cutoff are returned.

**Returns**

- `lengths` – Dictionary, keyed by target, of shortest paths.
Return type  dictionary

Examples

>>> G = nx.path_graph(5)
>>> path = nx.single_source_shortest_path(G, 0)
>>> path[4]
[0, 1, 2, 3, 4]

Notes

The shortest path is not necessarily unique. So there can be multiple paths between the source and each target
node, all of which have the same ‘shortest’ length. For each target node, this function returns only one of those
paths.

See also:

shortest_path()

networkx.algorithms.shortest_paths.unweighted.single_source_shortest_path_length

single_source_shortest_path_length \( (G, \text{source}, \text{cutoff}=\text{None}) \)
Compute the shortest path lengths from source to all reachable nodes.

Parameters

- \( G \) (NetworkX graph)
- source (node) – Starting node for path
- cutoff (integer, optional) – Depth to stop the search. Only paths of length <= cutoff are returned.

Returns lengths – Dict keyed by node to shortest path length to source.

Return type  dict

Examples

>>> G = nx.path_graph(5)
>>> length = nx.single_source_shortest_path_length(G, 0)
>>> length[4]
4
>>> for node in length:
...     print('{}: {}'.format(node, length[node]))
0: 0
1: 1
2: 2
3: 3
4: 4

See also:

shortest_path_length()
networkx.algorithms.shortest_paths.unweighted.all_pairs_shortest_path

all_pairs_shortest_path \((G, \text{cutoff}=\text{None})\)
Compute shortest paths between all nodes.

**Parameters**

- \(G\) (NetworkX graph)
- \(\text{cutoff}\) (integer, optional) – Depth at which to stop the search. Only paths of length at most \(\text{cutoff}\) are returned.

**Returns** lengths – Dictionary, keyed by source and target, of shortest paths.

**Return type** dictionary

**Examples**

```python
>>> G = nx.path_graph(5)
>>> path = dict(nx.all_pairs_shortest_path(G))
>>> print(path[0][4])
[0, 1, 2, 3, 4]
```

See also:

floyd_warshall()

networkx.algorithms.shortest_paths.unweighted.all_pairs_shortest_path_length

all_pairs_shortest_path_length \((G, \text{cutoff}=\text{None})\)
Computes the shortest path lengths between all nodes in \(G\).

**Parameters**

- \(G\) (NetworkX graph)
- \(\text{cutoff}\) (integer, optional) – Depth at which to stop the search. Only paths of length at most \(\text{cutoff}\) are returned.

**Returns** lengths – (source, dictionary) iterator with dictionary keyed by target and shortest path length as the key value.

**Return type** iterator

**Notes**

The iterator returned only has reachable node pairs.

**Examples**

```python
>>> G = nx.path_graph(5)
>>> length = dict(nx.all_pairs_shortest_path_length(G))
>>> for node in [0, 1, 2, 3, 4]:
...     print('1 - {}: {}'.format(node, length[1][node]))
1 - 0: 1
```

(continues on next page)
networkx.algorithms.shortest_paths.unweighted.predecessor

**predecessor** *(G, source, target=None, cutoff=None, return_seen=None)*

Returns dict of predecessors for the path from source to all nodes in G

**Parameters**

- **G** *(NetworkX graph)*
- **source** *(node label)* – Starting node for path
- **target** *(node label, optional)* – Ending node for path. If provided only predecessors between source and target are returned
- **cutoff** *(integer, optional)* – Depth to stop the search. Only paths of length <= cutoff are returned.

**Returns**

**pred** – Dictionary, keyed by node, of predecessors in the shortest path.

**Return type**

dictionary

**Examples**

```python
>>> G = nx.path_graph(4)
>>> list(G)
[0, 1, 2, 3]
>>> nx.predecessor(G, 0)
{0: [], 1: [0], 2: [1], 3: [2]}
```

Shortest path algorithms for weighted graphs.

<table>
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<tr>
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<tr>
<td><code>dijkstra_path(G, source, target[, weight])</code></td>
<td>Returns the shortest weighted path from source to target in G.</td>
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<td><code>dijkstra_path_length(G, source, target[, weight])</code></td>
<td>Returns the shortest weighted path length in G from source to target.</td>
</tr>
<tr>
<td><code>single_source_dijkstra(G, source[, ...])</code></td>
<td>Find shortest weighted paths and lengths from a source node.</td>
</tr>
<tr>
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<td>Find shortest weighted paths in G from a source node.</td>
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<tr>
<td><code>single_source_dijkstra_path_length(G, source)</code></td>
<td>Find shortest weighted path lengths in G from a source node.</td>
</tr>
<tr>
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<td>Find shortest weighted paths in G from a given set of source nodes.</td>
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<td><code>multi_source_dijkstra_path_length(G, sources)</code></td>
<td>Find shortest weighted path lengths in G from a given set of source nodes.</td>
</tr>
<tr>
<td><code>all_pairs_dijkstra_path(G[, cutoff, weight])</code></td>
<td>Compute shortest paths between all nodes in a weighted graph.</td>
</tr>
<tr>
<td><code>all_pairs_dijkstra_path_length(G[, cutoff, ...])</code></td>
<td>Compute shortest path lengths between all nodes in a weighted graph.</td>
</tr>
<tr>
<td><code>bidirectional_dijkstra(G, source, target[, ...])</code></td>
<td>Dijkstra’s algorithm for shortest paths using bidirectional search.</td>
</tr>
<tr>
<td><code>bellman_ford_path(G, source, target[, weight])</code></td>
<td>Returns the shortest path from source to target in a weighted graph G.</td>
</tr>
<tr>
<td><code>bellman_ford_path_length(G, source, target)</code></td>
<td>Returns the shortest path length from source to target in a weighted graph.</td>
</tr>
<tr>
<td><code>single_source_bellman_ford_path(G, source[, ...])</code></td>
<td>Compute shortest path between source and all other reachable nodes for a weighted graph.</td>
</tr>
<tr>
<td><code>single_source_bellman_ford_path_length(G, source)</code></td>
<td>Compute the shortest path length between source and all other reachable nodes for a weighted graph.</td>
</tr>
<tr>
<td><code>all_pairs_bellman_ford_path(G[, cutoff, weight])</code></td>
<td>Compute shortest paths between all nodes in a weighted graph.</td>
</tr>
<tr>
<td><code>all_pairs_bellman_ford_path_length(G[, cutoff, ...])</code></td>
<td>Compute shortest path lengths between all nodes in a weighted graph.</td>
</tr>
<tr>
<td><code>single_source_bellman_ford(G, source[, ...])</code></td>
<td>Compute shortest paths and lengths in a weighted graph.</td>
</tr>
<tr>
<td><code>bellman_ford_predecessor_and_distance(G, source)</code></td>
<td>Compute shortest path lengths and predecessors on shortest paths in weighted graphs.</td>
</tr>
<tr>
<td><code>negative_edge_cycle(G[, weight])</code></td>
<td>Return True if there exists a negative edge cycle anywhere in G.</td>
</tr>
<tr>
<td><code>johnson(G[, weight])</code></td>
<td>Uses Johnson’s Algorithm to compute shortest paths.</td>
</tr>
</tbody>
</table>

networkx.algorithms.shortest_paths.weighted.dijkstra_predecessor_and_distance

dijkstra_predecessor_and_distance(G, source, cutoff=None, weight='weight')

Compute weighted shortest path length and predecessors.

Uses Dijkstra’s Method to obtain the shortest weighted paths and return dictionaries of predecessors for each node and distance for each node from the source.

Parameters

- **G** (NetworkX graph)
- **source** (node label) – Starting node for path
- **cutoff** (integer or float, optional) – Depth to stop the search. Only return paths with length <= cutoff.
- **weight** (string or function) – If this is a string, then edge weights will be accessed via the edge attribute with this key (that is, the weight of the edge joining \( u \) to \( v \) will be \( G.\text{edges}[u, v][\text{weight}] \)). If no such edge attribute exists, the weight of the edge is assumed to be one.

If this is a function, the weight of an edge is the value returned by the function. The function must accept exactly three positional arguments: the two endpoints of an edge and the dictionary of edge attributes for that edge. The function must return a number.

Returns **pred, distance** – Returns two dictionaries representing a list of predecessors of a node and the distance to each node. Warning: If target is specified, the dicts are incomplete as they only contain information for the nodes along a path to target.
Return type  dictionaries

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

The list of predecessors contains more than one element only when there are more than one shortest paths to the key node.

Examples

```python
>>> import networkx as nx
>>> G = nx.path_graph(5, create_using = nx.DiGraph())
>>> pred, dist = nx.dijkstra_predecessor_and_distance(G, 0)
>>> sorted(pred.items())
[(0, []), (1, [0]), (2, [1]), (3, [2]), (4, [3])]
>>> sorted(dist.items())
[(0, 0), (1, 1), (2, 2), (3, 3), (4, 4)]
```

```python
>>> pred, dist = nx.dijkstra_predecessor_and_distance(G, 0, 1)
>>> sorted(pred.items())
[(0, []), (1, [0])]
>>> sorted(dist.items())
[(0, 0), (1, 1)]
```

networkx.algorithms.shortest_paths.weighted.dijkstra_path

dijkstra_path(G, source, target, weight='weight')

Returns the shortest weighted path from source to target in G.

Uses Dijkstra’s Method to compute the shortest weighted path between two nodes in a graph.

Parameters

- G (NetworkX graph)
- source (node) – Starting node
- target (node) – Ending node
- weight (string or function) – If this is a string, then edge weights will be accessed via the edge attribute with this key (that is, the weight of the edge joining u to v will be G.edges[u, v][weight]). If no such edge attribute exists, the weight of the edge is assumed to be one.

If this is a function, the weight of an edge is the value returned by the function. The function must accept exactly three positional arguments: the two endpoints of an edge and the dictionary of edge attributes for that edge. The function must return a number.

Returns path – List of nodes in a shortest path.

Return type  list

Raises NetworkXNoPath – If no path exists between source and target.
Examples

```python
>>> G=nx.path_graph(5)
>>> print(nx.dijkstra_path(G,0,4))
[0, 1, 2, 3, 4]
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

The weight function can be used to hide edges by returning None. So `weight = lambda u, v, d: 1 if d['color']=='red' else None` will find the shortest red path.

The weight function can be used to include node weights.

```python
>>> def func(u, v, d):
...     node_u_wt = G.nodes[u].get('node_weight', 1)
...     node_v_wt = G.nodes[v].get('node_weight', 1)
...     edge_wt = d.get('weight', 1)
...     return node_u_wt/2 + node_v_wt/2 + edge_wt
```

In this example we take the average of start and end node weights of an edge and add it to the weight of the edge.

See also:

`bidirectional_dijkstra()`, `bellman_ford_path()`

`networkx.algorithms.shortest_paths.weighted.dijkstra_path_length`

dijkstra_path_length (G, source, target, weight='weight')
Returns the shortest weighted path length in G from source to target.
Uses Dijkstra’s Method to compute the shortest weighted path length between two nodes in a graph.

Parameters

- **G** (NetworkX graph)
- **source** (node label) – starting node for path
- **target** (node label) – ending node for path
- **weight** (string or function) – If this is a string, then edge weights will be accessed via the edge attribute with this key (that is, the weight of the edge joining u to v will be `G.edges[u, v][weight]`). If no such edge attribute exists, the weight of the edge is assumed to be one.
  
  If this is a function, the weight of an edge is the value returned by the function. The function must accept exactly three positional arguments: the two endpoints of an edge and the dictionary of edge attributes for that edge. The function must return a number.

Returns **length** – Shortest path length.

Return type **number**

Raises **NetworkXNoPath** – If no path exists between source and target.

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Examples

```python
>>> G = nx.path_graph(5)
>>> print(nx.dijkstra_path_length(G, 0, 4))
4
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

The weight function can be used to hide edges by returning None. So `weight = lambda u, v, d: 1 if d['color'] == "red" else None` will find the shortest red path.

See also:

- `bidirectional_dijkstra()`, `bellman_ford_path_length()`

`networkx.algorithms.shortest_paths.weighted.single_source_dijkstra`

`single_source_dijkstra(G, source=None, target=None, cutoff=None, weight='weight')`

Find shortest weighted paths and lengths from a source node.

Compute the shortest path length between source and all other reachable nodes for a weighted graph.

Uses Dijkstra's algorithm to compute shortest paths and lengths between a source and all other reachable nodes in a weighted graph.

Parameters

- `G` (*NetworkX graph*)
- `source` (*node label*) – Starting node for path
- `target` (*node label, optional*) – Ending node for path
- `cutoff` (*integer or float, optional*) – Depth to stop the search. Only return paths with length <= cutoff.
- `weight` (*string or function*) – If this is a string, then edge weights will be accessed via the edge attribute with this key (that is, the weight of the edge joining `u` to `v` will be `G.edges[u, v][weight]`). If no such edge attribute exists, the weight of the edge is assumed to be one. If this is a function, the weight of an edge is the value returned by the function. The function must accept exactly three positional arguments: the two endpoints of an edge and the dictionary of edge attributes for that edge. The function must return a number.

Returns `distance, path` – If target is None, paths and lengths to all nodes are computed. The return value is a tuple of two dictionaries keyed by target nodes. The first dictionary stores distance to each target node. The second stores the path to each target node. If target is not None, returns a tuple (distance, path), where distance is the distance from source to target and path is a list representing the path from source to target.

Return type pair of dictionaries, or numeric and list.
Examples

```python
>>> G = nx.path_graph(5)
>>> length, path = nx.single_source_dijkstra(G, 0)
>>> print(length[4])
4
>>> for node in [0, 1, 2, 3, 4]:
...     print('{}: {}'.format(node, length[node]))
0: 0
1: 1
2: 2
3: 3
4: 4
>>> path[4]
[0, 1, 2, 3, 4]
>>> length, path = nx.single_source_dijkstra(G, 0, 1)
>>> length
1
>>> path
[0, 1]
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

The weight function can be used to hide edges by returning None. So `weight = lambda u, v, d: 1 if d['color']="red" else None` will find the shortest red path.

Based on the Python cookbook recipe (119466) at http://aspn.activestate.com/ASPN/Cookbook/Python/Recipe/119466

This algorithm is not guaranteed to work if edge weights are negative or are floating point numbers (overflows and roundoff errors can cause problems).

See also:

- `single_source_dijkstra_path()`, `single_source_dijkstra_path_length()`, `single_source_bellman_ford()`

`networkx.algorithms.shortest_paths.weighted.single_source_dijkstra_path`

`single_source_dijkstra_path(G, source, cutoff=None, weight='weight')`

Find shortest weighted paths in G from a source node.

Compute shortest path between source and all other reachable nodes for a weighted graph.

Parameters

- `G` (NetworkX graph)
- `source` (node) – Starting node for path.
- `cutoff` (integer or float, optional) – Depth to stop the search. Only return paths with length <= cutoff.
- `weight` (string or function) – If this is a string, then edge weights will be accessed via the edge attribute with this key (that is, the weight of the edge joining u to v will be G[u][v][weight].

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edges[u, v][weight]). If no such edge attribute exists, the weight of the edge is assumed to be one.

If this is a function, the weight of an edge is the value returned by the function. The function must accept exactly three positional arguments: the two endpoints of an edge and the dictionary of edge attributes for that edge. The function must return a number.

**Returns** paths – Dictionary of shortest path lengths keyed by target.

**Return type** dictionary

**Examples**

```python
>>> G=nx.path_graph(5)
>>> path=nx.single_source_dijkstra_path(G,0)
>>> path[4]
[0, 1, 2, 3, 4]
```

**Notes**

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

The weight function can be used to hide edges by returning None. So weight = lambda u, v, d: 1 if d['color']=='red' else None will find the shortest red path.

**See also:**

- single_source_dijkstra()
- single_source_bellman_ford()

**networkx.algorithms.shortest_paths.weighted.single_source_dijkstra_path_length**

**single_source_dijkstra_path_length** (G, source, cutoff=None, weight='weight')

Find shortest weighted path lengths in G from a source node.

Compute the shortest path length between source and all other reachable nodes for a weighted graph.

**Parameters**

- G (NetworkX graph)
- source (node label) – Starting node for path
- cutoff (integer or float, optional) – Depth to stop the search. Only return paths with length <= cutoff.
- weight (string or function) – If this is a string, then edge weights will be accessed via the edge attribute with this key (that is, the weight of the edge joining u to v will be G.edges[u, v][weight]). If no such edge attribute exists, the weight of the edge is assumed to be one.

If this is a function, the weight of an edge is the value returned by the function. The function must accept exactly three positional arguments: the two endpoints of an edge and the dictionary of edge attributes for that edge. The function must return a number.

**Returns** length – Dict keyed by node to shortest path length from source.

**Return type** dict
Examples

```python
>>> G = nx.path_graph(5)
>>> length = nx.single_source_dijkstra_path_length(G, 0)
>>> length[4]
4
>>> for node in [0, 1, 2, 3, 4]:
...    print(' {}: {}'.format(node, length[node]))
0: 0
1: 1
2: 2
3: 3
4: 4
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

The weight function can be used to hide edges by returning None. So `weight = lambda u, v, d: 1 if d['color']=="red" else None` will find the shortest red path.

See also:

- `single_source_dijkstra()`, `single_source_bellman_ford_path_length()`
- `networkx.algorithms.shortest_paths.weighted.multi_source_dijkstra_path`

`networkx.algorithms.shortest_paths.weighted.multi_source_dijkstra_path`

`multi_source_dijkstra_path(G, sources, cutoff=None, weight='weight')`

Find shortest weighted paths in G from a given set of source nodes.

Compute shortest path between any of the source nodes and all other reachable nodes for a weighted graph.

Parameters

- `G` *(NetworkX graph)*
- `sources` *(non-empty set of nodes)* – Starting nodes for paths. If this is just a set containing a single node, then all paths computed by this function will start from that node. If there are two or more nodes in the set, the computed paths may begin from any one of the start nodes.
- `cutoff` *(integer or float, optional)* – Depth to stop the search. Only return paths with length <= cutoff.
- `weight` *(string or function)* – If this is a string, then edge weights will be accessed via the edge attribute with this key (that is, the weight of the edge joining u to v will be `G.edges[u, v][weight]`). If no such edge attribute exists, the weight of the edge is assumed to be one.

If this is a function, the weight of an edge is the value returned by the function. The function must accept exactly three positional arguments: the two endpoints of an edge and the dictionary of edge attributes for that edge. The function must return a number.

Returns paths – Dictionary of shortest paths keyed by target.

Return type dictionary
Examples

```python
>>> G = nx.path_graph(5)
>>> path = nx.multi_source_dijkstra_path(G, {0, 4})
>>> path[1]
[0, 1]
>>> path[3]
[4, 3]
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

The weight function can be used to hide edges by returning None. So `weight = lambda u, v, d: 1 if d['color']=="red" else None` will find the shortest red path.

**Raises**

`ValueError` – If `sources` is empty.

See also:

- `multi_source_dijkstra()`, `multi_source_bellman_ford()`

```python
networkx.algorithms.shortest_paths.weighted.multi_source_dijkstra_path_length
```

**multi_source_dijkstra_path_length** *(G, sources, cutoff=None, weight='weight')*

Find shortest weighted path lengths in G from a given set of source nodes.

Compute the shortest path length between any of the source nodes and all other reachable nodes for a weighted graph.

**Parameters**

- **G** *(NetworkX graph)*
- **sources** *(non-empty set of nodes)* – Starting nodes for paths. If this is just a set containing a single node, then all paths computed by this function will start from that node. If there are two or more nodes in the set, the computed paths may begin from any one of the start nodes.
- **cutoff** *(integer or float, optional)* – Depth to stop the search. Only return paths with length <= cutoff.
- **weight** *(string or function)* – If this is a string, then edge weights will be accessed via the edge attribute with this key (that is, the weight of the edge joining u to v will be G.edges[u, v][weight]). If no such edge attribute exists, the weight of the edge is assumed to be one.

If this is a function, the weight of an edge is the value returned by the function. The function must accept exactly three positional arguments: the two endpoints of an edge and the dictionary of edge attributes for that edge. The function must return a number.

**Returns**

- **length** – Dict keyed by node to shortest path length to nearest source.

**Return type**

- **dict**
Examples

```python
>>> G = nx.path_graph(5)
>>> length = nx.multi_source_dijkstra_path_length(G, {0, 4})
>>> for node in [0, 1, 2, 3, 4]:
...     print('{}: {}'.format(node, length[node]))
0: 0
1: 1
2: 2
3: 1
4: 0
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

The weight function can be used to hide edges by returning None. So
```
weight = lambda u, v, d: 1 if d['color']=='red' else None
```
will find the shortest red path.

Raises ValueError – If sources is empty.

See also:

- multi_source_dijkstra()

See also:

- `networkx.algorithms.shortest_paths.weighted.all_pairs_dijkstra_path`

---

### all_pairs_dijkstra_path

#### all_pairs_dijkstra_path(G, cutoff=None, weight='weight')

Compute shortest paths between all nodes in a weighted graph.

**Parameters**

- **G** *(NetworkX graph)*
- **cutoff** *(integer or float, optional)* – Depth to stop the search. Only return paths with length <= cutoff.
- **weight** *(string or function)* – If this is a string, then edge weights will be accessed via the edge attribute with this key (that is, the weight of the edge joining u to v will be G.edges[u, v][weight]). If no such edge attribute exists, the weight of the edge is assumed to be one.

If this is a function, the weight of an edge is the value returned by the function. The function must accept exactly three positional arguments: the two endpoints of an edge and the dictionary of edge attributes for that edge. The function must return a number.

**Returns**

**distance** – Dictionary, keyed by source and target, of shortest paths.

**Return type**

- dictionary

---

### Examples

```python
>>> G = nx.path_graph(5)
>>> path = dict(nx.all_pairs_dijkstra_path(G))
>>> print(path[0][4])
[0, 1, 2, 3, 4]
```
Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

See also:

floyd_warshall(), all_pairs_bellman_ford_path()

networkx.algorithms.shortest_paths.weighted.all_pairs_dijkstra_path_length

all_pairs_dijkstra_path_length(G, cutoff=None, weight='weight')

Compute shortest path lengths between all nodes in a weighted graph.

Parameters

• G (NetworkX graph)
• cutoff (integer or float, optional) – Depth to stop the search. Only return paths with length <= cutoff.
• weight (string or function) – If this is a string, then edge weights will be accessed via the edge attribute with this key (that is, the weight of the edge joining u to v will be G.edges[u, v][weight]). If no such edge attribute exists, the weight of the edge is assumed to be one.

If this is a function, the weight of an edge is the value returned by the function. The function must accept exactly three positional arguments: the two endpoints of an edge and the dictionary of edge attributes for that edge. The function must return a number.

Returns distance – (source, dictionary) iterator with dictionary keyed by target and shortest path length as the key value.

Return type iterator

Examples

```python
>>> G = nx.path_graph(5)
>>> length = dict(nx.all_pairs_dijkstra_path_length(G))
>>> for node in [0, 1, 2, 3, 4]:
...     print('1 - {}: {}'.format(node, length[1][node]))
1 - 0: 1
1 - 1: 0
1 - 2: 1
1 - 3: 2
1 - 4: 3
>>> length[3][2]
1
>>> length[2][2]
0
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

The dictionary returned only has keys for reachable node pairs.
networkx.algorithms.shortest_paths.weighted.bidirectional_dijkstra

bidirectional_dijkstra \((G, \text{source}, \text{target}, \text{weight}='weight')\)
Dijkstra’s algorithm for shortest paths using bidirectional search.

Parameters

- \(G\) (NetworkX graph)
- \(\text{source}\) (node) – Starting node.
- \(\text{target}\) (node) – Ending node.
- \(\text{weight}\) (string or function) – If this is a string, then edge weights will be accessed via the edge attribute with this key (that is, the weight of the edge joining \(u\) to \(v\) will be \(G.\)edges\([u, v]\)[weight]). If no such edge attribute exists, the weight of the edge is assumed to be one.
  
  If this is a function, the weight of an edge is the value returned by the function. The function must accept exactly three positional arguments: the two endpoints of an edge and the dictionary of edge attributes for that edge. The function must return a number.

Returns length, path – length is the distance from source to target. path is a list of nodes on a path from source to target.

Return type number and list

Raises NetworkXNoPath – If no path exists between source and target.

Examples

```python
>>> G = nx.path_graph(5)
>>> length, path = nx.bidirectional_dijkstra(G, 0, 4)
>>> print(length)
4
>>> print(path)
[0, 1, 2, 3, 4]
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

In practice bidirectional Dijkstra is much more than twice as fast as ordinary Dijkstra.

Ordinary Dijkstra expands nodes in a sphere-like manner from the source. The radius of this sphere will eventually be the length of the shortest path. Bidirectional Dijkstra will expand nodes from both the source and the target, making two spheres of half this radius. Volume of the first sphere is \(\pi r^2 r\) while the others are \(2\pi r/2\pi r/2\), making up half the volume.

This algorithm is not guaranteed to work if edge weights are negative or are floating point numbers (overflows and roundoff errors can cause problems).

See also:
shortest_path(), shortest_path_length()
networkx.algorithms.shortest_paths.weighted.bellman_ford_path

bellman_ford_path$(G, \text{source}, \text{target}, \text{weight}='weight')$

Returns the shortest path from source to target in a weighted graph G.

Parameters

- $G$ (NetworkX graph)
- source (node) – Starting node
- target (node) – Ending node
- weight (string, optional (default=’weight’)) – Edge data key corresponding to the edge weight

Returns path – List of nodes in a shortest path.

Return type list

Raises NetworkXNoPath – If no path exists between source and target.

Examples

```python
>>> G=nx.path_graph(5)
>>> print(nx.bellman_ford_path(G, 0, 4))
[0, 1, 2, 3, 4]
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

See also:
dijkstra_path(), bellman_ford_path_length()

networkx.algorithms.shortest_paths.weighted.bellman_ford_path_length

bellman_ford_path_length$(G, \text{source}, \text{target}, \text{weight}='weight')$

Returns the shortest path length from source to target in a weighted graph.

Parameters

- $G$ (NetworkX graph)
- source (node label) – starting node for path
- target (node label) – ending node for path
- weight (string, optional (default=’weight’)) – Edge data key corresponding to the edge weight

Returns length – Shortest path length.

Return type number

Raises NetworkXNoPath – If no path exists between source and target.
Examples

```python
>>> G = nx.path_graph(5)
>>> print(nx.bellman_ford_path_length(G, 0, 4))
4
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

See also:

\[ \text{dijkstra_path_length(), bellman_ford_path()} \]

`networkx.algorithms.shortest_paths.weighted.single_source_bellman_ford_path`

\[ \text{single_source_bellman_ford_path}(G, \text{source}, \text{cutoff}=\text{None}, \text{weight}=\text{'weight'}) \]

Compute shortest path between source and all other reachable nodes for a weighted graph.

**Parameters**

- \( G \) (NetworkX graph)
- \( \text{source} \) (node) – Starting node for path.
- \( \text{weight} \) (string, optional (default=‘weight’)) – Edge data key corresponding to the edge weight
- \( \text{cutoff} \) (integer or float, optional) – Depth to stop the search. Only paths of length \( \leq \) cutoff are returned.

**Returns** paths – Dictionary of shortest path lengths keyed by target.

**Return type** dictionary

Examples

```python
>>> G = nx.path_graph(5)
>>> path = nx.single_source_bellman_ford_path(G, 0)
>>> path[4]
[0, 1, 2, 3, 4]
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

See also:

\[ \text{single_source_dijkstra(), single_source_bellman_ford()} \]
single_source_bellman_ford_path_length \((G, \text{source}, \text{cutoff}=\text{None}, \text{weight}=\text{‘weight’})\)

Compute the shortest path length between source and all other reachable nodes for a weighted graph.

**Parameters**

- \(G\) (NetworkX graph)
- \text{source} (node label) – Starting node for path
- \text{weight} (string, optional (default=’weight’) – Edge data key corresponding to the edge weight.
- \text{cutoff} (integer or float, optional) – Depth to stop the search. Only paths of length \(\leq\) cutoff are returned.

**Returns**

- **length** – (target, shortest path length) iterator
- **Return type** iterator

**Examples**

```python
g = nx.path_graph(5)
length = dict(nx.single_source_bellman_ford_path_length(g, 0))
length[4]
for node in [0, 1, 2, 3, 4]:
    print('{}: {}'.format(node, length[node]))
0: 0
1: 1
2: 2
3: 3
4: 4
```

**Notes**

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

**See also:**

\text{single_source_dijkstra()}, \text{single_source_bellman_ford()}
Returns distance – Dictionary, keyed by source and target, of shortest paths.

Return type dictionary

Examples

```python
>>> G = nx.path_graph(5)
>>> path = dict(nx.all_pairs_bellman_ford_path(G))
>>> print(path[0][4])
[0, 1, 2, 3, 4]
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.

See also:
floyd_warshall(), all_pairs_dijkstra_path()

networkx.algorithms.shortest_paths.weighted.all_pairs_bellman_ford_path_length

all_pairs_bellman_ford_path_length (G, cutoff=None, weight='weight')
Compute shortest path lengths between all nodes in a weighted graph.

Parameters

- G (NetworkX graph)
- weight (string, optional (default='weight')) – Edge data key corresponding to the edge weight
- cutoff (integer or float, optional) – Depth to stop the search. Only paths of length <= cutoff are returned.

Returns distance – (source, dictionary) iterator with dictionary keyed by target and shortest path length as the key value.

Return type iterator

Examples

```python
>>> G = nx.path_graph(5)
>>> length = dict(nx.all_pairs_bellman_ford_path_length(G))
>>> for node in [0, 1, 2, 3, 4]:
...     print('1 - {}: {}'.format(node, length[1][node]))
1 - 0: 1
1 - 1: 0
1 - 2: 1
1 - 3: 2
1 - 4: 3
>>> length[3][2]
1
>>> length[2][2]
0
```
Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.
The dictionary returned only has keys for reachable node pairs.

equation

networkx.algorithms.shortest_paths.weighted.single_source_bellman_ford

single_source_bellman_ford(G, source, target=None, cutoff=None, weight='weight')

Compute shortest paths and lengths in a weighted graph G.

Uses Bellman-Ford algorithm for shortest paths.

Parameters

- G (NetworkX graph)
- source (node label) – Starting node for path
- target (node label, optional) – Ending node for path
- cutoff (integer or float, optional) – Depth to stop the search. Only paths of length <= cutoff are returned.

Returns distance, path – If target is None, returns a tuple of two dictionaries keyed by node. The first dictionary stores distance from one of the source nodes. The second stores the path from one of the sources to that node. If target is not None, returns a tuple of (distance, path) where distance is the distance from source to target and path is a list representing the path from source to target.

Return type pair of dictionaries, or numeric and list

Examples

```python
>>> G = nx.path_graph(5)
>>> length, path = nx.single_source_bellman_ford(G, 0)
>>> print(length[4])
4
>>> for node in [0, 1, 2, 3, 4]:
...     print('{}/{}: /'.format(node, length[node]))
0: 0
1: 1
2: 2
3: 3
4: 4
>>> path[4]
[0, 1, 2, 3, 4]
```

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.
See also:

single_source_dijkstra(), single_source_bellman_ford_path(),
single_source_bellman_ford_path_length()

networkx.algorithms.shortest_paths.weighted.bellman_ford_predecessor_and_distance

bellman_ford_predecessor_and_distance(G, source, target=None, cutoff=None, weight='weight')

Compute shortest path lengths and predecessors on shortest paths in weighted graphs.

The algorithm has a running time of $O(mn)$ where $n$ is the number of nodes and $m$ is the number of edges. It is slower than Dijkstra but can handle negative edge weights.

Parameters

- G (NetworkX graph) – The algorithm works for all types of graphs, including directed graphs and multigraphs.
- source (node label) – Starting node for path
- weight (string or function) – If this is a string, then edge weights will be accessed via the edge attribute with this key (that is, the weight of the edge joining $u$ to $v$ will be $G$.edges[$u$, $v$][weight]). If no such edge attribute exists, the weight of the edge is assumed to be one.
If this is a function, the weight of an edge is the value returned by the function. The function must accept exactly three positional arguments: the two endpoints of an edge and the dictionary of edge attributes for that edge. The function must return a number.

Returns pred, dist – Returns two dictionaries keyed by node to predecessor in the path and to the distance from the source respectively. Warning: If target is specified, the dicts are incomplete as they only contain information for the nodes along a path to target.

Return type dictionaries

Raises NetworkXUnbounded – If the (di)graph contains a negative cost (di)cycle, the algorithm raises an exception to indicate the presence of the negative cost (di)cycle. Note: any negative weight edge in an undirected graph is a negative cost cycle.

Examples

```python
g = nx.path_graph(5, create_using = nx.DiGraph())
pred, dist = nx.bellman_ford_predecessor_and_distance(G, 0)
sorted(pred.items())
[(0, [None]), (1, [0]), (2, [1]), (3, [2]), (4, [3])]
sorted(dist.items())
[(0, 0), (1, 1), (2, 2), (3, 3), (4, 4)]
```

```python
g = nx.path_graph(5, create_using = nx.DiGraph())
pred, dist = nx.bellman_ford_predecessor_and_distance(G, 0, 1)
sorted(pred.items())
[(0, [None]), (1, [0])]
sorted(dist.items())
[(0, 0), (1, 1)]
```
>>> from nose.tools import assert_raises
>>> G = nx.cycle_graph(5, create_using = nx.DiGraph())
>>> G[1][2]['weight'] = -7
>>> assert_raises(nx.NetworkXUnbounded, nx.bellman_ford_predecessor_and_distance, G, 0)

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.
The dictionaries returned only have keys for nodes reachable from the source.
In the case where the (di)graph is not connected, if a component not containing the source contains a negative
cost (di)cycle, it will not be detected.

networkx.algorithms.shortest_paths.weighted.negative_edge_cycle

negative_edge_cycle (G, weight='weight')
Return True if there exists a negative edge cycle anywhere in G.

Parameters

- G (NetworkX graph)
- weight (string or function) – If this is a string, then edge weights will be accessed via
the edge attribute with this key (that is, the weight of the edge joining u to v will be
G.edges[u, v][weight]). If no such edge attribute exists, the weight of the edge is
assumed to be one.
If this is a function, the weight of an edge is the value returned by the function. The function
must accept exactly three positional arguments: the two endpoints of an edge and the
dictionary of edge attributes for that edge. The function must return a number.

Returns negative_cycle – True if a negative edge cycle exists, otherwise False.

Return type bool

Examples

>>> import networkx as nx
>>> G = nx.cycle_graph(5, create_using = nx.DiGraph())
>>> print(nx.negative_edge_cycle(G))
False
>>> G[1][2]['weight'] = -7
>>> print(nx.negative_edge_cycle(G))
True

Notes

Edge weight attributes must be numerical. Distances are calculated as sums of weighted edges traversed.
This algorithm uses bellman_ford_predecessor_and_distance() but finds negative cycles on any component by
first adding a new node connected to every node, and starting bellman_ford_predecessor_and_distance on that
node. It then removes that extra node.
networkx.algorithms.shortest_paths.weighted.johnson

johnson(G, weight='weight')
Uses Johnson’s Algorithm to compute shortest paths.

Johnson’s Algorithm finds a shortest path between each pair of nodes in a weighted graph even if negative weights are present.

Parameters

- G (NetworkX graph)
- weight (string or function) – If this is a string, then edge weights will be accessed via the edge attribute with this key (that is, the weight of the edge joining u to v will be G.edges[u, v][weight]). If no such edge attribute exists, the weight of the edge is assumed to be one.
  
If this is a function, the weight of an edge is the value returned by the function. The function must accept exactly three positional arguments: the two endpoints of an edge and the dictionary of edge attributes for that edge. The function must return a number.

Returns distance – Dictionary, keyed by source and target, of shortest paths.

Return type dictionary

Raises NetworkXError – If given graph is not weighted.

Examples

```python
>>> import networkx as nx
>>> graph = nx.DiGraph()
>>> graph.add_weighted_edges_from([('0', '3', 3), ('0', '1', -5),
... ('0', '2', 2), ('1', '2', 4), ('2', '3', 1)])
>>> paths = nx.johnson(graph, weight='weight')
>>> paths['0']['2']
['0', '1', '2']
```

Notes

Johnson’s algorithm is suitable even for graphs with negative weights. It works by using the Bellman–Ford algorithm to compute a transformation of the input graph that removes all negative weights, allowing Dijkstra’s algorithm to be used on the transformed graph.

The time complexity of this algorithm is $O(n^2 \log n + nm)$, where $n$ is the number of nodes and $m$ the number of edges in the graph. For dense graphs, this may be faster than the Floyd–Warshall algorithm.

See also:

- floyd_warshall_predecessor_and_distance()
- floyd_warshall_numpy()
- all_pairs_shortest_path()
- all_pairs_shortest_path_length()
- all_pairs_dijkstra_path()
- bellman_ford_predecessor_and_distance()
- all_pairs_bellman_ford_path()
- all_pairs_bellman_ford_path_length()

3.42.7 Dense Graphs

Floyd-Warshall algorithm for shortest paths.
floyd_warshall(G[, weight])  Find all-pairs shortest path lengths using Floyd’s algorithm.

floyd_warshall_predecessor_and_distance(G)  Find all-pairs shortest path lengths using Floyd’s algorithm.

floyd_warshall_numpy(G[, nodelist, weight])  Find all-pairs shortest path lengths using Floyd’s algorithm.

networkx.algorithms.shortest_paths.dense.floyd_warshall

floyd_warshall (G, weight='weight')
Find all-pairs shortest path lengths using Floyd’s algorithm.

Parameters

• G (NetworkX graph)
• weight (string, optional (default= ‘weight’)) – Edge data key corresponding to the edge weight.

Returns distance – A dictionary, keyed by source and target, of shortest paths distances between nodes.

Return type  dict

Notes

Floyd’s algorithm is appropriate for finding shortest paths in dense graphs or graphs with negative weights when Dijkstra’s algorithm fails. This algorithm can still fail if there are negative cycles. It has running time $O(n^3)$ with running space of $O(n^2)$.

See also:

floyd_warshall_predecessor_and_distance(),  floyd_warshall_numpy(),
all_pairs_shortest_path(), all_pairs_shortest_path_length()

networkx.algorithms.shortest_paths.dense.floyd_warshall_predecessor_and_distance

floyd_warshall_predecessor_and_distance (G, weight='weight')
Find all-pairs shortest path lengths using Floyd’s algorithm.

Parameters

• G (NetworkX graph)
• weight (string, optional (default= ‘weight’)) – Edge data key corresponding to the edge weight.

Returns predecessor,distance – Dictionaries, keyed by source and target, of predecessors and distances in the shortest path.

Return type  dictionaries

Examples
>>> G = nx.DiGraph()
>>> G.add_weighted_edges_from([('s', 'u', 10), ('s', 'x', 5),
... ('u', 'v', 1), ('u', 'x', 2), ('v', 'y', 1), ('x', 'u', 3),
... ('x', 'v', 5), ('x', 'y', 2), ('y', 's', 7), ('y', 'v', 6)])
>>> predecessors, _ = nx.floyd_warshall_predecessor_and_distance(G)
>>> print(reconstruct_path('s', 'v', predecessors))
['s', 'x', 'u', 'v']

Notes

Floyd’s algorithm is appropriate for finding shortest paths in dense graphs or graphs with negative weights when Dijkstra’s algorithm fails. This algorithm can still fail if there are negative cycles. It has running time \( O(n^3) \) with running space of \( O(n^2) \).

See also:

- `floyd_warshall()`
- `floyd_warshall_numpy()`
- `all_pairs_shortest_path()`
- `all_pairs_shortest_path_length()`

`networkx.algorithms.shortest_paths.dense.floyd_warshall_numpy`

**floyd_warshall_numpy** *(G, nodelist=None, weight='weight')*

Find all-pairs shortest path lengths using Floyd’s algorithm.

**Parameters**

- **G** *(NetworkX graph)*
- **nodelist** *(list, optional)* – The rows and columns are ordered by the nodes in nodelist. If nodelist is None then the ordering is produced by G.nodes().
- **weight** *(string, optional (default= 'weight'))* – Edge data key corresponding to the edge weight.

**Returns**

- **distance** – A matrix of shortest path distances between nodes. If there is no path between to nodes the corresponding matrix entry will be Inf.

**Return type** NumPy matrix

Notes

Floyd’s algorithm is appropriate for finding shortest paths in dense graphs or graphs with negative weights when Dijkstra’s algorithm fails. This algorithm can still fail if there are negative cycles. It has running time \( O(n^3) \) with running space of \( O(n^2) \).

### 3.42.8 A* Algorithm

Shortest paths and path lengths using the A* (“A star”) algorithm.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>astar_path(G, source, target[, heuristic, ...])</code></td>
<td>Return a list of nodes in a shortest path between source and target using the A* (“A-star”) algorithm.</td>
</tr>
<tr>
<td><code>astar_path_length(G, source, target[, ...])</code></td>
<td>Return the length of the shortest path between source and target using the A* (“A-star”) algorithm.</td>
</tr>
</tbody>
</table>
networkx.algorithms.shortest_paths.astar.astar_path

`astar_path(G, source, target, heuristic=None, weight='weight')`

Return a list of nodes in a shortest path between source and target using the A* (“A-star”) algorithm.

There may be more than one shortest path. This returns only one.

**Parameters**

- `G` (*NetworkX graph*)
- `source` (*node*) – Starting node for path
- `target` (*node*) – Ending node for path
- `heuristic` (*function*) – A function to evaluate the estimate of the distance from the a node to the target. The function takes two nodes arguments and must return a number.
- `weight` (*string, optional (default='weight')*) – Edge data key corresponding to the edge weight.

**Raises** NetworkXNoPath – If no path exists between source and target.

**Examples**

```python
>>> G = nx.path_graph(5)
>>> print(nx.astar_path(G, 0, 4))
[0, 1, 2, 3, 4]
>>> G = nx.grid_graph(dim=[3, 3])  # nodes are two-tuples (x,y)
>>> nx.set_edge_attributes(G, {e: e[1][0]*2 for e in G.edges()}, 'cost')
>>> def dist(a, b):
...     (x1, y1) = a
...     (x2, y2) = b
...     return ((x1 - x2) ** 2 + (y1 - y2) ** 2) ** 0.5
>>> print(nx.astar_path(G, (0, 0), (2, 2), heuristic=dist, weight='cost'))
[(0, 0), (0, 1), (0, 2), (1, 2), (2, 2)]
```

See also:

- `shortest_path()`, `dijkstra_path()`

networkx.algorithms.shortest_paths.astar.astar_path_length

`astar_path_length(G, source, target, heuristic=None, weight='weight')`

Return the length of the shortest path between source and target using the A* (“A-star”) algorithm.

**Parameters**

- `G` (*NetworkX graph*)
- `source` (*node*) – Starting node for path
- `target` (*node*) – Ending node for path
- `heuristic` (*function*) – A function to evaluate the estimate of the distance from the a node to the target. The function takes two nodes arguments and must return a number.

**Raises** NetworkXNoPath – If no path exists between source and target.
See also:

astar_path()

## 3.43 Simple Paths

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<th>Function</th>
<th>Description</th>
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<tr>
<td><code>all_simple_paths(G, source, target[, cutoff])</code></td>
<td>Generate all simple paths in the graph G from source to target.</td>
</tr>
<tr>
<td><code>is_simple_path(G, nodes)</code></td>
<td>Returns True if and only if the given nodes form a simple path in G.</td>
</tr>
<tr>
<td><code>shortest_simple_paths(G, source, target[, ...])</code></td>
<td>Generate all simple paths in the graph G from source to target, starting from shortest ones.</td>
</tr>
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</table>

### 3.43.1 networkx.algorithms.simple_paths.all_simple_paths

`all_simple_paths(G, source, target, cutoff=None)`

Generate all simple paths in the graph G from source to target.

A simple path is a path with no repeated nodes.

**Parameters**

- `G` *(NetworkX graph)*
- `source` *(node)* – Starting node for path
- `target` *(node)* – Ending node for path
- `cutoff` *(integer, optional)* – Depth to stop the search. Only paths of length <= cutoff are returned.

**Returns** `path_generator` – A generator that produces lists of simple paths. If there are no paths between the source and target within the given cutoff the generator produces no output.

**Return type** generator

### Examples

This iterator generates lists of nodes:

```python
g = nx.complete_graph(4)
for path in nx.all_simple_paths(g, source=0, target=3):
    print(path)
```

```
[0, 1, 2, 3]
[0, 1, 3]
[0, 2, 1, 3]
[0, 2, 3]
[0, 3]
```

You can generate only those paths that are shorter than a certain length by using the `cutoff` keyword argument:

```python
paths = nx.all_simple_paths(g, source=0, target=3, cutoff=2)
print(list(paths))
```

```
[[0, 1, 3], [0, 2, 3], [0, 3]]
```
To get each path as the corresponding list of edges, you can use the `networkx.utils.pairwise()` helper function:

```python
>>> paths = nx.all_simple_paths(G, source=0, target=3)
>>> for path in map(nx.utils.pairwise, paths):
...     print(list(path))
[(0, 1), (1, 2), (2, 3)]
[(0, 1), (1, 3)]
[(0, 2), (2, 1), (1, 3)]
[(0, 2), (2, 3)]
[(0, 3)]
```

Iterate over each path from the root nodes to the leaf nodes in a directed acyclic graph using a functional programming approach:

```python
>>> from itertools import chain
>>> from itertools import product
>>> from itertools import starmap
>>> from functools import partial

>>> chaini = chain.from_iterable

>>> G = nx.DiGraph([(0, 1), (1, 2), (0, 3), (3, 2)])
>>> roots = (v for v, d in G.in_degree() if d == 0)
>>> leaves = (v for v, d in G.out_degree() if d == 0)
>>> all_paths = partial(nx.all_simple_paths, G)
>>> list(chaini(starmap(all_paths, product(roots, leaves))))
[[0, 1, 2], [0, 3, 2]]
```

The same list computed using an iterative approach:

```python
>>> G = nx.DiGraph([(0, 1), (1, 2), (0, 3), (3, 2)])
>>> roots = (v for v, d in G.in_degree() if d == 0)
>>> leaves = (v for v, d in G.out_degree() if d == 0)
>>> all_paths = []
>>> for root in roots:
...     for leaf in leaves:
...         paths = nx.all_simple_paths(G, root, leaf)
...         all_paths.extend(paths)

>>> all_paths
[[0, 1, 2], [0, 3, 2]]
```

### Notes

This algorithm uses a modified depth-first search to generate the paths\(^1\). A single path can be found in \(O(V + E)\) time but the number of simple paths in a graph can be very large, e.g. \(O(n!)\) in the complete graph of order \(n\).

### References

See also:

- `all_shortest_paths()`, `shortest_path()`

---

3.43.2 networkx.algorithms.simple_paths.is_simple_path

is_simple_path(G, nodes)
Returns True if and only if the given nodes form a simple path in G.

A simple path in a graph is a nonempty sequence of nodes in which no node appears more than once in the sequence, and each adjacent pair of nodes in the sequence is adjacent in the graph.

Parameters nodes (list) – A list of one or more nodes in the graph G.

Returns Whether the given list of nodes represents a simple path in G.

Notes

A list of zero nodes is not a path and a list of one node is a path. Here’s an explanation why.

This function operates on node paths. One could also consider edge paths. There is a bijection between node paths and edge paths.

The length of a path is the number of edges in the path, so a list of nodes of length n corresponds to a path of length n - 1. Thus the smallest edge path would be a list of zero edges, the empty path. This corresponds to a list of one node.

To convert between a node path and an edge path, you can use code like the following:

```python
>>> from networkx.utils import pairwise
>>> nodes = [0, 1, 2, 3]
>>> edges = list(pairwise(nodes))
>>> edges
[(0, 1), (1, 2), (2, 3)]
>>> nodes = [edges[0][0]] + [v for u, v in edges]
>>> nodes
[0, 1, 2, 3]
```

Examples

```python
>>> G = nx.cycle_graph(4)
>>> nx.is_simple_path(G, [2, 3, 0])
True
>>> nx.is_simple_path(G, [0, 2])
False
```

3.43.3 networkx.algorithms.simple_paths.shortest_simple_paths

shortest_simple_paths(G, source, target, weight=None)

Generate all simple paths in the graph G from source to target, starting from shortest ones.

A simple path is a path with no repeated nodes.

If a weighted shortest path search is to be used, no negative weights are allowed.

Parameters

- G (NetworkX graph)
• **source** (*node*) – Starting node for path
• **target** (*node*) – Ending node for path
• **weight** (*string*) – Name of the edge attribute to be used as a weight. If None all edges are considered to have unit weight. Default value None.

**Returns** path_generator – A generator that produces lists of simple paths, in order from shortest to longest.

**Return type** generator

**Raises**
• NetworkXNoPath – If no path exists between source and target.
• NetworkXError – If source or target nodes are not in the input graph.
• NetworkXNotImplemented – If the input graph is a Multi[Di]Graph.

**Examples**

```python
>>> G = nx.cycle_graph(7)
>>> paths = list(nx.shortest_simple_paths(G, 0, 3))
>>> print(paths)
[[0, 1, 2, 3], [0, 6, 5, 4, 3]]
```

You can use this function to efficiently compute the k shortest/best paths between two nodes.

```python
>>> from itertools import islice
>>> def k_shortest_paths(G, source, target, k, weight=None):
...     return list(islice(nx.shortest_simple_paths(G, source, target, weight=weight), k))
>>> for path in k_shortest_paths(G, 0, 3, 2):
...     print(path)
[0, 1, 2, 3]
[0, 6, 5, 4, 3]
```

**Notes**

This procedure is based on algorithm by Jin Y. Yen[^1]. Finding the first 𝐾 paths requires 𝑂(𝐾𝑁^3) operations.

**See also:**

*all_shortest_paths*, *shortest_path*, *all_simple_paths*

**References**

### 3.44 Structural holes

Functions for computing measures of structural holes.

constraint(G[, nodes, weight])

Returns the constraint on all nodes in the graph G.

effective_size(G[, nodes, weight])

Returns the effective size of all nodes in the graph G.

local_constraint(G, u, v[, weight])

Returns the local constraint on the node u with respect to the node v in the graph G.

3.44.1 networkx.algorithms.structuralholes.constraint

constraint (G, nodes=None, weight=None)

Returns the constraint on all nodes in the graph G.

The constraint is a measure of the extent to which a node \( v \) is invested in those nodes that are themselves invested in the neighbors of \( v \). Formally, the constraint on \( v \), denoted \( c(v) \), is defined by

\[
c(v) = \sum_{w \in N(v) \setminus \{v\}} \ell(v, w)
\]

where \( N(v) \) is the subset of the neighbors of \( v \) that are either predecessors or successors of \( v \) and \( \ell(v, w) \) is the local constraint on \( v \) with respect to \( w \). For the definition of local constraint, see local_constraint().

Parameters

- \( G \) (NetworkX graph) – The graph containing \( v \). This can be either directed or undirected.
- nodes (container, optional) – Container of nodes in the graph \( G \) to compute the constraint. If None, the constraint of every node is computed.
- weight (None or string, optional) – If None, all edge weights are considered equal. Otherwise holds the name of the edge attribute used as weight.

Returns

Dictionary with nodes as keys and the constraint on the node as values.

Return type

dict

See also:

local_constraint()

References

3.44.2 networkx.algorithms.structuralholes.effective_size

effective_size (G, nodes=None, weight=None)

Returns the effective size of all nodes in the graph G.

The effective size of a node’s ego network is based on the concept of redundancy. A person’s ego network has redundancy to the extent that her contacts are connected to each other as well. The nonredundant part of a person’s relationships it’s the effective size of her ego network. Formally, the effective size of a node \( u \), denoted \( e(u) \), is defined by

\[
e(u) = \sum_{v \in N(u) \setminus \{u\}} \left( 1 - \sum_{w \in N(v)} p_{uw} m_{vw} \right)
\]

References


where $N(u)$ is the set of neighbors of $u$ and $p_{u,v}$ is the normalized mutual weight of the (directed or undirected) edges joining $u$ and $v$, for each vertex $u$ and $v$. And $m_{vw}$ is the mutual weight of $v$ and $w$ divided by $v$ highest mutual weight with any of its neighbors. The mutual weight of $u$ and $v$ is the sum of the weights of edges joining them (edge weights are assumed to be one if the graph is unweighted).

For the case of unweighted and undirected graphs, Borgatti proposed a simplified formula to compute effective size:

$$e(u) = n - \frac{2t}{n}$$

where $t$ is the number of ties in the ego network (not including ties to ego) and $n$ is the number of nodes (excluding ego).

**Parameters**
- **G** (*NetworkX graph*) – The graph containing $v$. Directed graphs are treated like undirected graphs when computing neighbors of $v$.
- **nodes** (*container, optional*) – Container of nodes in the graph $G$ to compute the effective size. If None, the effective size of every node is computed.
- **weight** (*None or string, optional*) – If None, all edge weights are considered equal. Otherwise holds the name of the edge attribute used as weight.

**Returns** Dictionary with nodes as keys and the constraint on the node as values.

**Return type** dict

**Notes**

Burt also defined the related concept of efficiency of a node’s ego network, which is its effective size divided by the degree of that node. So you can easily compute efficiency:

```python
g = nx.DiGraph()
g.add_edges_from([(0, 1), (0, 2), (1, 0), (2, 1)])
esize = nx.effective_size(g)
efficiency = {n: v / G.degree(n) for n, v in esize.items()}
```

**See also:**
- `constraint()`

**References**

3.44.3 networkx.algorithms.structuralholes.local_constraint

**local_constraint** $(G, u, v, \text{weight}={\text{None}})$

Returns the local constraint on the node $u$ with respect to the node $v$ in the graph $G$.

Formally, the local constraint on $u$ with respect to $v$, denoted $\ell(v)$, is defined by

$$\ell(u, v) = \left(p_{uv} + \sum_{w \in N(v)} p_{uw} p_{wv}\right)^2,$$
where \( N(v) \) is the set of neighbors of \( v \) and \( p_{uv} \) is the normalized mutual weight of the (directed or undirected) edges joining \( u \) and \( v \), for each vertex \( u \) and \( v \). The mutual weight of \( u \) and \( v \) is the sum of the weights of edges joining them (edge weights are assumed to be one if the graph is unweighted).

**Parameters**

- **\( G \) (NetworkX graph)** – The graph containing \( u \) and \( v \). This can be either directed or undirected.
- **\( u \) (node)** – A node in the graph \( G \).
- **\( v \) (node)** – A node in the graph \( G \).
- **weight** (None or string, optional) – If None, all edge weights are considered equal. Otherwise holds the name of the edge attribute used as weight.

**Returns** The constraint of the node \( v \) in the graph \( G \).

**Return type** float

**See also:** constraint()

**References**

3.45 Swap

Swap edges in a graph.

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<td><code>double_edge_swap(G[, nswap, max_tries])</code></td>
<td>Swap two edges in the graph while keeping the node degrees fixed.</td>
</tr>
<tr>
<td><code>connected_double_edge_swap(G[, nswap, ...])</code></td>
<td>Attempts the specified number of double-edge swaps in the graph ( G ).</td>
</tr>
</tbody>
</table>

3.45.1 networkx.algorithms.swap.double_edge_swap

`double_edge_swap(G, nswap=1, max_tries=100)`

Swap two edges in the graph while keeping the node degrees fixed.

A double-edge swap removes two randomly chosen edges \( u-v \) and \( x-y \) and creates the new edges \( u-x \) and \( v-y \):

\[
\begin{array}{cc}
  u & v \\
  \text{becomes} & | \\
  x & y
\end{array}
\]

If either the edge \( u-x \) or \( v-y \) already exist no swap is performed and another attempt is made to find a suitable edge pair.

**Parameters**

- **\( G \) (graph)** – An undirected graph
- **\( nswap \) (integer (optional, default=1))** – Number of double-edge swaps to perform
- **\( max_tries \) (integer (optional))** – Maximum number of attempts to swap edges

Returns G – The graph after double edge swaps.

Return type graph

Notes

Does not enforce any connectivity constraints.
The graph G is modified in place.

3.45.2 networkx.algorithms.swap.connected_double_edge_swap

c connected_double_edge_swap (G, nswap=1, _window_threshold=3)

Attempts the specified number of double-edge swaps in the graph G.

A double-edge swap removes two randomly chosen edges (u, v) and (x, y) and creates the new edges (u, x) and (v, y):

u--v   u v
becomes  |

x--y   x y

If either (u, x) or (v, y) already exist, then no swap is performed so the actual number of swapped edges is always at most nswap.

Parameters

• G (graph) – An undirected graph
• nswap (integer (optional, default=1)) – Number of double-edge swaps to perform
• _window_threshold (integer) – The window size below which connectedness of the graph will be checked after each swap.

The “window” in this function is a dynamically updated integer that represents the number of swap attempts to make before checking if the graph remains connected. It is an optimization used to decrease the running time of the algorithm in exchange for increased complexity of implementation.

If the window size is below this threshold, then the algorithm checks after each swap if the graph remains connected by checking if there is a path joining the two nodes whose edge was just removed. If the window size is above this threshold, then the algorithm performs do all the swaps in the window and only then check if the graph is still connected.

Returns The number of successful swaps

Return type int

Raises NetworkXError – If the input graph is not connected, or if the graph has fewer than four nodes.

Notes

The initial graph G must be connected, and the resulting graph is connected. The graph G is modified in place.
References

3.46 Tournament

Functions concerning tournament graphs.

A tournament graph is a complete oriented graph. In other words, it is a directed graph in which there is exactly one directed edge joining each pair of distinct nodes. For each function in this module that accepts a graph as input, you must provide a tournament graph. The responsibility is on the caller to ensure that the graph is a tournament graph.

To access the functions in this module, you must access them through the `networkx.algorithms.tournament` module:

```python
>>> import networkx as nx
>>> from networkx.algorithms import tournament

>>> G = nx.DiGraph([(0, 1), (1, 2), (2, 0)])
>>> tournament.is_tournament(G)
True
```

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<th>Function</th>
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<td><code>hamiltonian_path(G)</code></td>
<td>Returns a Hamiltonian path in the given tournament graph.</td>
</tr>
<tr>
<td><code>is_reachable(G, s, t)</code></td>
<td>Decides whether there is a path from s to t in the tournament.</td>
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<tr>
<td><code>is_strongly_connected(G)</code></td>
<td>Decides whether the given tournament is strongly connected.</td>
</tr>
<tr>
<td><code>is_tournament(G)</code></td>
<td>Returns True if and only if G is a tournament.</td>
</tr>
<tr>
<td><code>random_tournament(n)</code></td>
<td>Returns a random tournament graph on n nodes.</td>
</tr>
<tr>
<td><code>score_sequence(G)</code></td>
<td>Returns the score sequence for the given tournament graph.</td>
</tr>
</tbody>
</table>

3.46.1 networkx.algorithms.tournament.hamiltonian_path

`hamiltonian_path(G)`

Returns a Hamiltonian path in the given tournament graph.

Each tournament has a Hamiltonian path. If furthermore, the tournament is strongly connected, then the returned Hamiltonian path is a Hamiltonian cycle (by joining the endpoints of the path).

**Parameters**
- `G` (**NetworkX graph**) – A directed graph representing a tournament.

**Returns**
- Whether the given graph is a tournament graph.

**Return type** `bool`

**Notes**

This is a recursive implementation with an asymptotic running time of $O(n^2)$, ignoring multiplicative polylogarithmic factors, where $n$ is the number of nodes in the graph.

3.46.2 networkx.algorithms.tournament.is_reachable

`is_reachable(G, s, t)`

Decides whether there is a path from s to t in the tournament.
This function is more theoretically efficient than the reachability checks than the shortest path algorithms in `networkx.algorithms.shortest_paths`.

The given graph must be a tournament, otherwise this function’s behavior is undefined.

Parameters

- G (NetworkX graph) – A directed graph representing a tournament.
- s (node) – A node in the graph.
- t (node) – A node in the graph.

Returns Whether there is a path from s to t in G.

Return type bool

Notes

Although this function is more theoretically efficient than the generic shortest path functions, a speedup requires the use of parallelism. Though it may in the future, the current implementation does not use parallelism, thus you may not see much of a speedup.

This algorithm comes from [1].

References

3.46.3 networkx.algorithms.tournament.is_strongly_connected

is_strongly_connected(G)

Decides whether the given tournament is strongly connected.

This function is more theoretically efficient than the is_strongly_connected() function.

The given graph must be a tournament, otherwise this function’s behavior is undefined.

Parameters G (NetworkX graph) – A directed graph representing a tournament.

Returns Whether the tournament is strongly connected.

Return type bool

Notes

Although this function is more theoretically efficient than the generic strong connectivity function, a speedup requires the use of parallelism. Though it may in the future, the current implementation does not use parallelism, thus you may not see much of a speedup.

This algorithm comes from [1].

References

3.46.4 networkx.algorithms.tournament.is_tournament

is_tournament(G)

Returns True if and only if G is a tournament.
A tournament is a directed graph, with neither self-loops nor multi-edges, in which there is exactly one directed edge joining each pair of distinct nodes.

**Parameters**

- G *(NetworkX graph)* – A directed graph representing a tournament.

**Returns**

Whether the given graph is a tournament graph.

**Return type**

bool

**Notes**

Some definitions require a self-loop on each node, but that is not the convention used here.

### 3.46.5 `networkx.algorithms.tournament.random_tournament`

**random_tournament** *(n)*

Returns a random tournament graph on *n* nodes.

**Parameters**

- n *(int)* – The number of nodes in the returned graph.

**Returns**

Whether the given graph is a tournament graph.

**Return type**

bool

**Notes**

This algorithm adds, for each pair of distinct nodes, an edge with uniformly random orientation. In other words, \( \text{binom}(n)(2) \) flips of an unbiased coin decide the orientations of the edges in the graph.

### 3.46.6 `networkx.algorithms.tournament.score_sequence`

**score_sequence** *(G)*

Returns the score sequence for the given tournament graph.

The score sequence is the sorted list of the out-degrees of the nodes of the graph.

**Parameters**

- G *(NetworkX graph)* – A directed graph representing a tournament.

**Returns**

A sorted list of the out-degrees of the nodes of *G*.

**Return type**

list

### 3.47 Traversal

#### 3.47.1 Depth First Search

Basic algorithms for depth-first searching the nodes of a graph.

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<td><code>dfs_edges</code></td>
<td>Iterate over edges in a depth-first-search (DFS).</td>
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<tr>
<td><code>dfs_tree</code></td>
<td>Return oriented tree constructed from a depth-first-search from source.</td>
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<th>Method</th>
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<tr>
<td><code>dfs_predecessors(G[, source, depth_limit])</code></td>
<td>Return dictionary of predecessors in depth-first-search from source.</td>
</tr>
<tr>
<td><code>dfs_successors(G[, source, depth_limit])</code></td>
<td>Return dictionary of successors in depth-first-search from source.</td>
</tr>
<tr>
<td><code>dfs_preorder_nodes(G[, source, depth_limit])</code></td>
<td>Generate nodes in a depth-first-search pre-ordering starting at source.</td>
</tr>
<tr>
<td><code>dfs_postorder_nodes(G[, source, depth_limit])</code></td>
<td>Generate nodes in a depth-first-search post-ordering starting at source.</td>
</tr>
<tr>
<td><code>dfs_labeled_edges(G[, source, depth_limit])</code></td>
<td>Iterate over edges in a depth-first-search (DFS) labeled by type.</td>
</tr>
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</table>

#### networkx.algorithms.traversal.depth_first_search.dfs_edges

**dfs_edges** *(G, source=None, depth_limit=None)*

Iterate over edges in a depth-first-search (DFS).

**Parameters**

- **G** *(NetworkX graph)*
- **source** *(node, optional)* – Specify starting node for depth-first search and return edges in the component reachable from source.
- **depth_limit** *(int, optional (default=len(G)))* – Specify the maximum search depth.

**Returns**

- **edges** – A generator of edges in the depth-first-search.

**Return type** generator

**Examples**

```python
>>> G = nx.path_graph(5)
>>> list(nx.dfs_edges(G, source=0))
[(0, 1), (1, 2), (2, 3), (3, 4)]
>>> list(nx.dfs_edges(G, source=0, depth_limit=2))
[(0, 1), (1, 2)]
```

**Notes**

If a source is not specified then a source is chosen arbitrarily and repeatedly until all components in the graph are searched.

The implementation of this function is adapted from David Eppstein’s depth-first search function in PADS, with modifications to allow depth limits based on the Wikipedia article “Depth-limited search”.

**See also:**

- `dfs_preorder_nodes()`, `dfs_postorder_nodes()`, `dfs_labeled_edges()`

#### networkx.algorithms.traversal.depth_first_search.dfs_tree

**dfs_tree** *(G, source=None, depth_limit=None)*

Return oriented tree constructed from a depth-first-search from source.
Parameters

- G (NetworkX graph)
- source (node, optional) – Specify starting node for depth-first search.
- depth_limit (int, optional (default=len(G))) – Specify the maximum search depth.

Returns T – An oriented tree

Return type NetworkX DiGraph

Examples

```python
>>> G = nx.path_graph(5)
>>> T = nx.dfs_tree(G, source=0, depth_limit=2)
>>> list(T.edges())
[(0, 1), (1, 2)]

>>> T = nx.dfs_tree(G, source=0)
>>> list(T.edges())
[(0, 1), (1, 2), (2, 3), (3, 4)]
```

networkx.algorithms.traversal.depth_first_search.dfs_predecessors

dfs_predecessors (G, source=None, depth_limit=None)  
Return dictionary of predecessors in depth-first-search from source.

Parameters

- G (NetworkX graph)
- source (node, optional) – Specify starting node for depth-first search and return edges in the component reachable from source.
- depth_limit (int, optional (default=len(G))) – Specify the maximum search depth.

Returns pred – A dictionary with nodes as keys and predecessor nodes as values.

Return type dict

Examples

```python
>>> G = nx.path_graph(4)
>>> nx.dfs_predecessors(G, source=0)
{1: 0, 2: 1, 3: 2}

>>> nx.dfs_predecessors(G, source=0, depth_limit=2)
{1: 0, 2: 1}
```

Notes

If a source is not specified then a source is chosen arbitrarily and repeatedly until all components in the graph are searched.

The implementation of this function is adapted from David Eppstein’s depth-first search function in PADS, with modifications to allow depth limits based on the Wikipedia article “Depth-limited search”.

3.47. Traversal
networkx.algorithms.traversal.depth_first_search.dfs_successors
dfs_successors \((G, \text{source}=\text{None}, \text{depth\_limit}=\text{None})\)
Return dictionary of successors in depth-first-search from source.

Parameters

- \(G\) (NetworkX graph)
- \text{source} (node, optional) – Specify starting node for depth-first search and return edges in the component reachable from source.
- \text{depth\_limit} (int, optional (default=len(G))) – Specify the maximum search depth.

Returns succ – A dictionary with nodes as keys and list of successor nodes as values.

Return type dict

Examples

```python
>>> G = nx.path_graph(5)
>>> nx.dfs_successors(G, source=0)
{0: [1], 1: [2], 2: [3], 3: [4]}
```

Notes

If a source is not specified then a source is chosen arbitrarily and repeatedly until all components in the graph are searched.

The implementation of this function is adapted from David Eppstein’s depth-first search function in PADS, with modifications to allow depth limits based on the Wikipedia article “Depth-limited search”.

networkx.algorithms.traversal.depth_first_search.dfs_preorder_nodes
dfs_preorder_nodes \((G, \text{source}=\text{None}, \text{depth\_limit}=\text{None})\)
Generate nodes in a depth-first-search pre-ordering starting at source.

Parameters

- \(G\) (NetworkX graph)
- \text{source} (node, optional) – Specify starting node for depth-first search and return edges in the component reachable from source.
- \text{depth\_limit} (int, optional (default=len(G))) – Specify the maximum search depth.

Returns nodes – A generator of nodes in a depth-first-search pre-ordering.

Return type generator

Examples
NetworkX Reference, Release 2.2rc1.dev20180319181321

```python
>>> G = nx.path_graph(5)
>>> list(nx.dfs_preorder_nodes(G, source=0))
[0, 1, 2, 3, 4]
>>> list(nx.dfs_preorder_nodes(G, source=0, depth_limit=2))
[0, 1, 2]
```

Notes

If a source is not specified then a source is chosen arbitrarily and repeatedly until all components in the graph are searched.

The implementation of this function is adapted from David Eppstein’s depth-first search function in PADS, with modifications to allow depth limits based on the Wikipedia article “Depth-limited search”.

See also:

dfs_edges(), dfs_postorder_nodes(), dfs_labeled_edges()

networkx.algorithms.traversal.depth_first_search.dfs_postorder_nodes

dfs_postorder_nodes (G, source=None, depth_limit=None)
Generate nodes in a depth-first-search post-ordering starting at source.

Parameters

• G (NetworkX graph)
• source (node, optional) – Specify starting node for depth-first search and return edges in the component reachable from source.
• depth_limit (int, optional (default=len(G))) – Specify the maximum search depth.

Returns nodes – A generator of nodes in a depth-first-search post-ordering.

Return type generator

Examples

```python
>>> G = nx.path_graph(5)
>>> list(nx.dfs_postorder_nodes(G, source=0))
[4, 3, 2, 1, 0]
>>> list(nx.dfs_postorder_nodes(G, source=0, depth_limit=2))
[1, 0]
```

Notes

If a source is not specified then a source is chosen arbitrarily and repeatedly until all components in the graph are searched.

The implementation of this function is adapted from David Eppstein’s depth-first search function in PADS, with modifications to allow depth limits based on the Wikipedia article “Depth-limited search”.

See also:

dfs_edges(), dfs_preorder_nodes(), dfs_labeled_edges()
networkx.algorithms.traversal.depth_first_search.dfs_labeled_edges

dfs_labeled_edges \((G, \text{source}=\text{None}, \text{depth_limit}=\text{None})\)
Iterate over edges in a depth-first-search (DFS) labeled by type.

Parameters

- \(G\) (*NetworkX graph*)
- \(\text{source}\) (*node, optional*) – Specify starting node for depth-first search and return edges in the component reachable from source.
- \(\text{depth_limit}\) (*int, optional (default=\(\text{len}(G)\))*) – Specify the maximum search depth.

Returns **edges** – A generator of triples of the form \((u, v, d)\), where \((u, v)\) is the edge being explored in the depth-first search and \(d\) is one of the strings ‘forward’, ‘nontree’, or ‘reverse’. A ‘forward’ edge is one in which \(u\) has been visited but \(v\) has not. A ‘nontree’ edge is one in which both \(u\) and \(v\) have been visited but the edge is not in the DFS tree. A ‘reverse’ edge is on in which both \(u\) and \(v\) have been visited and the edge is in the DFS tree.

Return type **generator**

Examples

The labels reveal the complete transcript of the depth-first search algorithm in more detail than, for example, `dfs_edges()`:

```python
>>> from pprint import pprint

>>> G = nx.DiGraph([(0, 1), (1, 2), (2, 1)])

>>> pprint(list(nx.dfs_labeled_edges(G, source=0)))
[(0, 0, 'forward'),
 (0, 1, 'forward'),
 (1, 2, 'forward'),
 (2, 1, 'nontree'),
 (1, 2, 'reverse'),
 (0, 1, 'reverse'),
 (0, 0, 'reverse')]
```

Notes

If a source is not specified then a source is chosen arbitrarily and repeatedly until all components in the graph are searched.

The implementation of this function is adapted from David Eppstein’s depth-first search function in PADS, with modifications to allow depth limits based on the Wikipedia article “Depth-limited search”.

See also:

- `dfs_edges()`, `dfs_preorder_nodes()`, `dfs_postorder_nodes()`

### 3.47.2 Breadth First Search

Basic algorithms for breadth-first searching the nodes of a graph.
bfs_edges(G, source[, reverse])

Iterate over edges in a breadth-first-search starting at source.

Parameters

- G (NetworkX graph)
- source (node) – Specify starting node for breadth-first search and return edges in the component reachable from source.
- reverse (bool, optional) – If True traverse a directed graph in the reverse direction

Returns edges – A generator of edges in the breadth-first-search.

Return type generator

Examples

To get the edges in a breadth-first search:

```python
>>> G = nx.path_graph(3)
>>> list(nx.bfs_edges(G, 0))
[(0, 1), (1, 2)]
```

To get the nodes in a breadth-first search order:

```python
>>> G = nx.path_graph(3)
>>> root = 2
>>> edges = nx.bfs_edges(G, root)
>>> nodes = [root] + [v for u, v in edges]
>>> nodes
[2, 1, 0]
```

Notes


bfs_tree(G, source[, reverse])

Return an oriented tree constructed from of a breadth-first-search starting at source.

Parameters
• **G** *(NetworkX graph)*
• **source** *(node)* – Specify starting node for breadth-first search and return edges in the component reachable from source.
• **reverse** *(bool, optional)* – If True traverse a directed graph in the reverse direction

**Returns**
- **T** – An oriented tree

**Return type**
- NetworkX DiGraph

### Examples
```
>>> G = nx.path_graph(3)
>>> print(list(nx.bfs_tree(G, 1).edges()))
[(1, 0), (1, 2)]
```

### Notes

**networkx.algorithms.traversal.breadth_first_search.bfs_predecessors**

**bfs_predecessors** *(G, source)*
Returns an iterator of predecessors in breadth-first-search from source.

**Parameters**
- **G** *(NetworkX graph)*
- **source** *(node)* – Specify starting node for breadth-first search and return edges in the component reachable from source.

**Returns**
- **pred** – (node, predecessors) iterator where predecessors is the list of predecessors of the node.

**Return type**
- iterator

### Examples
```
>>> G = nx.path_graph(3)
>>> print(dict(nx.bfs_predecessors(G, 0)))
{1: 0, 2: 1}
>>> H = nx.Graph()
>>> H.add_edges_from([(0, 1), (0, 2), (1, 3), (1, 4), (2, 5), (2, 6)])
>>> dict(nx.bfs_predecessors(H, 0))
{1: 0, 2: 0, 3: 1, 4: 1, 5: 2, 6: 2}
```

### Notes
networkx.algorithms.traversal.breadth_first_search.bfs_successors

bfs_successors (G, source)

Returns an iterator of successors in breadth-first-search from source.

Parameters

• G (NetworkX graph)
• source (node) – Specify starting node for breadth-first search and return edges in the component reachable from source.

Returns succ – (node, successors) iterator where successors is the list of successors of the node.

Return type iterator

Examples

```python
>>> G = nx.path_graph(3)
>>> print(dict(nx.bfs_successors(G,0))
{0: [1], 1: [2]}
>>> H = nx.Graph()
>>> H.add_edges_from([(0, 1), (0, 2), (1, 3), (1, 4), (2, 5), (2, 6)])
>>> dict(nx.bfs_successors(H, 0))
{0: [1, 2], 1: [3, 4], 2: [5, 6]}
```

Notes


3.47.3 Beam search

Basic algorithms for breadth-first searching the nodes of a graph.

bfs_beam_edges(G, source, value[, width]) Iterates over edges in a beam search.

networkx.algorithms.traversal.beamsearch.bfs_beam_edges

bfs_beam_edges (G, source, value, width=None)

Iterates over edges in a beam search.

The beam search is a generalized breadth-first search in which only the “best” \( w \) neighbors of the current node are enqueued, where \( w \) is the beam width and “best” is an application-specific heuristic. In general, a beam search with a small beam width might not visit each node in the graph.

Parameters

• G (NetworkX graph)
• source (node) – Starting node for the breadth-first search; this function iterates over only those edges in the component reachable from this node.
• value (function) – A function that takes a node of the graph as input and returns a real number indicating how “good” it is. A higher value means it is more likely to be visited
sooner during the search. When visiting a new node, only the width neighbors with the highest value are enqueued (in decreasing order of value).

- **width (int (default = None))** – The beam width for the search. This is the number of neighbors (ordered by value) to enqueue when visiting each new node.

**Yields edge** – Edges in the beam search starting from source, given as a pair of nodes.

**Examples**

To give nodes with, for example, a higher centrality precedence during the search, set the value function to return the centrality value of the node:

```python
>>> G = nx.karate_club_graph()
>>> centrality = nx.eigenvector_centrality(G)
>>> source = 0
>>> width = 5
>>> for u, v in nx.bfs_beam_edges(G, source, centrality.get, width):
...     print((u, v))
```

### 3.47.4 Depth First Search on Edges

**Depth First Search on Edges**

Algorithms for a depth-first traversal of edges in a graph.

#### edge_dfs(G[, source, orientation])

A directed, depth-first traversal of edges in G, beginning at source.

**Examples**

```python
>>> edge_dfs(G)  # A directed, depth-first traversal of edges in G, beginning at source.
```

**networkx.algorithms.traversal.edgedfs.edge_dfs**

**edge_dfs (G, source=’None’, orientation=’original’)**

A directed, depth-first traversal of edges in G, beginning at source.

**Parameters**

- **G (graph)** – A directed/undirected graph/multigraph.

- **source (node, list of nodes)** – The node from which the traversal begins. If None, then a source is chosen arbitrarily and repeatedly until all edges from each node in the graph are searched.

- **orientation (’original’, ’reverse’, ’ignore’)** – For directed graphs and directed multigraphs, edge traversals need not respect the original orientation of the edges. When set to ‘reverse’, then every edge will be traversed in the reverse direction. When set to ‘ignore’, then each directed edge is treated as a single undirected edge that can be traversed in either direction. For undirected graphs and undirected multigraphs, this parameter is meaningless and is not consulted by the algorithm.

**Yields edge (directed edge)** – A directed edge indicating the path taken by the depth-first traversal. For graphs, edge is of the form (u, v) where u and v are the tail and head of the edge as determined by the traversal. For multigraphs, edge is of the form (u, v, key), where key is the key of the edge. When the graph is directed, then u and v are always in the order of the actual directed edge. If orientation is ‘reverse’ or ‘ignore’, then edge takes the form (u, v,
key, direction) where direction is a string, ‘forward’ or ‘reverse’, that indicates if the edge was traversed in the forward (tail to head) or reverse (head to tail) direction, respectively.

Examples

```python
>>> import networkx as nx
>>> nodes = [0, 1, 2, 3]
>>> edges = [(0, 1), (1, 0), (1, 0), (2, 1), (3, 1)]

>>> list(nx.edge_dfs(nx.Graph(edges), nodes))
[(0, 1), (1, 2), (1, 3)]

>>> list(nx.edge_dfs(nx.DiGraph(edges), nodes))
[(0, 1), (1, 0), (2, 1), (3, 1)]

>>> list(nx.edge_dfs(nx.MultiGraph(edges), nodes))
[(0, 1, 0), (1, 0, 1), (0, 1, 2), (1, 2, 0), (1, 3, 0)]

>>> list(nx.edge_dfs(nx.MultiDiGraph(edges), nodes))
[(0, 1, 0), (1, 0, 0), (1, 0, 1), (2, 1, 0), (3, 1, 0)]

>>> list(nx.edge_dfs(nx.DiGraph(edges), nodes, orientation='ignore'))
[(0, 1, 'forward'), (1, 0, 'forward'), (2, 1, 'reverse'), (3, 1, 'reverse')]

>>> list(nx.edge_dfs(nx.MultiDiGraph(edges), nodes, orientation='ignore'))
[(0, 1, 'forward'), (1, 0, 0, 'forward'), (1, 0, 1, 'reverse'), (2, 1, 0, 'reverse'), (3, 1, 0, 'reverse')]
```

Notes

The goal of this function is to visit edges. It differs from the more familiar depth-first traversal of nodes, as provided by `networkx.algorithms.traversal.depth_first_search.dfs_edges()`, in that it does not stop once every node has been visited. In a directed graph with edges [(0, 1), (1, 2), (2, 1)], the edge (2, 1) would not be visited if not for the functionality provided by this function.

See also:

dfs_edges()

3.48 Tree

3.48.1 Recognition

Recognition Tests

A forest is an acyclic, undirected graph, and a tree is a connected forest. Depending on the subfield, there are various conventions for generalizing these definitions to directed graphs.

In one convention, directed variants of forest and tree are defined in an identical manner, except that the direction of the edges is ignored. In effect, each directed edge is treated as a single undirected edge. Then, additional restrictions are imposed to define branchings and arborescences.
In another convention, directed variants of forest and tree correspond to the previous convention’s branchings and arborescences, respectively. Then two new terms, *polyforest* and *polytree*, are defined to correspond to the other convention’s forest and tree.

Summarizing:

| -----------------------------+ | -----------------------------+ |
| | Convention A | Convention B |
| -----------------------------+ | -----------------------------+ |
| forest | polyforest |
| tree | polytree |
| branching | forest |
| arborescence | tree |

Each convention has its reasons. The first convention emphasizes definitional similarity in that directed forests and trees are only concerned with acyclicity and do not have an in-degree constraint, just as their undirected counterparts do not. The second convention emphasizes functional similarity in the sense that the directed analog of a spanning tree is a spanning arborescence. That is, take any spanning tree and choose one node as the root. Then every edge is assigned a direction such there is a directed path from the root to every other node. The result is a spanning arborescence.

NetworkX follows convention “A”. Explicitly, these are:

**undirected forest** An undirected graph with no undirected cycles.

**undirected tree** A connected, undirected forest.

**directed forest** A directed graph with no undirected cycles. Equivalently, the underlying graph structure (which ignores edge orientations) is an undirected forest. In convention B, this is known as a polyforest.

**directed tree** A weakly connected, directed forest. Equivalently, the underlying graph structure (which ignores edge orientations) is an undirected tree. In convention B, this is known as a polytree.

**branching** A directed forest with each node having, at most, one parent. So the maximum in-degree is equal to 1. In convention B, this is known as a forest.

**arborescence** A directed tree with each node having, at most, one parent. So the maximum in-degree is equal to 1. In convention B, this is known as a tree.

For trees and arborescences, the adjective “spanning” may be added to designate that the graph, when considered as a forest/branching, consists of a single tree/arborescence that includes all nodes in the graph. It is true, by definition, that every tree/arborescence is spanning with respect to the nodes that define the tree/arborescence and so, it might seem redundant to introduce the notion of “spanning”. However, the nodes may represent a subset of nodes from a larger graph, and it is in this context that the term “spanning” becomes a useful notion.

| **is_tree(G)** | Returns True if G is a tree. |
| **is_forest(G)** | Returns True if G is a forest. |
| **is_arborescence(G)** | Returns True if G is an arborescence. |
| **is_branching(G)** | Returns True if G is a branching. |

**networkx.algorithms.tree.recognition.is_tree**

**is_tree(G)**

Returns True if G is a tree.

A tree is a connected graph with no undirected cycles.

For directed graphs, G is a tree if the underlying graph is a tree. The underlying graph is obtained by treating each directed edge as a single undirected edge in a multigraph.
Parameters  \( G \) (graph) – The graph to test.
Returns  \( b \) – A boolean that is True if \( G \) is a tree.
Return type  bool

Notes

In another convention, a directed tree is known as a polytree and then tree corresponds to an arborescence.

See also:

\( \text{is\_arborescence()} \)

**networkx.algorithms.tree.recognition.is_forest**

is_forest \((G)\)
Returns True if \( G \) is a forest.
A forest is a graph with no undirected cycles.
For directed graphs, \( G \) is a forest if the underlying graph is a forest. The underlying graph is obtained by treating each directed edge as a single undirected edge in a multigraph.

Parameters  \( G \) (graph) – The graph to test.
Returns  \( b \) – A boolean that is True if \( G \) is a forest.
Return type  bool

Notes

In another convention, a directed forest is known as a polyforest and then forest corresponds to a branching.

See also:

\( \text{is\_branching()} \)

**networkx.algorithms.tree.recognition.is_arborescence**

is_arborescence \((G)\)
Returns True if \( G \) is an arborescence.
An arborescence is a directed tree with maximum in-degree equal to 1.

Parameters  \( G \) (graph) – The graph to test.
Returns  \( b \) – A boolean that is True if \( G \) is an arborescence.
Return type  bool

Notes

In another convention, an arborescence is known as a tree.

See also:

\( \text{is\_tree()} \)
is_branching \((G)\)

Returns True if \(G\) is a branching.

A branching is a directed forest with maximum in-degree equal to 1.

**Parameters**

- \(G\) (directed graph) – The directed graph to test.

**Returns**

- \(b\) – A boolean that is True if \(G\) is a branching.

**Return type**

- \(bool\)

**Notes**

In another convention, a branching is also known as a forest.

**See also**

- is_forest()

### 3.48.2 Branchings and Spanning Arborescences

Algorithms for finding optimum branchings and spanning arborescences.

This implementation is based on:


<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>branching_weight ((G, \text{attr='weight', default=1}))</td>
<td>Returns the total weight of a branching.</td>
</tr>
<tr>
<td>greedy_branching ((G, \text{attr='weight', default=1, kind='max'}))</td>
<td>Returns a branching obtained through a greedy algorithm.</td>
</tr>
<tr>
<td>maximum_branching ((G, \text{attr=\text{default}}))</td>
<td>Returns a maximum branching from (G).</td>
</tr>
<tr>
<td>minimum_branching ((G, \text{attr=\text{default}}))</td>
<td>Returns a minimum branching from (G).</td>
</tr>
<tr>
<td>maximum_spanning_arborescence ((G, \text{attr=\text{default}}))</td>
<td>Returns a maximum spanning arborescence from (G).</td>
</tr>
<tr>
<td>minimum_spanning_arborescence ((G, \text{attr=\text{default}}))</td>
<td>Returns a minimum spanning arborescence from (G).</td>
</tr>
<tr>
<td>Edmonds ((G, \text{seed}))</td>
<td>Edmonds algorithm for finding optimal branchings and spanning arborescences.</td>
</tr>
</tbody>
</table>

**networkx.algorithms.tree.branchings.branching_weight**

branching_weight \((G, \text{attr='weight', default=1})\)

Returns the total weight of a branching.

**networkx.algorithms.tree.branchings.greedy_branching**

greedy_branching \((G, \text{attr='weight', default=1, kind='max'})\)

Returns a branching obtained through a greedy algorithm.

This algorithm is wrong, and cannot give a proper optimal branching. However, we include it for pedagogical reasons, as it can be helpful to see what its outputs are.
The output is a branching, and possibly, a spanning arborescence. However, it is not guaranteed to be optimal in either case.

**Parameters**

- **G** (*DiGraph*) – The directed graph to scan.
- **attr** (*str*) – The attribute to use as weights. If None, then each edge will be treated equally with a weight of 1.
- **default** (*float*) – When attr is not None, then if an edge does not have that attribute, default specifies what value it should take.
- **kind** (*str*) – The type of optimum to search for: ‘min’ or ‘max’ greedy branching.

**Returns** B – The greedily obtained branching.

**Return type** directed graph

`networkx.algorithms.tree.branchings.maximum_branching`

**maximum_branching** *(G, attr='weight', default=1)*

Returns a maximum branching from G.

**Parameters**

- **G** ((multi)digraph-like) – The graph to be searched.
- **attr** (*str*) – The edge attribute used to in determining optimality.
- **default** (*float*) – The value of the edge attribute used if an edge does not have the attribute attr.

**Returns** B – A maximum branching.

**Return type** (multi)digraph-like

`networkx.algorithms.tree.branchings.minimum_branching`

**minimum_branching** *(G, attr='weight', default=1)*

Returns a minimum branching from G.

**Parameters**

- **G** ((multi)digraph-like) – The graph to be searched.
- **attr** (*str*) – The edge attribute used to in determining optimality.
- **default** (*float*) – The value of the edge attribute used if an edge does not have the attribute attr.

**Returns** B – A minimum branching.

**Return type** (multi)digraph-like

`networkx.algorithms.tree.branchings.maximum_spanning_arborescence`

**maximum_spanning_arborescence** *(G, attr='weight', default=1)*

Returns a maximum spanning arborescence from G.

**Parameters**
• **G** *(multi)digraph-like* – The graph to be searched.

• **attr** *(str)* – The edge attribute used to in determining optimality.

• **default** *(float)* – The value of the edge attribute used if an edge does not have the attribute `attr`.

**Returns** B – A maximum spanning arborescence.

**Return type** *(multi)digraph-like*

**Raises** `NetworkXException` – If the graph does not contain a maximum spanning arborescence.

---

networkx.algorithms.tree.branchings.minimum_spanning_arborescence

**minimum_spanning_arborescence** *(G, attr='weight', default=1)*

Returns a minimum spanning arborescence from G.

**Parameters**

• **G** *(multi)digraph-like* – The graph to be searched.

• **attr** *(str)* – The edge attribute used to in determining optimality.

• **default** *(float)* – The value of the edge attribute used if an edge does not have the attribute `attr`.

**Returns** B – A minimum spanning arborescence.

**Return type** *(multi)digraph-like*

**Raises** `NetworkXException` – If the graph does not contain a minimum spanning arborescence.

---

networkx.algorithms.tree.branchings.Edmonds

**class Edmonds** *(G, seed=None)*

Edmonds algorithm for finding optimal branchings and spanning arborescences.

**__init__** *(G, seed=None)*

`x.__init__(...) initializes x; see help(type(x)) for signature`

**Methods**

**__init__**(G[, seed])

`x.__init__(...)` initializes x; see help(type(x)) for signature

**find_optimum**(attr, default, kind, style)

Returns a branching from G.

---

### 3.48.3 Encoding and decoding

Functions for encoding and decoding trees.

Since a tree is a highly restricted form of graph, it can be represented concisely in several ways. This module includes functions for encoding and decoding trees in the form of nested tuples and Prüfer sequences. The former requires a rooted tree, whereas the latter can be applied to unrooted trees. Furthermore, there is a bijection from Prüfer sequences to labeled trees.
from_nested_tuple(sequence[, ...]) Returns the rooted tree corresponding to the given nested tuple.

to_nested_tuple(T, root[, canonical_form]) Returns a nested tuple representation of the given tree.

from_prufer_sequence(sequence) Returns the tree corresponding to the given Prüfer sequence.

to_prufer_sequence(T) Returns the Prüfer sequence of the given tree.

networkx.algorithms.tree.coding.from_nested_tuple

from_nested_tuple (sequence, sensible_relabeling=False)
Returns the rooted tree corresponding to the given nested tuple.

The nested tuple representation of a tree is defined recursively. The tree with one node and no edges is represented by the empty tuple, (0). A tree with k subtrees is represented by a tuple of length k in which each element is the nested tuple representation of a subtree.

Parameters

- sequence (tuple) – A nested tuple representing a rooted tree.
- sensible_relabeling (bool) – Whether to relabel the nodes of the tree so that nodes are labeled in increasing order according to their breadth-first search order from the root node.

Returns

The tree corresponding to the given nested tuple, whose root node is node 0. If sensible_relabeling is True, nodes will be labeled in breadth-first search order starting from the root node.

Return type
NetworkX graph

Notes

This function is not the inverse of to_nested_tuple(); the only guarantee is that the rooted trees are isomorphic.

See also:

to_nested_tuple(), from_prufer_sequence()

Examples

Sensible relabeling ensures that the nodes are labeled from the root starting at 0:

```python
>>> balanced = ((((), ()), ()), ((), ()))
>>> T = nx.from_nested_tuple(balanced, sensible_relabeling=True)
>>> edges = [(0, 1), (0, 2), (1, 3), (1, 4), (2, 5), (2, 6)]
>>> all((u, v) in T.edges() or (v, u) in T.edges() for (u, v) in edges)
True
```

networkx.algorithms.tree.coding.to_nested_tuple

to_nested_tuple (T, root, canonical_form=False)
Returns a nested tuple representation of the given tree.
The nested tuple representation of a tree is defined recursively. The tree with one node and no edges is represented by the empty tuple, (). A tree with \( k \) subtrees is represented by a tuple of length \( k \) in which each element is the nested tuple representation of a subtree.

**Parameters**

- \( T \) (*NetworkX graph*) – An undirected graph object representing a tree.
- \( \text{root} \) (*node*) – The node in \( T \) to interpret as the root of the tree.
- \( \text{canonical\_form} \) (*bool*) – If True, each tuple is sorted so that the function returns a canonical form for rooted trees. This means “lighter” subtrees will appear as nested tuples before “heavier” subtrees. In this way, each isomorphic rooted tree has the same nested tuple representation.

**Returns** A nested tuple representation of the tree.

**Return type** tuple

**Notes**

This function is not the inverse of *from_nested_tuple()*; the only guarantee is that the rooted trees are isomorphic.

**See also:**

*from_nested_tuple()* , *to_prufer_sequence()*

**Examples**

The tree need not be a balanced binary tree:

```python
>>> T = nx.Graph()
>>> T.add_edges_from([(0, 1), (0, 2), (0, 3)])
>>> T.add_edges_from([(1, 4), (1, 5)])
>>> T.add_edges_from([(3, 6), (3, 7)])
>>> root = 0
>>> nx.to_nested_tuple(T, root)
((), ((), ()), ((), ()))
```

Continuing the above example, if \( \text{canonical\_form} \) is True, the nested tuples will be sorted:

```python
>>> nx.to_nested_tuple(T, root, canonical_form=True)
((), ((), ()), ((), ()))
```

Even the path graph can be interpreted as a tree:

```python
>>> T = nx.path_graph(4)
>>> root = 0
>>> nx.to_nested_tuple(T, root)
((), (), ((), ()))
```

**networkx.algorithms.tree.coding.from_prufer_sequence**

*from_prufer_sequence* (*sequence*)

Returns the tree corresponding to the given Prüfer sequence.
A *Prüfer sequence* is a list of $n - 2$ numbers between 0 and $n - 1$, inclusive. The tree corresponding to a given Prüfer sequence can be recovered by repeatedly joining a node in the sequence with a node with the smallest potential degree according to the sequence.

**Parameters**
- *sequence* (*list*) – A Prüfer sequence, which is a list of $n - 2$ integers between zero and $n - 1$, inclusive.

**Returns**
The tree corresponding to the given Prüfer sequence.

**Return type**
NetworkX graph

**Notes**

There is a bijection from labeled trees to Prüfer sequences. This function is the inverse of the `from_prufer_sequence()` function.

Sometimes Prüfer sequences use nodes labeled from 1 to $n$ instead of from 0 to $n - 1$. This function requires nodes to be labeled in the latter form. You can use `networkx.relabel_nodes()` to relabel the nodes of your tree to the appropriate format.

This implementation is from\(^1\) and has a running time of $O(n \log n)$.

**References**

See also:

`from_nested_tuple()`, `to_prufer_sequence()`

**Examples**

There is a bijection between Prüfer sequences and labeled trees, so this function is the inverse of the `to_prufer_sequence()` function:

```python
>>> edges = [(0, 3), (1, 3), (2, 3), (3, 4), (4, 5)]
>>> tree = nx.Graph(edges)
>>> sequence = nx.to_prufer_sequence(tree)
>>> sequence
[3, 3, 3, 4]
>>> tree2 = nx.from_prufer_sequence(sequence)
>>> list(tree2.edges()) == edges
True
```

Returns  The Prüfer sequence of the given tree.

Return type  list

Raises

- NetworkXPointlessConcept – If the number of nodes in T is less than two.
- NotATree – If T is not a tree.
- KeyError – If the set of nodes in T is not {0, ..., n - 1}.

Notes

There is a bijection from labeled trees to Prüfer sequences. This function is the inverse of the from_prufer_sequence() function.

Sometimes Prüfer sequences use nodes labeled from 1 to n instead of from 0 to n - 1. This function requires nodes to be labeled in the latter form. You can use relabel_nodes() to relabel the nodes of your tree to the appropriate format.

This implementation is from¹ and has a running time of $O(n \log n)$.

See also:

to_nested_tuple(), from_prufer_sequence()

References

Examples

There is a bijection between Prüfer sequences and labeled trees, so this function is the inverse of the from_prufer_sequence() function:

```python
>>> edges = [(0, 3), (1, 3), (2, 3), (3, 4), (4, 5)]
>>> tree = nx.Graph(edges)
>>> sequence = nx.to_prufer_sequence(tree)
>>> sequence
[3, 3, 3, 4]
>>> tree2 = nx.from_prufer_sequence(sequence)
>>> list(tree2.edges()) == edges
True
```

3.48.4 Operations

Operations on trees.

| `join(rooted_trees[, label_attribute])` | Returns a new rooted tree with a root node joined with the roots of each of the given rooted trees. |

networkx.algorithms.tree.operations.join

join(rooted_trees, label_attribute=None)

Returns a new rooted tree with a root node joined with the roots of each of the given rooted trees.

Parameters

- **rooted_trees** (list) – A list of pairs in which each left element is a NetworkX graph object representing a tree and each right element is the root node of that tree. The nodes of these trees will be relabeled to integers.

- **label_attribute** (str) – If provided, the old node labels will be stored in the new tree under this node attribute. If not provided, the node attribute '_old' will store the original label of the node in the rooted trees given in the input.

Returns The rooted tree whose subtrees are the given rooted trees. The new root node is labeled 0. Each non-root node has an attribute, as described under the keyword argument label_attribute, that indicates the label of the original node in the input tree.

Return type NetworkX graph

Notes

Graph, edge, and node attributes are propagated from the given rooted trees to the created tree. If there are any overlapping graph attributes, those from later trees will overwrite those from earlier trees in the tuple of positional arguments.

Examples

Join two full balanced binary trees of height \( h \) to get a full balanced binary tree of depth \( h + 1 \):

```python
>>> h = 4
>>> left = nx.balanced_tree(2, h)
>>> right = nx.balanced_tree(2, h)
>>> joined_tree = nx.join([(left, 0), (right, 0)])
>>> nx.is_isomorphic(joined_tree, nx.balanced_tree(2, h + 1))
True
```

3.48.5 Spanning Trees

Algorithms for calculating min/max spanning trees/forests.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>minimum_spanning_tree(G[, weight,...])</td>
<td>Returns a minimum spanning tree or forest on an undirected graph G.</td>
</tr>
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<td>maximum_spanning_tree(G[, weight,...])</td>
<td>Returns a maximum spanning tree or forest on an undirected graph G.</td>
</tr>
<tr>
<td>minimum_spanning_edges(G[, algorithm,...])</td>
<td>Generate edges in a minimum spanning forest of an undirected weighted graph.</td>
</tr>
<tr>
<td>maximum_spanning_edges(G[, algorithm,...])</td>
<td>Generate edges in a maximum spanning forest of an undirected weighted graph.</td>
</tr>
</tbody>
</table>
networkx.algorithms.tree.mst.minimum_spanning_tree

minimum_spanning_tree(G, weight='weight', algorithm='kruskal', ignore_nan=False)

Returns a minimum spanning tree or forest on an undirected graph G.

Parameters

- G (undirected graph) – An undirected graph. If G is connected, then the algorithm finds a spanning tree. Otherwise, a spanning forest is found.
- weight (str) – Data key to use for edge weights.
- algorithm (string) – The algorithm to use when finding a minimum spanning tree. Valid choices are ‘kruskal’, ‘prim’, or ‘boruvka’. The default is ‘kruskal’.
- ignore_nan (bool (default: False)) – If a NaN is found as an edge weight normally an exception is raised. If ignore_nan is True then that edge is ignored instead.

Returns G – A minimum spanning tree or forest.

Return type NetworkX Graph

Examples

```python
>>> G = nx.cycle_graph(4)
>>> G.add_edge(0, 3, weight=2)
>>> T = nx.minimum_spanning_tree(G)
>>> sorted(T.edges(data=True))
[(0, 1, {}), (1, 2, {}), (2, 3, {})]
```

Notes

For Borůvka’s algorithm, each edge must have a weight attribute, and each edge weight must be distinct.

For the other algorithms, if the graph edges do not have a weight attribute a default weight of 1 will be used.

There may be more than one tree with the same minimum or maximum weight. See networkx.tree.recognition for more detailed definitions.

Isolated nodes with self-loops are in the tree as edgeless isolated nodes.

networkx.algorithms.tree.mst.maximum_spanning_tree

maximum_spanning_tree(G, weight='weight', algorithm='kruskal', ignore_nan=False)

Returns a maximum spanning tree or forest on an undirected graph G.

Parameters

- G (undirected graph) – An undirected graph. If G is connected, then the algorithm finds a spanning tree. Otherwise, a spanning forest is found.
- weight (str) – Data key to use for edge weights.
- algorithm (string) – The algorithm to use when finding a minimum spanning tree. Valid choices are ‘kruskal’, ‘prim’, or ‘boruvka’. The default is ‘kruskal’.
- ignore_nan (bool (default: False)) – If a NaN is found as an edge weight normally an exception is raised. If ignore_nan is True then that edge is ignored instead.
Returns G – A minimum spanning tree or forest.

Return type NetworkX Graph

Examples

```
>>> G = nx.cycle_graph(4)
>>> G.add_edge(0, 3, weight=2)
>>> T = nx.maximum_spanning_tree(G)
>>> sorted(T.edges(data=True))
[(0, 1, {}), (0, 3, {'weight': 2}), (1, 2, {})]
```

Notes

For Borůvka’s algorithm, each edge must have a weight attribute, and each edge weight must be distinct.

For the other algorithms, if the graph edges do not have a weight attribute a default weight of 1 will be used.

There may be more than one tree with the same minimum or maximum weight. See networkx.tree.recognition for more detailed definitions.

Isolated nodes with self-loops are in the tree as edgeless isolated nodes.

networkx.algorithms.tree.mst.minimum_spanning_edges

minimum_spanning_edges(G, algorithm='kruskal', weight='weight', keys=True, data=True, ignore_nan=False)
Generate edges in a minimum spanning forest of an undirected weighted graph.

A minimum spanning tree is a subgraph of the graph (a tree) with the minimum sum of edge weights. A spanning forest is a union of the spanning trees for each connected component of the graph.

Parameters

- G (undirected Graph) – An undirected graph. If G is connected, then the algorithm finds a spanning tree. Otherwise, a spanning forest is found.
- algorithm (string) – The algorithm to use when finding a minimum spanning tree. Valid choices are ‘kruskal’, ‘prim’, or ‘boruvka’. The default is ‘kruskal’.
- weight (string) – Edge data key to use for weight (default ‘weight’).
- keys (bool) – Whether to yield edge key in multigraphs in addition to the edge. If G is not a multigraph, this is ignored.
- data (bool, optional) – If True yield the edge data along with the edge.
- ignore_nan (bool (default: False)) – If a NaN is found as an edge weight normally an exception is raised. If ignore_nan is True then that edge is ignored instead.

Returns edges – An iterator over edges in a maximum spanning tree of G. Edges connecting nodes u and v are represented as tuples: (u, v, k, d) or (u, v, k) or (u, v, d) or (u, v)

If G is a multigraph, keys indicates whether the edge key k will be reported in the third position in the edge tuple. data indicates whether the edge datadict d will appear at the end of the edge tuple.
If \( G \) is not a multigraph, the tuples are \((u, v, d)\) if \( \text{data} \) is \( \text{True} \) or \((u, v)\) if \( \text{data} \) is \( \text{False} \).

**Return type** iterator

**Examples**

```python
>>> from networkx.algorithms import tree

Find minimum spanning edges by Kruskal’s algorithm
```

```python
>>> G = nx.cycle_graph(4)
>>> G.add_edge(0, 3, weight=2)
>>> mst = tree.minimum_spanning_edges(G, algorithm='kruskal', data=False)
>>> edgelist = list(mst)
>>> sorted(edgelist)
[(0, 1), (1, 2), (2, 3)]
```

Find minimum spanning edges by Prim’s algorithm
```
>>> G = nx.cycle_graph(4)
>>> G.add_edge(0, 3, weight=2)
>>> mst = tree.minimum_spanning_edges(G, algorithm='prim', data=False)
>>> edgelist = list(mst)
>>> sorted(edgelist)
[(0, 1), (1, 2), (2, 3)]
```

**Notes**

For Borůvka’s algorithm, each edge must have a weight attribute, and each edge weight must be distinct.

For the other algorithms, if the graph edges do not have a weight attribute a default weight of 1 will be used.


**networkx.algorithms.tree.mst.maximum_spanning_edges**

maximum_spanning_edges \((G, \text{algorithm}='\text{kruskal}', \text{weight}='\text{weight}', \text{keys}=\text{True}, \text{data}=\text{True}, \text{ignore_nan}=\text{False})\)

Generate edges in a maximum spanning forest of an undirected weighted graph.

A maximum spanning tree is a subgraph of the graph (a tree) with the maximum possible sum of edge weights. A spanning forest is a union of the spanning trees for each connected component of the graph.

**Parameters**

- \( G \) (undirected Graph) – An undirected graph. If \( G \) is connected, then the algorithm finds a spanning tree. Otherwise, a spanning forest is found.
- **algorithm** (string) – The algorithm to use when finding a maximum spanning tree. Valid choices are ‘kruskal’, ‘prim’, or ‘boruvka’. The default is ‘kruskal’.
- **weight** (string) – Edge data key to use for weight (default ‘weight’).
- **keys** (bool) – Whether to yield edge key in multigraphs in addition to the edge. If \( G \) is not a multigraph, this is ignored.
• **data** (bool, optional) – If True yield the edge data along with the edge.

• **ignore_nan** (bool (default: False)) – If a NaN is found as an edge weight normally an exception is raised. If ignore_nan is True then that edge is ignored instead.

**Returns**

- **edges** – An iterator over edges in a maximum spanning tree of G. Edges connecting nodes u and v are represented as tuples: (u, v, k, d) or (u, v, k) or (u, v, d) or (u, v)

   If G is a multigraph, keys indicates whether the edge key k will be reported in the third position in the edge tuple. data indicates whether the edge datadict d will appear at the end of the edge tuple.

   If G is not a multigraph, the tuples are (u, v, d) if data is True or (u, v) if data is False.

**Return type** iterator

**Examples**

```python
>>> from networkx.algorithms import tree

Find maximum spanning edges by Kruskal’s algorithm

```python
g = nx.cycle_graph(4)
g.add_edge(0, 3, weight=2)
mst = tree.maximum_spanning_edges(g, algorithm='kruskal', data=False)
edgelist = list(mst)
sorted(edgelist)
```

Find maximum spanning edges by Prim’s algorithm

```python
g = nx.cycle_graph(4)
g.add_edge(0, 3, weight=2) # assign weight 2 to edge 0-3
mst = tree.maximum_spanning_edges(g, algorithm='prim', data=False)
edgelist = list(mst)
sorted(edgelist)
```

**Notes**

For Borůvka’s algorithm, each edge must have a weight attribute, and each edge weight must be distinct.

For the other algorithms, if the graph edges do not have a weight attribute a default weight of 1 will be used.

Modified code from David Eppstein, April 2006 http://www.ics.uci.edu/~eppstein/PADS/

**3.48.6 Exceptions**

Functions for encoding and decoding trees.

Since a tree is a highly restricted form of graph, it can be represented concisely in several ways. This module includes functions for encoding and decoding trees in the form of nested tuples and Prüfer sequences. The former requires a
rooted tree, whereas the latter can be applied to unrooted trees. Furthermore, there is a bijection from Prüfer sequences to labeled trees.

<table>
<thead>
<tr>
<th>NotATree</th>
<th>Raised when a function expects a tree (that is, a connected undirected graph with no cycles) but gets a non-tree graph as input instead.</th>
</tr>
</thead>
</table>

networkx.algorithms.tree.coding.NotATree

exception NotATree

Raised when a function expects a tree (that is, a connected undirected graph with no cycles) but gets a non-tree graph as input instead.

### 3.49 Triads

Functions for analyzing triads of a graph.

<table>
<thead>
<tr>
<th>triadic_census(G)</th>
<th>Determines the triadic census of a directed graph.</th>
</tr>
</thead>
</table>

#### 3.49.1 networkx.algorithms.triads.triadic_census

**triadic_census** *(G)*

Determines the triadic census of a directed graph.

The triadic census is a count of how many of the 16 possible types of triads are present in a directed graph.

- **Parameters** *G* *(digraph)* – A NetworkX DiGraph
- **Returns** *census* – Dictionary with triad names as keys and number of occurrences as values.
- **Return type** *dict*

**Notes**

This algorithm has complexity $O(m)$ where $m$ is the number of edges in the graph.

**See also:**

triad_graph()

**References**

### 3.50 Vitality

Vitality measures.

<table>
<thead>
<tr>
<th>closeness_vitality(G[, node, weight, ...])</th>
<th>Returns the closeness vitality for nodes in the graph.</th>
</tr>
</thead>
</table>
3.50.1 networkx.algorithms.vitality.closeness_vitality

**closeness_vitality** *(G, node=None, weight=None, wiener_index=None)*

Returns the closeness vitality for nodes in the graph.

The *closeness vitality* of a node, defined in Section 3.6.2 of [1], is the change in the sum of distances between all node pairs when excluding that node.

**Parameters**

- **G** *(NetworkX graph)* – A strongly-connected graph.
- **weight** *(string)* – The name of the edge attribute used as weight. This is passed directly to the *wiener_index()* function.
- **node** *(object)* – If specified, only the closeness vitality for this node will be returned. Otherwise, a dictionary mapping each node to its closeness vitality will be returned.

**Other Parameters**

- **wiener_index** *(number)* – If you have already computed the Wiener index of the graph G, you can provide that value here. Otherwise, it will be computed for you.

**Returns**

If *node* is None, this function returns a dictionary with nodes as keys and closeness vitality as the value. Otherwise, it returns only the closeness vitality for the specified *node*.

The closeness vitality of a node may be negative infinity if removing that node would disconnect the graph.

**Return type** dictionary or float

**Examples**

```python
>>> G = nx.cycle_graph(3)
>>> nx.closeness_vitality(G)
{0: 2.0, 1: 2.0, 2: 2.0}
```

**See also:**

closeness_centrality()

**References**

3.51 Voronoi cells

Functions for computing the Voronoi cells of a graph.

**voronoi_cells** *(G, center_nodes[, weight])*

Returns the Voronoi cells centered at *center_nodes* with respect to the shortest-path distance metric.

3.51.1 networkx.algorithms.voronoi.voronoi_cells

**voronoi_cells** *(G, center_nodes, weight='weight')*

Returns the Voronoi cells centered at *center_nodes* with respect to the shortest-path distance metric.
If \( C \) is a set of nodes in the graph and \( c \) is an element of \( C \), the Voronoi cell centered at a node \( c \) is the set of all nodes \( v \) that are closer to \( c \) than to any other center node in \( C \) with respect to the shortest-path distance metric.\(^1\)

For directed graphs, this will compute the “outward” Voronoi cells, as defined in\(^1\), in which distance is measured from the center nodes to the target node. For the “inward” Voronoi cells, use the \texttt{DiGraph.reverse()} method to reverse the orientation of the edges before invoking this function on the directed graph.

**Parameters**
- \( G \) (\texttt{NetworkX\ graph})
- \texttt{center_nodes} (set) – A nonempty set of nodes in the graph \( G \) that represent the center of the Voronoi cells.
- \texttt{weight} (\texttt{string\ or\ function}) – The edge attribute (or an arbitrary function) representing the weight of an edge. This keyword argument is as described in the documentation for \texttt{multi_source_dijkstra_path()}, for example.

**Returns** A mapping from center node to set of all nodes in the graph closer to that center node than to any other center node. The keys of the dictionary are the element of \texttt{center_nodes}, and the values of the dictionary form a partition of the nodes of \( G \).

**Return type** dictionary

**Examples**

To get only the partition of the graph induced by the Voronoi cells, take the collection of all values in the returned dictionary:

```python
>>> G = nx.path_graph(6)
>>> center_nodes = {0, 3}
>>> cells = nx.voronoi_cells(G, center_nodes)
>>> partition = set(map(frozenset, cells.values()))
>>> sorted(map(sorted, partition))
[[0, 1], [2, 3, 4, 5]]
```

**Raises** \texttt{ValueError} – If \texttt{center_nodes} is empty.

**References**

3.52 Wiener index

Functions related to the Wiener index of a graph.

\[ \text{wiener_index}(G[, weight]) \] Returns the Wiener index of the given graph.

3.52.1 networkx.algorithms.wiener.wiener_index

\[ \text{wiener_index}(G, weight=None) \] Returns the Wiener index of the given graph.

The Wiener index of a graph is the sum of the shortest-path distances between each pair of reachable nodes. For pairs of nodes in undirected graphs, only one orientation of the pair is counted.

Parameters

- G (NetworkX graph)
- weight (object) – The edge attribute to use as distance when computing shortest-path distances. This is passed directly to the networkx.shortest_path_length() function.

Returns The Wiener index of the graph G.

Return type float

Raises NetworkXError – If the graph G is not connected.

Notes

If a pair of nodes is not reachable, the distance is assumed to be infinity. This means that for graphs that are not strongly-connected, this function returns inf.

The Wiener index is not usually defined for directed graphs, however this function uses the natural generalization of the Wiener index to directed graphs.

Examples

The Wiener index of the (unweighted) complete graph on n nodes equals the number of pairs of the n nodes, since each pair of nodes is at distance one:

```python
>>> import networkx as nx
>>> n = 10
>>> G = nx.complete_graph(n)
>>> nx.wiener_index(G) == n * (n - 1) / 2
True
```

Graphs that are not strongly-connected have infinite Wiener index:

```python
>>> G = nx.empty_graph(2)
>>> nx.wiener_index(G)
inf
```
CHAPTER
FOUR

FUNCTIONS

Functional interface to graph methods and assorted utilities.

4.1 Graph

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>degree(G[, nbunch, weight])</td>
<td>Return a degree view of single node or of nbunch of nodes.</td>
</tr>
<tr>
<td>degree_histogram(G)</td>
<td>Return a list of the frequency of each degree value.</td>
</tr>
<tr>
<td>density(G)</td>
<td>Return the density of a graph.</td>
</tr>
<tr>
<td>info(G[, n])</td>
<td>Print short summary of information for the graph G or the node n.</td>
</tr>
<tr>
<td>create_empty_copy(G[, with_data])</td>
<td>Return a copy of the graph G with all of the edges removed.</td>
</tr>
<tr>
<td>is_directed(G)</td>
<td>Return True if graph is directed.</td>
</tr>
<tr>
<td>add_star(G_to_add_to, nodes_for_star, **attr)</td>
<td>Add a star to Graph G_to_add_to.</td>
</tr>
<tr>
<td>add_path(G_to_add_to, nodes_for_path, **attr)</td>
<td>Add a path to the Graph G_to_add_to.</td>
</tr>
<tr>
<td>add_cycle(G_to_add_to, nodes_for_cycle, **attr)</td>
<td>Add a cycle to the Graph G_to_add_to.</td>
</tr>
</tbody>
</table>

4.1.1 networkx.classes.function.degree

degree(G, nbunch=None, weight=None)

Return a degree view of single node or of nbunch of nodes. If nbunch is omitted, then return degrees of all nodes.

4.1.2 networkx.classes.function.degree_histogram

degree_histogram(G)

Return a list of the frequency of each degree value.

Parameters G (Networkx graph) – A graph

Returns hist – A list of frequencies of degrees. The degree values are the index in the list.

Return type list

Notes

Note: the bins are width one, hence len(list) can be large (Order(number_of_edges))
4.1.3 networkx.classes.function.density

density(G)

Return the density of a graph.

The density for undirected graphs is

\[ d = \frac{2m}{n(n-1)} \]

and for directed graphs is

\[ d = \frac{m}{n(n-1)} \]

where \( n \) is the number of nodes and \( m \) is the number of edges in \( G \).

Notes

The density is 0 for a graph without edges and 1 for a complete graph. The density of multigraphs can be higher than 1.

Self loops are counted in the total number of edges so graphs with self loops can have density higher than 1.

4.1.4 networkx.classes.function.info

info(G, n=None)

Print short summary of information for the graph \( G \) or the node \( n \).

Parameters

- \( G \) (Networkx graph) – A graph
- \( n \) (node (any hashable)) – A node in the graph \( G \)

4.1.5 networkx.classes.function.create_empty_copy

create_empty_copy(G, with_data=True)

Return a copy of the graph \( G \) with all of the edges removed.

Parameters

- \( G \) (graph) – A NetworkX graph
- \( \) with_data (bool (default=True)) – Propagate Graph and Nodes data to the new graph.

See also:

empty_graph()

4.1.6 networkx.classes.function.is_directed

is_directed(G)

Return True if graph is directed.
4.1.7 networkx.classes.function.add_star

add_star(G_to_add_to, nodes_for_star, **attr)

Add a star to Graph G_to_add_to.

The first node in nodes_for_star is the middle of the star. It is connected to all other nodes.

Parameters

- G_to_add_to (graph) – A NetworkX graph
- nodes_for_star (iterable container) – A container of nodes.
- attr (keyword arguments, optional (default= no attributes)) – Attributes to add to every edge in star.

See also:

add_path(), add_cycle()

Examples

```python
>>> G = nx.Graph()
>>> nx.add_star(G, [0, 1, 2, 3])
>>> nx.add_star(G, [10, 11, 12], weight=2)
```

4.1.8 networkx.classes.function.add_path

add_path(G_to_add_to, nodes_for_path, **attr)

Add a path to the Graph G_to_add_to.

Parameters

- G_to_add_to (graph) – A NetworkX graph
- nodes_for_path (iterable container) – A container of nodes. A path will be constructed from the nodes (in order) and added to the graph.
- attr (keyword arguments, optional (default= no attributes)) – Attributes to add to every edge in path.

See also:

add_star(), add_cycle()

Examples

```python
>>> G = nx.Graph()
>>> nx.add_path(G, [0, 1, 2, 3])
>>> nx.add_path(G, [10, 11, 12], weight=7)
```

4.1.9 networkx.classes.function.add_cycle

add_cycle(G_to_add_to, nodes_for_cycle, **attr)

Add a cycle to the Graph G_to_add_to.
Parameters

- **G_to_add_to** (*graph*) – A NetworkX graph
- **nodes_for_cycle** (*iterable container*) – A container of nodes. A cycle will be constructed from the nodes (in order) and added to the graph.
- **attr** (*keyword arguments, optional (default= no attributes]*) – Attributes to add to every edge in cycle.

See also:

*add_path(), add_star()*

Examples

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> nx.add_cycle(G, [0, 1, 2, 3])
>>> nx.add_cycle(G, [10, 11, 12], weight=7)
```

### 4.2 Nodes

| nodes(G) | Return an iterator over the graph nodes. |
| number_of_nodes(G) | Return the number of nodes in the graph. |
| all_neighbors(graph, node) | Returns all of the neighbors of a node in the graph. |
| non_neighbors(graph, node) | Returns the non-neighbors of the node in the graph. |
| common_neighbors(G, u, v) | Return the common neighbors of two nodes in a graph. |

#### 4.2.1 networkx.classes.function.nodes

**nodes(G)**

Return an iterator over the graph nodes.

#### 4.2.2 networkx.classes.function.number_of_nodes

**number_of_nodes(G)**

Return the number of nodes in the graph.

#### 4.2.3 networkx.classes.function.all_neighbors

**all_neighbors(graph, node)**

Returns all of the neighbors of a node in the graph.

If the graph is directed returns predecessors as well as successors.

**Parameters**

- **graph** (*NetworkX graph*) – Graph to find neighbors.
- **node** (*node*) – The node whose neighbors will be returned.

**Returns** neighbors – Iterator of neighbors
Return type iterator

### 4.2.4 networkx.classes.function.non_neighbors

**non_neighbors** *(graph, node)*

Returns the non-neighbors of the node in the graph.

**Parameters**

- *graph* *(NetworkX graph)* – Graph to find neighbors.
- *node* *(node)* – The node whose neighbors will be returned.

**Returns** non_neighbors – Iterator of nodes in the graph that are not neighbors of the node.

**Return type** iterator

### 4.2.5 networkx.classes.function.common_neighbors

**common_neighbors** *(G, u, v)*

Return the common neighbors of two nodes in a graph.

**Parameters**

- *G* *(graph)* – A NetworkX undirected graph.
- *u, v* *(nodes)* – Nodes in the graph.

**Returns** cnbors – Iterator of common neighbors of u and v in the graph.

**Return type** iterator

**Raises** NetworkXError – If u or v is not a node in the graph.

**Examples**

```python
>>> G = nx.complete_graph(5)
>>> sorted(nx.common_neighbors(G, 0, 1))
[2, 3, 4]
```

### 4.3 Edges

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>edges</strong> <em>(G[, nbunch])</em></td>
<td>Return an edge view of edges incident to nodes in nbunch.</td>
</tr>
<tr>
<td><strong>number_of_edges</strong> <em>(G)</em></td>
<td>Return the number of edges in the graph.</td>
</tr>
<tr>
<td><strong>non_edges</strong> <em>(graph)</em></td>
<td>Returns the non-existent edges in the graph.</td>
</tr>
</tbody>
</table>

### 4.3.1 networkx.classes.function.edges

**edges** *(G, nbunch=None)*

Return an edge view of edges incident to nodes in nbunch.

Return all edges if nbunch is unspecified or nbunch=None.

For digraphs, edges=out_edges
4.3.2 `networkx.classes.function.number_of_edges`

`number_of_edges(G)`
Return the number of edges in the graph.

4.3.3 `networkx.classes.function.non_edges`

`non_edges(graph)`
Returns the non-existent edges in the graph.

- **Parameters**
  - `graph` *(NetworkX graph)* – Graph to find non-existent edges.

- **Returns**
  - `non_edges` – Iterator of edges that are not in the graph.

- **Return type** iterator

4.4 Self loops

| `selfloop_edges(G[, data, keys, default])` | Returns an iterator over selfloop edges. |
| `number_of_selfloops(G)` | Return the number of selfloop edges. |
| `nodes_with_selfloops(G)` | Returns an iterator over nodes with self loops. |

4.4.1 `networkx.classes.function.selfloop_edges`

`selfloop_edges(G, data=False, keys=False, default=None)`
Returns an iterator over selfloop edges.

A selfloop edge has the same node at both ends.

- **Parameters**
  - `data` *(string or bool, optional (default=False))* – Return selfloop edges as two tuples (u, v) (data=False) or three-tuples (u, v, datadict) (data=True) or three-tuples (u, v, datavalue) (data='attrname')
  - `keys` *(bool, optional (default=False))* – If True, return edge keys with each edge.
  - `default` *(value, optional (default=None))* – Value used for edges that don’t have the requested attribute. Only relevant if data is not True or False.

- **Returns**
  - `edgeiter` – An iterator over all selfloop edges.

- **Return type** iterator over edge tuples

- **See also**
  - `nodes_with_selfloops(G), number_of_selfloops(G)`

**Examples**

```python
>>> G = nx.MultiGraph()  # or Graph, DiGraph, MultiDiGraph, etc
>>> ekey = G.add_edge(1, 1)
>>> ekey = G.add_edge(1, 2)
>>> list(nx.selfloop_edges(G))
```
>>> list(nx.selfloop_edges(G, data=True))
[(1, 1, {})]

>>> list(nx.selfloop_edges(G, keys=True))
[(1, 1, 0)]

>>> list(nx.selfloop_edges(G, keys=True, data=True))
[(1, 1, 0, {})]

### 4.4.2 networkx.classes.function.number_of_selfloops

**number_of_selfloops** *(G)*

Return the number of selfloop edges.

A selfloop edge has the same node at both ends.

**Returns**

- nloops – The number of selfloops.

**Return type**

int

**See also:**

nodes_with_selfloops(), selfloop_edges()

#### Examples

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_edge(1, 1)
>>> G.add_edge(1, 2)
>>> nx.number_of_selfloops(G)
1
```

### 4.4.3 networkx.classes.function.nodes_with_selfloops

**nodes_with_selfloops** *(G)*

Returns an iterator over nodes with self loops.

A node with a self loop has an edge with both ends adjacent to that node.

**Returns**

- nodelist – A iterator over nodes with self loops.

**Return type**

iterator

**See also:**

selfloop_edges(), number_of_selfloops()

#### Examples

```python
>>> G = nx.Graph()  # or DiGraph, MultiGraph, MultiDiGraph, etc
>>> G.add_edge(1, 1)
>>> G.add_edge(1, 2)
>>> list(nx.nodes_with_selfloops(G))
[1]
```
4.5 Attributes

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>set_node_attributes(G, values[, name])</code></td>
<td>Sets node attributes from a given value or dictionary of values.</td>
</tr>
<tr>
<td><code>get_node_attributes(G, name)</code></td>
<td>Get node attributes from graph</td>
</tr>
<tr>
<td><code>set_edge_attributes(G, values[, name])</code></td>
<td>Sets edge attributes from a given value or dictionary of values.</td>
</tr>
<tr>
<td><code>get_edge_attributes(G, name)</code></td>
<td>Get edge attributes from graph</td>
</tr>
</tbody>
</table>

### 4.5.1 networkx.classes.function.set_node_attributes

**set_node_attributes(G, values, name=None)**

Sets node attributes from a given value or dictionary of values.

**Parameters**

- **G** *(NetworkX Graph)*
- **values** *(scalar value, dict-like)* – What the node attribute should be set to. If `values` is not a dictionary, then it is treated as a single attribute value that is then applied to every node in `G`. This means that if you provide a mutable object, like a list, updates to that object will be reflected in the node attribute for each edge. The attribute name will be `name`.

If `values` is a dict or a dict of dict, the corresponding node’s attributes will be updated to `values`.

- **name** *(string (optional, default=None))* – Name of the node attribute to set if `values` is a scalar.

**Examples**

After computing some property of the nodes of a graph, you may want to assign a node attribute to store the value of that property for each node:

```python
>>> G = nx.path_graph(3)
>>> bb = nx.betweenness_centrality(G)
>>> isinstance(bb, dict)
True
>>> nx.set_node_attributes(G, bb, 'betweenness')
>>> G.nodes[1]['betweenness']
1.0
```

If you provide a list as the second argument, updates to the list will be reflected in the node attribute for each node:

```python
>>> G = nx.path_graph(3)
>>> labels = []
>>> nx.set_node_attributes(G, labels, 'labels')
>>> labels.append('foo')
>>> G.nodes[0]['labels']
['foo']
>>> G.nodes[1]['labels']
['foo']
>>> G.nodes[2]['labels']
['foo']
```
If you provide a dictionary of dictionaries as the second argument, the entire dictionary will be used to update node attributes:

```python
>>> G = nx.path_graph(3)
>>> attrs = {0: {'attr1': 20, 'attr2': 'nothing'}, 1: {'attr2': 3}}
>>> nx.set_node_attributes(G, attrs)
>>> G.nodes[0]['attr1']
20
>>> G.nodes[0]['attr2']
'nothing'
>>> G.nodes[1]['attr2']
3
>>> G.nodes[2]
{}
```

4.5.2 `networkx.classes.function.get_node_attributes`

`get_node_attributes`(G, name)
Get node attributes from graph

Parameters
- G (NetworkX Graph)
- name (string) – Attribute name

Returns
Return type Dictionary of attributes keyed by node.

Examples

```python
>>> G = nx.Graph()
>>> G.add_nodes_from([1, 2, 3], color='red')
>>> color = nx.get_node_attributes(G, 'color')
>>> color[1]
'red'
```

4.5.3 `networkx.classes.function.set_edge_attributes`

`set_edge_attributes`(G, values, name=None)
Sets edge attributes from a given value or dictionary of values.

Parameters
- G (NetworkX Graph)
- values (scalar value, dict-like) – What the edge attribute should be set to. If values is not a dictionary, then it is treated as a single attribute value that is then applied to every edge in G. This means that if you provide a mutable object, like a list, updates to that object will be reflected in the edge attribute for each edge. The attribute name will be name.
- name (string) – Attribute name

If values is a dict or a dict of dict, the corresponding edge attributes will be updated to values. For multigraphs, the tuples must be of the form (u, v, key), where u and v are nodes and key is the key corresponding to the edge. For non-multi-graphs, the keys must be tuples of the form (u, v).
• **name** *(string (optional, default=None)) – Name of the edge attribute to set if values is a scalar.*

**Examples**

After computing some property of the edges of a graph, you may want to assign an edge attribute to store the value of that property for each edge:

```python
>>> G = nx.path_graph(3)
>>> bb = nx.edge_betweenness_centrality(G, normalized=False)
>>> nx.set_edge_attributes(G, bb, 'betweenness')
>>> G.edges[1, 2]['betweenness']
2.0
```

If you provide a list as the second argument, updates to the list will be reflected in the edge attribute for each edge:

```python
>>> labels = []
>>> nx.set_edge_attributes(G, labels, 'labels')
>>> labels.append('foo')
>>> G.edges[0, 1]['labels']
['foo']
>>> G.edges[1, 2]['labels']
['foo']
```

If you provide a dictionary of dictionaries as the second argument, the entire dictionary will be used to update edge attributes:

```python
>>> G = nx.path_graph(3)
>>> attrs = {0, 1}: {'attr1': 20, 'attr2': 'nothing'}, ...
           (1, 2): {'attr2': 3})
>>> nx.set_edge_attributes(G, attrs)
>>> G[0][1]['attr1']
20
>>> G[0][1]['attr2']
'nothing'
>>> G[1][2]['attr2']
3
```

**4.5.4 networkx.classes.function.get_edge_attributes**

**get_edge_attributes** *(G, name)*

Get edge attributes from graph

- **Parameters**
  - `G` *(NetworkX Graph)*
  - `name` *(string)* – Attribute name

- **Returns**
  - `Dictionary of attributes keyed by edge. For (di)graphs, the keys are 2-tuples of the form ((u, v). For multi(di)graphs, the keys are 3-tuples of the form (u, v, key).)*
  - `If you provide a list as the second argument, updates to the list will be reflected in the edge attribute for each edge:

```python
>>> labels = []
>>> nx.set_edge_attributes(G, labels, 'labels')
>>> labels.append('foo')
>>> G.edges[0, 1]['labels']
['foo']
>>> G.edges[1, 2]['labels']
['foo']
```

If you provide a dictionary of dictionaries as the second argument, the entire dictionary will be used to update edge attributes:

```python
>>> G = nx.path_graph(3)
>>> attrs = {0, 1}: {'attr1': 20, 'attr2': 'nothing'}, ...
           (1, 2): {'attr2': 3})
>>> nx.set_edge_attributes(G, attrs)
>>> G[0][1]['attr1']
20
>>> G[0][1]['attr2']
'nothing'
>>> G[1][2]['attr2']
3
```

**4.5.4 networkx.classes.function.get_edge_attributes**

- **Parameters**
  - `G` *(NetworkX Graph)*
  - `name` *(string)* – Attribute name

- **Returns**
  - `Dictionary of attributes keyed by edge. For (di)graphs, the keys are 2-tuples of the form ((u, v). For multi(di)graphs, the keys are 3-tuples of the form (u, v, key).)
Examples

```python
>>> G = nx.Graph()
>>> nx.add_path(G, [1, 2, 3], color='red')
>>> color = nx.get_edge_attributes(G, 'color')
>>> color[(1, 2)]
'red'
```

### 4.6 Freezing graph structure

<table>
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<tr>
<th>Method</th>
<th>Description</th>
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<tbody>
<tr>
<td><code>freeze(G)</code></td>
<td>Modify graph to prevent further change by adding or removing nodes or edges. Node and edge data can still be modified.</td>
</tr>
<tr>
<td><code>is_frozen(G)</code></td>
<td>Return True if graph is frozen.</td>
</tr>
</tbody>
</table>

#### 4.6.1 networkx.classes.function.freeze

**freeze**

Modify graph to prevent further change by adding or removing nodes or edges. Node and edge data can still be modified.

**Parameters**  
`G (graph)` – A NetworkX graph

**Examples**

```python
>>> G = nx.path_graph(4)
>>> G = nx.freeze(G)
>>> try:
...     G.add_edge(4, 5)
... except nx.NetworkXError as e:
...     print(str(e))
Frozen graph can't be modified
```

**Notes**

To “unfreeze” a graph you must make a copy by creating a new graph object:

```python
>>> graph = nx.path_graph(4)
>>> frozen_graph = nx.freeze(graph)
>>> unfrozen_graph = nx.Graph(frozen_graph)
>>> nx.is_frozen(unfrozen_graph)
False
```

**See also:**

`is_frozen()`
4.6.2 networkx.classes.function.is_frozen

\texttt{is\_frozen}(G)

Return True if graph is frozen.

\textbf{Parameters} \texttt{G (graph)} – A NetworkX graph

\textbf{See also:}

\texttt{freeze()}

---

460 Chapter 4. Functions
5.1 Atlas

Generators for the small graph atlas.

<table>
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<tr>
<th>Function</th>
<th>Description</th>
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<tbody>
<tr>
<td><code>graph_atlas(i)</code></td>
<td>Returns graph number ( i ) from the Graph Atlas.</td>
</tr>
<tr>
<td><code>graph_atlas_g()</code></td>
<td>Return the list of all graphs with up to seven nodes named in the Graph Atlas.</td>
</tr>
</tbody>
</table>

5.1.1 networkx.generators.atlas.graph_atlas

`graph_atlas(i)`

Returns graph number \( i \) from the Graph Atlas.

For more information, see `graph_atlas_g()`.

- **Parameters** \( i \) (int) – The index of the graph from the atlas to get. The graph at index 0 is assumed to be the null graph.

- **Returns** A list of `Graph` objects, the one at index \( i \) corresponding to the graph \( i \) in the Graph Atlas.

- **Return type** list

See also:

`graph_atlas_g()`

Notes

The time required by this function increases linearly with the argument \( i \), since it reads a large file sequentially in order to generate the graph\(^1\).

References

5.1.2 networkx.generators.atlas.graph_atlas_g

`graph_atlas_g()`

Return the list of all graphs with up to seven nodes named in the Graph Atlas.

---

The graphs are listed in increasing order by
1. number of nodes,
2. number of edges,
3. degree sequence (for example 111223 < 112222),
4. number of automorphisms,
in that order, with three exceptions as described in the Notes section below. This causes the list to correspond
with the index of the graphs in the Graph Atlas [atlas], with the first graph, \( G[0] \), being the null graph.

**Returns** A list of `Graph` objects, the one at index \( i \) corresponding to the graph \( i \) in the Graph Atlas.

**Return type** list

**See also:**

`graph_atlas()`

**Notes**

This function may be expensive in both time and space, since it reads a large file sequentially in order to populate
the list.

Although the NetworkX atlas functions match the order of graphs given in the “Atlas of Graphs” book, there
are (at least) three errors in the ordering described in the book. The following three pairs of nodes violate the
lexicographically nondecreasing sorted degree sequence rule:

- graphs 55 and 56 with degree sequences 001111 and 000112,
- graphs 1007 and 1008 with degree sequences 333444 and 333336,
- graphs 1012 and 1213 with degree sequences 1244555 and 124456.

**References**

5.2 Classic

Generators for some classic graphs.

The typical graph generator is called as follows:

```python
>>> G = nx.complete_graph(100)
```

returning the complete graph on \( n \) nodes labeled 0, \( \ldots \), 99 as a simple graph. Except for empty_graph, all the generators
in this module return a `Graph` class (i.e. a simple, undirected graph).

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>balanced_tree(r, h[, create_using])</code></td>
<td>Return the perfectly balanced ( r )-ary tree of height ( h ).</td>
</tr>
<tr>
<td><code>barbell_graph(m1, m2[, create_using])</code></td>
<td>Return the Barbell Graph: two complete graphs connected by a path.</td>
</tr>
<tr>
<td><code>complete_graph(n[, create_using])</code></td>
<td>Return the complete graph ( K_n ) with ( n ) nodes.</td>
</tr>
<tr>
<td><code>complete_multipartite_graph(*subset_sizes)</code></td>
<td>Returns the complete multipartite graph with the specified subset sizes.</td>
</tr>
<tr>
<td><code>circular_ladder_graph(n[, create_using])</code></td>
<td>Return the circular ladder graph ( C_{L_n} ) of length ( n ).</td>
</tr>
<tr>
<td><code>cycle_graph(n[, create_using])</code></td>
<td>Return the cycle graph ( C_n ) of cyclically connected nodes.</td>
</tr>
</tbody>
</table>

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Table 2 – continued from previous page

<table>
<thead>
<tr>
<th>Function Name</th>
<th>Description</th>
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<tbody>
<tr>
<td><code>dorogovtsev_goltsev_mendes_graph(n[, ...])</code></td>
<td>Return the hierarchically constructed Dorogovtsev-Goltsev-Mendes graph.</td>
</tr>
<tr>
<td><code>empty_graph([n, create_using])</code></td>
<td>Return the empty graph with n nodes and zero edges.</td>
</tr>
<tr>
<td><code>ladder_graph(n[, create_using])</code></td>
<td>Return the Ladder graph of length n.</td>
</tr>
<tr>
<td><code>lollipop_graph(m, n[, create_using])</code></td>
<td>Return the Lollipop Graph; K_m connected to P_n.</td>
</tr>
<tr>
<td><code>null_graph([create_using])</code></td>
<td>Return the Null graph with no nodes or edges.</td>
</tr>
<tr>
<td><code>path_graph(n[, create_using])</code></td>
<td>Return the Path graph P_n of linearly connected nodes.</td>
</tr>
<tr>
<td><code>star_graph(n[, create_using])</code></td>
<td>Return the star graph</td>
</tr>
<tr>
<td><code>trivial_graph([create_using])</code></td>
<td>Return the Trivial graph with one node (with label 0) and no edges.</td>
</tr>
<tr>
<td><code>turan_graph(n, r)</code></td>
<td>Return the Turan Graph</td>
</tr>
<tr>
<td><code>wheel_graph(n[, create_using])</code></td>
<td>Return the wheel graph</td>
</tr>
</tbody>
</table>

5.2.1 networkx.generators.classic.balanced_tree

`balanced_tree(r, h, create_using=None)`

Return the perfectly balanced r-ary tree of height h.

Parameters

- r (int) – Branching factor of the tree; each node will have r children.
- h (int) – Height of the tree.
- create_using (Graph, optional (default None)) – If provided this graph is cleared of nodes and edges and filled with the new graph. Usually used to set the type of the graph.

Returns

- G – A balanced r-ary tree of height h.
- Return type NetworkX graph

Notes

This is the rooted tree where all leaves are at distance h from the root. The root has degree r and all other internal nodes have degree r + 1.

Node labels are integers, starting from zero.

A balanced tree is also known as a complete r-ary tree.

5.2.2 networkx.generators.classic.barbell_graph

`barbell_graph(m1, m2, create_using=None)`

Return the Barbell Graph: two complete graphs connected by a path.

For m1 > 1 and m2 >= 0.

Two identical complete graphs K_{m1} form the left and right bells, and are connected by a path P_{m2}.

The 2*m1+m2 nodes are numbered 0, ..., m1-1 for the left barbell, m1, ..., m1+m2-1 for the path, and m1+m2, ..., 2*m1+m2-1 for the right barbell.

The 3 subgraphs are joined via the edges (m1-1, m1) and (m1+m2-1, m1+m2). If m2=0, this is merely two complete graphs joined together.

This graph is an extremal example in David Aldous and Jim Fill’s e-text on Random Walks on Graphs.

5.2. Classic
5.2.3 `networkx.generators.classic.complete_graph`

`complete_graph(n, create_using=None)`

Return the complete graph $K_n$ with $n$ nodes.

**Parameters**

- `n` *(int or iterable container of nodes)* – If $n$ is an integer, nodes are from `range(n)`. If $n$ is a container of nodes, those nodes appear in the graph.

- `create_using` *(Graph, optional (default None))* – If provided this graph is cleared of nodes and edges and filled with the new graph. Usually used to set the type of the graph.

**Examples**

```python
>>> G = nx.complete_graph(9)
>>> len(G)
9
>>> G.size()
36
>>> G = nx.complete_graph(range(11, 14))
>>> list(G.nodes())
[11, 12, 13]
>>> G = nx.complete_graph(4, nx.DiGraph())
>>> G.is_directed()
True
```

5.2.4 `networkx.generators.classic.complete_multipartite_graph`

`complete_multipartite_graph(*subset_sizes)`

Returns the complete multipartite graph with the specified subset sizes.

**Parameters**

- `subset_sizes` *(tuple of integers or tuple of node iterables)* – The arguments can either all be integer number of nodes or they can all be iterables of nodes. If integers, they represent the number of vertices in each subset of the multipartite graph. If iterables, each is used to create the nodes for that subset. The length of `subset_sizes` is the number of subsets.

**Returns**

- `G` – Returns the complete multipartite graph with the specified subsets.

For each node, the node attribute ‘subset’ is an integer indicating which subset contains the node.

**Return type** NetworkX Graph

**Examples**

Creating a complete tripartite graph, with subsets of one, two, and three vertices, respectively.

```python
>>> import networkx as nx
>>> G = nx.complete_multipartite_graph(1, 2, 3)
>>> [G.nodes[u]["subset"] for u in G]
[0, 1, 1, 2, 2, 2]
>>> list(G.edges(0))
[(0, 1), (0, 2), (0, 3), (0, 4), (0, 5)]
```

(continues on next page)
Notes

This function generalizes several other graph generator functions.

- If no subset sizes are given, this returns the null graph.
- If a single subset size \( n \) is given, this returns the empty graph on \( n \) nodes.
- If two subset sizes \( m \) and \( n \) are given, this returns the complete bipartite graph on \( m + n \) nodes.
- If subset sizes \( 1 \) and \( n \) are given, this returns the star graph on \( n + 1 \) nodes.

See also:

complete_bipartite_graph()

5.2.5 networkx.generators.classic.circular_ladder_graph

circular_ladder_graph \((n, create\_using=None)\)

Return the circular ladder graph \( CL_n \) of length \( n \).

\( CL_n \) consists of two concentric \( n \)-cycles in which each of the \( n \) pairs of concentric nodes are joined by an edge.

Node labels are the integers 0 to \( n-1 \)

5.2.6 networkx.generators.classic.cycle_graph

cycle_graph \((n, create\_using=None)\)

Return the cycle graph \( C_n \) of cyclically connected nodes.

\( C_n \) is a path with its two end-nodes connected.

Parameters

- \( n \) (int or iterable container of nodes) – If \( n \) is an integer, nodes are from range \((n)\). If \( n \) is a container of nodes, those nodes appear in the graph.
- create\_using (Graph, optional (default Graph())) – If provided this graph is cleared of nodes and edges and filled with the new graph. Usually used to set the type of the graph.

Notes

If create\_using is directed, the direction is in increasing order.
5.2.7 networkx.generators.classic.dorogovtsev_goltsev_mendes_graph

dorogovtsev_goltsev_mendes_graph(n, create_using=None)
Return the hierarchically constructed Dorogovtsev-Goltsev-Mendes graph.

n is the generation. See: arXiv:/cond-mat/0112143 by Dorogovtsev, Goltsev and Mendes.

5.2.8 networkx.generators.classic.empty_graph

empty_graph(n=0, create_using=None)
Return the empty graph with n nodes and zero edges.

Parameters

• n (int or iterable container of nodes (default = 0)) – If n is an integer, nodes are from
  range(n). If n is a container of nodes, those nodes appear in the graph.
• create_using (Graph, optional (default Graph())) – If provided this graph is cleared of
  nodes and edges and filled with the new graph. Usually used to set the type of the graph.

Examples

```python
>>> G = nx.empty_graph(10)
>>> G.number_of_nodes()
10
>>> G.number_of_edges()
0
>>> G = nx.empty_graph("ABC")
>>> G.number_of_nodes()
3
>>> sorted(G)
['A', 'B', 'C']
```

Notes

The variable create_using should point to a “graph”-like object that will be cleared (nodes and edges will
be removed) and refitted as an empty “graph” with nodes specified in n. This capability is useful for specifying the
class-nature of the resulting empty “graph” (i.e. Graph, DiGraph, MyWeirdGraphClass, etc.).

The variable create_using has two main uses: Firstly, the variable create_using can be used to create an empty
digraph, multigraph, etc. For example,

```python
>>> n = 10
>>> G = nx.empty_graph(n, create_using=nx.DiGraph())
```

will create an empty digraph on n nodes.

Secondly, one can pass an existing graph (digraph, multigraph, etc.) via create_using. For example, if G is an
existing graph (resp. digraph, multigraph, etc.), then empty_graph(n, create_using=G) will empty G (i.e. delete
all nodes and edges using G.clear()) and then add n nodes and zero edges, and return the modified graph.

See also create_empty_copy(G).
5.2.9 networkx.generators.classic.ladder_graph

ladder_graph(n, create_using=None)

Return the Ladder graph of length n.

This is two paths of n nodes, with each pair connected by a single edge.
Node labels are the integers 0 to 2*n - 1.

5.2.10 networkx.generators.classic.lollipop_graph

lollipop_graph(m, n, create_using=None)

Return the Lollipop Graph; K_m connected to P_n.
This is the Barbell Graph without the right barbell.

Parameters

- m, n (int or iterable container of nodes (default = 0)) – If an integer, nodes are from range(m) and range(m,m+n). If a container, the entries are the coordinate of the node.
  The nodes for m appear in the complete graph K_m and the nodes for n appear in the path P_n.
- create_using (Graph, optional (default Graph())) – If provided this graph is cleared of nodes and edges and filled with the new graph. Usually used to set the type of the graph.

Notes

The 2 subgraphs are joined via an edge (m-1, m). If n=0, this is merely a complete graph.
(This graph is an extremal example in David Aldous and Jim Fill’s etext on Random Walks on Graphs.)

5.2.11 networkx.generators.classic.null_graph

null_graph(create_using=None)

Return the Null graph with no nodes or edges.
See empty_graph for the use of create_using.

5.2.12 networkx.generators.classic.path_graph

path_graph(n, create_using=None)

Return the Path graph P_n of linearly connected nodes.

Parameters

- n (int or iterable) – If an integer, node labels are 0 to n with center 0. If an iterable of nodes, the center is the first.
- create_using (Graph, optional (default Graph())) – If provided this graph is cleared of nodes and edges and filled with the new graph. Usually used to set the type of the graph.
5.2.13 networkx.generators.classic.star_graph

star_graph \((n, create_using=None)\)

Return the star graph

The star graph consists of one center node connected to \(n\) outer nodes.

Parameters

- \(n\) \((\text{int or iterable})\) – If an integer, node labels are 0 to \(n\) with center 0. If an iterable of nodes, the center is the first.
- \(create\_using\) \((\text{Graph, optional (default Graph())})\) – If provided this graph is cleared of nodes and edges and filled with the new graph. Usually used to set the type of the graph.

Notes

The graph has \(n+1\) nodes for integer \(n\). So star_graph(3) is the same as star_graph(range(4)).

5.2.14 networkx.generators.classic.trivial_graph

trivial_graph \((create_using=None)\)

Return the Trivial graph with one node (with label 0) and no edges.

5.2.15 networkx.generators.classic.turan_graph

turan_graph \((n, r)\)

Return the Turan Graph

The Turan Graph is a complete multipartite graph on \(n\) vertices with \(r\) disjoint subsets. It is the graph with the edges for any graph with \(n\) vertices and \(r\) disjoint subsets.

Given \(n\) and \(r\), we generate a complete multipartite graph with \(r - (n \mod r)\) partitions of size \(n/r\), rounded down, and \(n \mod r\) partitions of size \(n/r + 1\), rounded down.

Parameters

- \(n\) \((\text{int})\) – The number of vertices.
- \(r\) \((\text{int})\) – The number of partitions. Must be less than or equal to \(n\).

Notes

Must satisfy \(1 <= r <= n\). The graph has \((r - 1)(n^2)/(2r)\) edges, rounded down.

5.2.16 networkx.generators.classic.wheel_graph

wheel_graph \((n, create\_using=None)\)

Return the wheel graph

The wheel graph consists of a hub node connected to a cycle of \((n-1)\) nodes.

Parameters
5.3 Expanders

Provides explicit constructions of expander graphs.

| margulis_gabber_galil_graph(n[, create_using]) | Returns the Margulis-Gabber-Galil undirected MultiGraph on \( n^2 \) nodes. |
| chordal_cycle_graph(p[, create_using]) | Returns the chordal cycle graph on \( p \) nodes. |

### 5.3.1 networkx.generators.expanders.margulis_gabber_galil_graph

`margulis_gabber_galil_graph(n, create_using=None)`

Return the Margulis-Gabber-Galil undirected MultiGraph on \( n^2 \) nodes.

The undirected MultiGraph is regular with degree 8. Nodes are integer pairs. The second-largest eigenvalue of the adjacency matrix of the graph is at most \( 5 \sqrt{2} \), regardless of \( n \).

**Parameters**

- **n (int)** – Determines the number of nodes in the graph: \( n^2 \).
- **create_using (graph-like)** – A graph-like object that receives the constructed edges. If None, then a `MultiGraph` instance is used.

**Returns**

- **G** – The constructed undirected multigraph.

**Return type**

- **graph**

**Raises**

- **NetworkXError** – If the graph is directed or not a multigraph.

### 5.3.2 networkx.generators.expanders.chordal_cycle_graph

`chordal_cycle_graph(p, create_using=None)`

Return the chordal cycle graph on \( p \) nodes.

The returned graph is a cycle graph on \( p \) nodes with chords joining each vertex \( x \) to its inverse modulo \( p \). This graph is a (mildly explicit) 3-regular expander\(^1\).

\( p \) must be a prime number.

**Parameters**

- **p (a prime number)** – The number of vertices in the graph. This also indicates where the chordal edges in the cycle will be created.
- **create_using (graph-like)** – A graph-like object that receives the constructed edges. If None, then a `MultiGraph` instance is used.

Returns $G$ – The constructed undirected multigraph.

Return type graph

Raises NetworkXError – If the graph provided in create_using is directed or not a multigraph.

References

## 5.4 Lattice

Functions for generating grid graphs and lattices

The `grid_2d_graph()`, `triangular_lattice_graph()`, and `hexagonal_lattice_graph()` functions correspond to the three regular tilings of the plane, the square, triangular, and hexagonal tilings, respectively. `grid_graph()` and `hypercube_graph()` are similar for arbitrary dimensions. Useful relevant discussion can be found about Triangular Tiling, and Square, Hex and Triangle Grids

<table>
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<th>Description</th>
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<td><code>grid_2d_graph(m, n[, periodic, create_using])</code></td>
<td>Returns the two-dimensional grid graph.</td>
</tr>
<tr>
<td><code>grid_graph(dim[, periodic])</code></td>
<td>Returns the $n$-dimensional grid graph.</td>
</tr>
<tr>
<td><code>hexagonal_lattice_graph(m, n[, periodic, ...])</code></td>
<td>Returns an $m$ by $n$ hexagonal lattice graph.</td>
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<tr>
<td><code>hypercube_graph(n)</code></td>
<td>Returns the $n$-dimensional hypercube graph.</td>
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<tr>
<td><code>triangular_lattice_graph(m, n[, periodic, ...])</code></td>
<td>Returns the $m$ by $n$ triangular lattice graph.</td>
</tr>
</tbody>
</table>

### 5.4.1 networkx.generators.lattice.grid_2d_graph

`grid_2d_graph (m, n, periodic=False, create_using=None)`

Returns the two-dimensional grid graph.

The grid graph has each node connected to its four nearest neighbors.

Parameters

- `m, n` (*int or iterable container of nodes*) – If an integer, nodes are from `range(n)`. If a container, elements become the coordinate of the nodes.
- `periodic` (*bool (default: False)*) – If this is `True` the nodes on the grid boundaries are joined to the corresponding nodes on the opposite grid boundaries.
- `create_using` (*NetworkX graph (default: Graph())*) – If provided this graph is cleared of nodes and edges and filled with the new graph. Usually used to set the type of the graph.

Returns The (possibly periodic) grid graph of the specified dimensions.

Return type NetworkX graph

### 5.4.2 networkx.generators.lattice.grid_graph

`grid_graph (dim[, periodic=False])`

Returns the $n$-dimensional grid graph.

The dimension $n$ is the length of the list `dim` and the size in each dimension is the value of the corresponding list element.

Parameters
• **dim** (*list or tuple of numbers or iterables of nodes*) – ‘dim’ is a tuple or list with, for each dimension, either a number that is the size of that dimension or an iterable of nodes for that dimension. The dimension of the grid_graph is the length of **dim**.

• **periodic** (*bool*) – If **periodic** is **True** the nodes on the grid boundaries are joined to the corresponding nodes on the opposite grid boundaries.

**Returns** The (possibly periodic) grid graph of the specified dimensions.

**Return type** NetworkX graph

**Examples**

To produce a 2 by 3 by 4 grid graph, a graph on 24 nodes:

```python
>>> from networkx import grid_graph
>>> G = grid_graph(dim=[2, 3, 4])
>>> len(G)
24
>>> G = grid_graph(dim=[range(7, 9), range(3, 6)])
>>> len(G)
6
```

---

5.4.3 networkx.generators.lattice.hexagonal_lattice_graph

hexagonal_lattice_graph (*m*, *n*, **periodic**=*False*, **with_positions**=*True*, **create_using**=*None*)

Returns an *m* by *n* hexagonal lattice graph.

The **hexagonal lattice graph** is a graph whose nodes and edges are the hexagonal tiling of the plane.

The returned graph will have *m* rows and *n* columns of hexagons. Odd numbered columns are shifted up relative to even numbered columns.

Positions of nodes are computed by default or **with_positions** is **True**. Node positions creating the standard embedding in the plane with sidelength 1 and are stored in the node attribute ‘pos’. **pos** = networkx.get_node_attributes(G, 'pos') creates a dict ready for drawing.

**Parameters**

- **m** (*int*) – The number of rows of hexagons in the lattice.
- **n** (*int*) – The number of columns of hexagons in the lattice.
- **periodic** (*bool*) – Whether to make a periodic grid by joining the boundary vertices. For this to work *n* must be odd and both *n* > 1 and *m* > 1. The periodic connections create another row and column of hexagons so these graphs have fewer nodes as boundary nodes are identified.
- **with_positions** (*bool (default: True)*) – Store the coordinates of each node in the graph node attribute ‘pos’. The coordinates provide a lattice with vertical columns of hexagons offset to interleave and cover the plane. Periodic positions shift the nodes vertically in a nonlinear way so the edges don’t overlap so much.
- **create_using** (*NetworkX graph*) – If specified, this must be an instance of a NetworkX graph class. It will be cleared of nodes and edges and filled with the new graph. Usually used to set the type of the graph. If graph is directed, edges will point up or right.

**Returns** The *m* by *n* hexagonal lattice graph.
5.4.4 networkx.generators.lattice.hypercube_graph

**hypercube_graph** *(n)*

Returns the \(n\)-dimensional hypercube graph.

The nodes are the integers between 0 and \(2 \cdot n - 1\), inclusive.

For more information on the hypercube graph, see the Wikipedia article Hypercube graph.

**Parameters**

- **n** (*int*) – The dimension of the hypercube. The number of nodes in the graph will be \(2^{n}\).

**Returns**

The hypercube graph of dimension \(n\).

**Return type** NetworkX graph

5.4.5 networkx.generators.lattice.triangular_lattice_graph

**triangular_lattice_graph** *(m, n, periodic=False, with_positions=True, create_using=None)*

Returns the \(m\) by \(n\) triangular lattice graph.

The triangular lattice graph is a two-dimensional grid graph in which each square unit has a diagonal edge (each grid unit has a chord).

The returned graph has \(m\) rows and \(n\) columns of triangles. Rows and columns include both triangles pointing up and down. Rows form a strip of constant height. Columns form a series of diamond shapes, staggered with the columns on either side. Another way to state the size is that the nodes form a grid of \(m+1\) rows and \((n + 1) \mod 2\) columns. The odd row nodes are shifted horizontally relative to the even rows.

Directed graph types have edges pointed up or right.

Positions of nodes are computed by default or with_positions is True. The position of each node (embedded in a euclidean plane) is stored in the graph using equilateral triangles with sidelength 1. The height between rows of nodes is thus \(\sqrt{3}/2\). Nodes lie in the first quadrant with the node \((0, 0)\) at the origin.

**Parameters**

- **m** (*int*) – The number of rows in the lattice.
- **n** (*int*) – The number of columns in the lattice.
- **periodic** (*bool (default: False)*) – If True, join the boundary vertices of the grid using periodic boundary conditions. The join between boundaries is the final row and column of triangles. This means there is one row and one column fewer nodes for the periodic lattice. Periodic lattices require \(m \geq 3, n \geq 5\) and are allowed but misaligned if \(m\) or \(n\) are odd.
- **with_positions** (*bool (default: True)*) – Store the coordinates of each node in the graph node attribute `pos`. The coordinates provide a lattice with equilateral triangles. Periodic positions shift the nodes vertically in a nonlinear way so the edges don’t overlap so much.
- **create_using** (*NetworkX graph*) – If specified, this must be an instance of a NetworkX graph class. It will be cleared of nodes and edges and filled with the new graph. Usually used to set the type of the graph.

**Returns**

The \(m\) by \(n\) triangular lattice graph.

**Return type** NetworkX graph
5.5 Small

Various small and named graphs, together with some compact generators.

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<td><code>make_small_graph(graph_description[, create_using])</code></td>
<td>Return the small graph described by graph_description.</td>
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<tr>
<td><code>LCF_graph(n, shift_list, repeats[, create_using])</code></td>
<td>Return the cubic graph specified in LCF notation.</td>
</tr>
<tr>
<td><code>bull_graph([create_using])</code></td>
<td>Return the Bull graph.</td>
</tr>
<tr>
<td><code>chvatal_graph([create_using])</code></td>
<td>Return the Chvátal graph.</td>
</tr>
<tr>
<td><code>cubical_graph([create_using])</code></td>
<td>Return the 3-regular Platonic Cubical graph.</td>
</tr>
<tr>
<td><code>desargues_graph([create_using])</code></td>
<td>Return the Desargues graph.</td>
</tr>
<tr>
<td><code>diamond_graph([create_using])</code></td>
<td>Return the Diamond graph.</td>
</tr>
<tr>
<td><code>dodecahedral_graph([create_using])</code></td>
<td>Return the Platonic Dodecahedral graph.</td>
</tr>
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<td><code>frucht_graph([create_using])</code></td>
<td>Return the Frucht Graph.</td>
</tr>
<tr>
<td><code>heawood_graph([create_using])</code></td>
<td>Return the Heawood graph, a (3,6) cage.</td>
</tr>
<tr>
<td><code>house_graph([create_using])</code></td>
<td>Return the House graph (square with triangle on top).</td>
</tr>
<tr>
<td><code>house_x_graph([create_using])</code></td>
<td>Return the House graph with a cross inside the house square.</td>
</tr>
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<td><code>icosahedral_graph([create_using])</code></td>
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<td><code>krackhardt_kite_graph([create_using])</code></td>
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<td>Return the Pappus graph.</td>
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<td>Return the Petersen graph.</td>
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<td>Return a small maze with a cycle.</td>
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<td>Return the 3-regular Platonic Tetrahedral graph.</td>
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<tr>
<td><code>truncated_cube_graph([create_using])</code></td>
<td>Return the skeleton of the truncated cube.</td>
</tr>
<tr>
<td><code>truncated_tetrahedron_graph([create_using])</code></td>
<td>Return the skeleton of the truncated Platonic tetrahedron.</td>
</tr>
<tr>
<td><code> tutte_graph([create_using])</code></td>
<td>Return the Tutte graph.</td>
</tr>
</tbody>
</table>

5.5.1 `networkx.generators.small.make_small_graph`

`make_small_graph (graph_description, create_using=None)`

Return the small graph described by graph_description.

graph_description is a list of the form [ltype,name,n,xlist]

Here ltype is one of “adjacencylist” or “edgelist”, name is the name of the graph and n the number of nodes.
This constructs a graph of n nodes with integer labels 0,...,n-1.

If ltype=“adjacencylist” then xlist is an adjacency list with exactly n entries, in with the j'th entry (which can be empty) specifies the nodes connected to vertex j.
Try the “square” graph C_4 can be obtained by

```python
>>> G=nx.make_small_graph(["adjacencylist","C_4",4,[[2,4],[1,3],[4,2],[1,3]]])
```

or, since we do not need to add edges twice,

```python
>>> G=nx.make_small_graph(["adjacencylist","C_4",4,[[2,4],[3],[4],[1]]])
```

If ltype=“edgelist” then xlist is an edge list written as [v1,w2],[v2,w2]...[vk,wk], where vj and wj integers in the range 1,...,n e.g. the “square” graph C_4 can be obtained by

```python
>>> G=nx.make_small_graph(["edgelist","C_4",4,[[1,2],[3,4],[2,3],[4,1]]])
```
Use the create_using argument to choose the graph class/type.

5.5.2 networkx.generators.small.LCF_graph

LCF_graph\( (n, \text{shift\_list}, \text{repeats}, \text{create\_using}=\text{None}) \)
Return the cubic graph specified in LCF notation.

LCF notation (LCF=Lederberg-Coxeter-Fruchte) is a compressed notation used in the generation of various cubic Hamiltonian graphs of high symmetry. See, for example, dodecahedral_graph, desargues_graph, heawood_graph and pappus_graph below.

- \( n \) (number of nodes) The starting graph is the \( n \)-cycle with nodes \( 0, \ldots, n-1 \). (The null graph is returned if \( n < 0 \).)
- \( \text{shift\_list} = [s1,s2,\ldots,sk] \), a list of integer shifts mod \( n \),
- \( \text{repeats} \) integer specifying the number of times that shifts in \( \text{shift\_list} \) are successively applied to each \( v_{\text{current}} \) in the \( n \)-cycle to generate an edge between \( v_{\text{current}} \) and \( v_{\text{current}}+\text{shift} \mod n \).

For \( v1 \) cycling through the \( n \)-cycle a total of \( k \)*\text{repeats} with \( \text{shift} \) cycling through \( \text{shift\_list} \) \text{repeats} times connect \( v1 \) with \( v1+\text{shift} \mod n \)

The utility graph \( K_{3,3} \)

```python
>>> G = nx.LCF_graph(6, [3, -3], 3)
```

The Heawood graph

```python
>>> G = nx.LCF_graph(14, [5, -5], 7)
```

See [http://mathworld.wolfram.com/LCFNotation.html](http://mathworld.wolfram.com/LCFNotation.html) for a description and references.

5.5.3 networkx.generators.small.bull_graph

bull_graph\( (\text{create\_using}=\text{None}) \)
Return the Bull graph.

5.5.4 networkx.generators.small.chvatal_graph

chvatal_graph\( (\text{create\_using}=\text{None}) \)
Return the Chvátal graph.

5.5.5 networkx.generators.small.cubical_graph

cubical_graph\( (\text{create\_using}=\text{None}) \)
Return the 3-regular Platonic Cubical graph.

5.5.6 networkx.generators.small.desargues_graph

desargues_graph\( (\text{create\_using}=\text{None}) \)
Return the Desargues graph.
5.5.7 networkx.generators.small.diamond_graph

diamond_graph (create_using=None)
    Return the Diamond graph.

5.5.8 networkx.generators.small.dodecahedral_graph

dodecahedral_graph (create_using=None)
    Return the Platonic Dodecahedral graph.

5.5.9 networkx.generators.small.frucht_graph

frucht_graph (create_using=None)
    Return the Frucht Graph.

    The Frucht Graph is the smallest cubical graph whose automorphism group consists only of the identity element.

5.5.10 networkx.generators.small.heawood_graph

heawood_graph (create_using=None)
    Return the Heawood graph, a (3,6) cage.

5.5.11 networkx.generators.small.house_graph

house_graph (create_using=None)
    Return the House graph (square with triangle on top).

5.5.12 networkx.generators.small.house_x_graph

house_x_graph (create_using=None)
    Return the House graph with a cross inside the house square.

5.5.13 networkx.generators.small.icosahedral_graph

icosahedral_graph (create_using=None)
    Return the Platonic Icosahedral graph.

5.5.14 networkx.generators.small.krackhardt_kite_graph

krackhardt_kite_graph (create_using=None)
    Return the Krackhardt Kite Social Network.

    A 10 actor social network introduced by David Krackhardt to illustrate: degree, betweenness, centrality, closeness, etc. The traditional labeling is: Andre=1, Beverley=2, Carol=3, Diane=4, Ed=5, Fernando=6, Garth=7, Heather=8, Ike=9, Jane=10.
5.5.15 networkx.generators.small.moebius_kantor_graph

`moebius_kantor_graph(create_using=None)`
Return the Moebius-Kantor graph.

5.5.16 networkx.generators.small.octahedral_graph

`octahedral_graph(create_using=None)`
Return the Platonic Octahedral graph.

5.5.17 networkx.generators.small.pappus_graph

`pappus_graph()`
Return the Pappus graph.

5.5.18 networkx.generators.small.petersen_graph

`petersen_graph(create_using=None)`
Return the Petersen graph.

5.5.19 networkx.generators.small.sedgewick_maze_graph

`sedgewick_maze_graph(create_using=None)`
Return a small maze with a cycle.
This is the maze used in Sedgewick, 3rd Edition, Part 5, Graph Algorithms, Chapter 18, e.g. Figure 18.2 and following. Nodes are numbered 0,..,7

5.5.20 networkx.generators.small.tetrahedral_graph

`tetrahedral_graph(create_using=None)`
Return the 3-regular Platonic Tetrahedral graph.

5.5.21 networkx.generators.small.truncated_cube_graph

`truncated_cube_graph(create_using=None)`
Return the skeleton of the truncated cube.

5.5.22 networkx.generators.small.truncated_tetrahedron_graph

`truncated_tetrahedron_graph(create_using=None)`
Return the skeleton of the truncated Platonic tetrahedron.

5.5.23 networkx.generators.small.tutte_graph

`tutte_graph(create_using=None)`
Return the Tutte graph.
5.6 Random Graphs

Generators for random graphs.

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<td><code>gnp_random_graph</code></td>
<td>Returns a $G_{n,p}$ random graph, also known as an Erdős-Rényi graph or a binomial graph.</td>
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<td><code>dense_gnm_random_graph</code></td>
<td>Returns a $G_{n,m}$ random graph.</td>
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<td><code>random_shell_graph</code></td>
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<td><code>random_powerlaw_tree</code></td>
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5.6.1 `networkx.generators.random_graphs.fast_gnp_random_graph`

**fast_gnp_random_graph** ($n, p, seed=None, directed=False$)

Returns a $G_{n,p}$ random graph, also known as an Erdős-Rényi graph or a binomial graph.

**Parameters**

- $n$ (int) – The number of nodes.
- $p$ (float) – Probability for edge creation.
- seed (int, optional) – Seed for random number generator (default=None).
- directed (bool, optional (default=False)) – If True, this function returns a directed graph.

**Notes**

The $G_{n,p}$ graph algorithm chooses each of the $[n(n-1)]/2$ (undirected) or $n(n-1)$ (directed) possible edges with probability $p$.

This algorithm\(^1\) runs in $O(n+m)$ time, where $m$ is the expected number of edges, which equals $pn(n-1)/2$. This should be faster than `gnp_random_graph()` when $p$ is small and the expected number of edges is small.

(that is, the graph is sparse).

See also:

gnp_random_graph()

References

5.6.2 networkx.generators.random_graphs.gnp_random_graph

gnp_random_graph \( (n, p, \text{seed}={\text{None}}, \text{directed}={\text{False}}) \)
Returns a \( G_{n,p} \) random graph, also known as an Erdős-Rényi graph or a binomial graph.
The \( G_{n,p} \) model chooses each of the possible edges with probability \( p \).
The functions binomial_graph() and erdos_renyi_graph() are aliases of this function.

Parameters

- \( n \) (int) – The number of nodes.
- \( p \) (float) – Probability for edge creation.
- \( \text{seed} \) (int, optional) – Seed for random number generator (default=None).
- \( \text{directed} \) (bool, optional (default=False)) – If True, this function returns a directed graph.

See also:

fast_gnp_random_graph()

Notes

This algorithm\(^2\) runs in \( O(n^2) \) time. For sparse graphs (that is, for small values of \( p \)),
fast_gnp_random_graph() is a faster algorithm.

References

5.6.3 networkx.generators.random_graphs.dense_gnm_random_graph

dense_gnm_random_graph \( (n, m, \text{seed}={\text{None}}) \)
Returns a \( G_{n,m} \) random graph.

In the \( G_{n,m} \) model, a graph is chosen uniformly at random from the set of all graphs with \( n \) nodes and \( m \) edges.
This algorithm should be faster than gnm_random_graph() for dense graphs.

Parameters

- \( n \) (int) – The number of nodes.
- \( m \) (int) – The number of edges.
- \( \text{seed} \) (int, optional) – Seed for random number generator (default=None).

See also:

gnm_random_graph()

Notes

Algorithm by Keith M. Briggs Mar 31, 2006. Inspired by Knuth’s Algorithm S (Selection sampling technique), in section 3.4.2 of\(^1\).

References

5.6.4 networkx.generators.random_graphs.gnm_random_graph

\texttt{gnm\_random\_graph}(n, m, seed=None, directed=False)

Returns a $G_{n,m}$ random graph.

In the $G_{n,m}$ model, a graph is chosen uniformly at random from the set of all graphs with $n$ nodes and $m$ edges.

This algorithm should be faster than \texttt{dense\_gnm\_random\_graph()} for sparse graphs.

Parameters

- \texttt{n (int)} – The number of nodes.
- \texttt{m (int)} – The number of edges.
- \texttt{seed (int, optional)} – Seed for random number generator (default=None).
- \texttt{directed (bool, optional (default=False))} – If True return a directed graph

See also:

dense_gnm_random_graph()

5.6.5 networkx.generators.random_graphs.erdos_renyi_graph

\texttt{erdos\_renyi\_graph}(n, p, seed=None, directed=False)

Returns a $G_{n,p}$ random graph, also known as an Erdős-Rényi graph or a binomial graph.

The $G_{n,p}$ model chooses each of the possible edges with probability $p$.

The functions \texttt{binomial\_graph()} and \texttt{erdos\_renyi\_graph()} are aliases of this function.

Parameters

- \texttt{n (int)} – The number of nodes.
- \texttt{p (float)} – Probability for edge creation.
- \texttt{seed (int, optional)} – Seed for random number generator (default=None).
- \texttt{directed (bool, optional (default=False))} – If True, this function returns a directed graph

See also:

fast_gnp_random_graph()

Notes

This algorithm\(^2\) runs in \(O(n^2)\) time. For sparse graphs (that is, for small values of \(p\)), `fast_gnp_random_graph()` is a faster algorithm.

References

5.6.6 networkx.generators.random_graphs.binomial_graph

`binomial_graph(n, p, seed=None, directed=False)`

Returns a \(G_{n,p}\) random graph, also known as an Erdős-Rényi graph or a binomial graph. The \(G_{n,p}\) model chooses each of the possible edges with probability \(p\).

The functions `binomial_graph()` and `erdos_renyi_graph()` are aliases of this function.

Parameters

- `n` (int) – The number of nodes.
- `p` (float) – Probability for edge creation.
- `seed` (int, optional) – Seed for random number generator (default=None).
- `directed` (bool, optional (default=False)) – If True, this function returns a directed graph.

See also:

`fast_gnp_random_graph()`

Notes

This algorithm\(^2\) runs in \(O(n^2)\) time. For sparse graphs (that is, for small values of \(p\)), `fast_gnp_random_graph()` is a faster algorithm.

References

5.6.7 networkx.generators.random_graphs.newman_watts_strogatz_graph

`newman_watts_strogatz_graph(n, k, p, seed=None)`


Parameters

- `n` (int) – The number of nodes.
- `k` (int) – Each node is joined with its \(k\) nearest neighbors in a ring topology.
- `p` (float) – The probability of adding a new edge for each edge.
- `seed` (int, optional) – The seed for the random number generator (the default is None).


Notes

First create a ring over \( n \) nodes\(^1\). Then each node in the ring is connected with its \( k \) nearest neighbors (or \( k - 1 \) neighbors if \( k \) is odd). Then shortcuts are created by adding new edges as follows: for each edge \((u, v)\) in the underlying "\( n \)-ring with \( k \) nearest neighbors" with probability \( p \) add a new edge \((u, w)\) with randomly-chosen existing node \( w \). In contrast with \texttt{watts_strogatz_graph()}, no edges are removed.

See also:

\texttt{watts_strogatz_graph()}

References

5.6.8 \texttt{networkx.generators.random_graphs.watts_strogatz_graph}

\texttt{watts_strogatz_graph}(n, k, p, seed=None)

Return a Watts–Strogatz small-world graph.

Parameters

- \( n \) (\texttt{int}) – The number of nodes
- \( k \) (\texttt{int}) – Each node is joined with its \( k \) nearest neighbors in a ring topology.
- \( p \) (\texttt{float}) – The probability of rewiring each edge
- \texttt{seed} (\texttt{int, optional}) – Seed for random number generator (default=None)

See also:

\texttt{newman_watts_strogatz_graph()}, \texttt{connected_watts_strogatz_graph()}

Notes

First create a ring over \( n \) nodes\(^1\). Then each node in the ring is joined to its \( k \) nearest neighbors (or \( k - 1 \) neighbors if \( k \) is odd). Then shortcuts are created by replacing some edges as follows: for each edge \((u, v)\) in the underlying "\( n \)-ring with \( k \) nearest neighbors" with probability \( p \) replace it with a new edge \((u, w)\) with uniformly random choice of existing node \( w \).

In contrast with \texttt{newman_watts_strogatz_graph()}, the random rewiring does not increase the number of edges. The rewired graph is not guaranteed to be connected as in \texttt{connected_watts_strogatz_graph()}.

References

5.6.9 \texttt{networkx.generators.random_graphs.connected_watts_strogatz_graph}

\texttt{connected_watts_strogatz_graph}(n, k, p, tries=100, seed=None)

Returns a connected Watts–Strogatz small-world graph.

Attempts to generate a connected graph by repeated generation of Watts–Strogatz small-world graphs. An exception is raised if the maximum number of tries is exceeded.


NetworkX Reference, Release 2.2rc1.dev20180319181321

Parameters

- **n** *(int)* – The number of nodes
- **k** *(int)* – Each node is joined with its k nearest neighbors in a ring topology.
- **p** *(float)* – The probability of rewiring each edge
- **tries** *(int)* – Number of attempts to generate a connected graph.
- **seed** *(int, optional)* – The seed for random number generator.

See also:

newman_watts_strogatz_graph(), watts_strogatz_graph()

5.6.10 networkx.generators.random_graphs.random_regular_graph

random_regular_graph *(d, n, seed=None)*

Returns a random d-regular graph on n nodes.

The resulting graph has no self-loops or parallel edges.

Parameters

- **d** *(int)* – The degree of each node.
- **n** *(integer)* – The number of nodes. The value of n \times d must be even.
- **seed** *(hashable object)* – The seed for random number generator.

Notes

The nodes are numbered from 0 to n – 1.

Kim and Vu’s paper shows that this algorithm samples in an asymptotically uniform way from the space of random graphs when \( d = O(n^{1/3-\epsilon}) \).

Raises **NetworkXError** – If n \times d is odd or d is greater than or equal to n.

References

5.6.11 networkx.generators.random_graphs.barabasi_albert_graph

barabasi_albert_graph *(n, m, seed=None)*

Returns a random graph according to the Barabási–Albert preferential attachment model.

A graph of n nodes is grown by attaching new nodes each with m edges that are preferentially attached to existing nodes with high degree.

Parameters

- **n** *(int)* – Number of nodes
- **m** *(int)* – Number of edges to attach from a new node to existing nodes
- **seed** *(int, optional)* – Seed for random number generator (default=None).

Returns **G**

---

Return type  

*Graph*

Raises  

`NetworkXError` – If \( m \) does not satisfy \( 1 \leq m < n \).

References

5.6.12  

`networkx.generators.random_graphs.powerlaw_cluster_graph`

**powerlaw_cluster_graph**  

\((n, m, p, \text{seed}=None)\)

Holme and Kim algorithm for growing graphs with powerlaw degree distribution and approximate average clustering.

Parameters

- \( n \) (`int`) – the number of nodes
- \( m \) (`int`) – the number of random edges to add for each new node
- \( p \) (`float`) – Probability of adding a triangle after adding a random edge
- \( \text{seed} \) (`int, optional`) – Seed for random number generator (default=None).

Notes

The average clustering has a hard time getting above a certain cutoff that depends on \( m \). This cutoff is often quite low. The transitivity (fraction of triangles to possible triangles) seems to decrease with network size.

It is essentially the Barabási–Albert (BA) growth model with an extra step that each random edge is followed by a chance of making an edge to one of its neighbors too (and thus a triangle).

This algorithm improves on BA in the sense that it enables a higher average clustering to be attained if desired.

It seems possible to have a disconnected graph with this algorithm since the initial \( m \) nodes may not be all linked to a new node on the first iteration like the BA model.

Raises  

`NetworkXError` – If \( m \) does not satisfy \( 1 \leq m \leq n \) or \( p \) does not satisfy \( 0 \leq p \leq 1 \).

References

5.6.13  

`networkx.generators.random_graphs.random_kernel_graph`

**random_kernel_graph**  

\((n, \text{kernel_integral}, \text{kernel_root}=None, \text{seed}=None)\)

Return an random graph based on the specified kernel.

The algorithm chooses each of the \( \binom{n(n-1)}{2} \) possible edges with probability specified by a kernel \( \kappa(x, y) \). The kernel \( \kappa(x, y) \) must be a symmetric (in \( x, y \)), non-negative, bounded function.

Parameters

- \( n \) (`int`) – The number of nodes
- `kernel_integral` (`function`) – Function that returns the definite integral of the kernel \( \kappa(x, y) \),
  \[ F(y, a, b) := \int_a^b \kappa(x, y)dx \]

References

• **kernel_root** *(function (optional)) – Function that returns the root $b$ of the equation $F(y, a, b) = r$. If None, the root is found using scipy.optimize.brentq() (this requires SciPy).

• **seed** *(int, optional) – Seed for random number generator (default=None)*

### Notes

The kernel is specified through its definite integral which must be provided as one of the arguments. If the integral and root of the kernel integral can be found in $O(1)$ time then this algorithm runs in time $O(n + m)$ where $m$ is the expected number of edges$^2$.

The nodes are set to integers from 0 to $n - 1$.

### Examples

Generate an Erdős–Rényi random graph $G(n, c/n)$, with kernel $\kappa(x, y) = c$ where $c$ is the mean expected degree.

```python
>>> def integral(u, w, z):
...     return c * (z - w)

>>> def root(u, w, r):
...     return r / c + w

>>> c = 1

>>> graph = nx.random_kernel_graph(1000, integral, root)
```

See also:

gnp_random_graph(), expected_degree_graph()

### References

5.6.14 networkx.generators.random_graphs.random_lobster

**random_lobster** *(n, p1, p2, seed=None)*

Returns a random lobster graph.

A lobster is a tree that reduces to a caterpillar when pruning all leaf nodes. A caterpillar is a tree that reduces to a path graph when pruning all leaf nodes; setting $p2$ to zero produces a caterpillar.

#### Parameters

- **n** *(int) – The expected number of nodes in the backbone*
- **p1** *(float) – Probability of adding an edge to the backbone*
- **p2** *(float) – Probability of adding an edge one level beyond backbone*
- **seed** *(int, optional) – Seed for random number generator (default=None).*

5.6.15 networkx.generators.random_graphs.random_shell_graph

random_shell_graph(constructor, seed=None)
Returns a random shell graph for the constructor given.

Parameters
• constructor (list of three-tuples) – Represents the parameters for a shell, starting at the center shell. Each element of the list must be of the form \((n, m, d)\), where \(n\) is the number of nodes in the shell, \(m\) is the number of edges in the shell, and \(d\) is the ratio of inter-shell (next) edges to intra-shell edges. If \(d\) is zero, there will be no intra-shell edges, and if \(d\) is one there will be all possible intra-shell edges.
• seed (int, optional) – Seed for random number generator (default=None).

Examples
>>> constructor = [(10, 20, 0.8), (20, 40, 0.8)]
>>> G = nx.random_shell_graph(constructor)

5.6.16 networkx.generators.random_graphs.random_powerlaw_tree

random_powerlaw_tree(n, gamma=3, seed=None, tries=100)
Returns a tree with a power law degree distribution.

Parameters
• n (int) – The number of nodes.
• gamma (float) – Exponent of the power law.
• seed (int, optional) – Seed for random number generator (default=None).
• tries (int) – Number of attempts to adjust the sequence to make it a tree.

Raises NetworkXError – If no valid sequence is found within the maximum number of attempts.

Notes
A trial power law degree sequence is chosen and then elements are swapped with new elements from a powerlaw distribution until the sequence makes a tree (by checking, for example, that the number of edges is one smaller than the number of nodes).

5.6.17 networkx.generators.random_graphs.random_powerlaw_tree_sequence

random_powerlaw_tree_sequence(n, gamma=3, seed=None, tries=100)
Returns a degree sequence for a tree with a power law distribution.

Parameters
• n (int) – The number of nodes.
• gamma (float) – Exponent of the power law.
• seed (int, optional) – Seed for random number generator (default=None).
• tries (int) – Number of attempts to adjust the sequence to make it a tree.
NetworkX Reference, Release 2.2rc1.dev20180319181321

Raises

NetworkXError – If no valid sequence is found within the maximum number of attempts.

Notes

A trial power law degree sequence is chosen and then elements are swapped with new elements from a power law distribution until the sequence makes a tree (by checking, for example, that the number of edges is one smaller than the number of nodes).

5.7 Duplication Divergence

Functions for generating graphs based on the “duplication” method.

These graph generators start with a small initial graph then duplicate nodes and (partially) duplicate their edges. These functions are generally inspired by biological networks.

5.7.1 networkx.generators.duplication.duplication_divergence_graph

duplication_divergence_graph(n, p[, seed]) Returns an undirected graph using the duplication-divergence model.

Parameters

- n (int) – The desired number of nodes in the graph.
- p (float) – The probability for retaining the edge of the replicated node.
- seed (int, optional) – A seed for the random number generator of random (default=None).

Returns G

Return type Graph

Raises NetworkXError – If p is not a valid probability. If n is less than 2.

Notes

This algorithm appears in [1].

This implementation disallows the possibility of generating disconnected graphs.

References

5.7.2 networkx.generators.duplication.partial_duplication_graph

partial_duplication_graph(N, n, p, q[, seed]) Return a random graph using the partial duplication model.
Parameters

- **N (int)** – The total number of nodes in the final graph.
- **n (int)** – The number of nodes in the initial clique.
- **p (float)** – The probability of joining each neighbor of a node to the duplicate node. Must be a number in the between zero and one, inclusive.
- **q (float)** – The probability of joining the source node to the duplicate node. Must be a number in the between zero and one, inclusive.
- **seed (int, optional)** – Seed for random number generator (default=None).

Notes

A graph of nodes is grown by creating a fully connected graph of size *n*. The following procedure is then repeated until a total of *N* nodes have been reached.

1. A random node, *u*, is picked and a new node, *v*, is created.
2. For each neighbor of *u* an edge from the neighbor to *v* is created with probability *p*.
3. An edge from *u* to *v* is created with probability *q*.

This algorithm appears in [1].

This implementation allows the possibility of generating disconnected graphs.

References

5.8 Degree Sequence

Generate graphs with a given degree sequence or expected degree sequence.

<table>
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<td><code>configuration_model(degree_sequence[, ...])</code></td>
<td>Return a random graph with the given degree sequence.</td>
</tr>
<tr>
<td><code>directed_configuration_model(...)[, ...)</code></td>
<td>Return a directed random graph with the given degree sequences.</td>
</tr>
<tr>
<td><code>expected_degree_graph(w[, seed, selfloops])</code></td>
<td>Return a random graph with given expected degrees.</td>
</tr>
<tr>
<td><code>havel_hakimi_graph(degree_sequence[, create_using])</code></td>
<td>Return a simple graph with given degree sequence constructed using the Havel-Hakimi algorithm.</td>
</tr>
<tr>
<td><code>directed_havel_hakimi_graph(in_degree_sequence, ...)</code></td>
<td>Return a directed graph with the given degree sequences.</td>
</tr>
<tr>
<td><code>degree_sequence_tree(degree_sequence[, ...])</code></td>
<td>Make a tree for the given degree sequence.</td>
</tr>
<tr>
<td><code>random_degree_sequence_graph(sequence[, ...])</code></td>
<td>Return a simple random graph with the given degree sequence.</td>
</tr>
</tbody>
</table>

5.8.1 networkx.generators.degree_seq.configuration_model

`configuration_model (degree_sequence, create_using=None, seed=None)`

Return a random graph with the given degree sequence.

The configuration model generates a random pseudograph (graph with parallel edges and self loops) by randomly assigning edges to match the given degree sequence.
Parameters

- **deg_sequence** *(list of nonnegative integers)* – Each list entry corresponds to the degree of a node.
- **create_using** *(graph, optional (default MultiGraph))* – Return graph of this type. The instance will be cleared.
- **seed** *(hashable object, optional)* – Seed for random number generator.

Returns G – A graph with the specified degree sequence. Nodes are labeled starting at 0 with an index corresponding to the position in deg_sequence.

Return type **MultiGraph**

Raises **NetworkXError** – If the degree sequence does not have an even sum.

See also:

is_graphical()

Notes

As described by Newman\(^1\).

A non-graphical degree sequence (not realizable by some simple graph) is allowed since this function returns graphs with self loops and parallel edges. An exception is raised if the degree sequence does not have an even sum.

This configuration model construction process can lead to duplicate edges and loops. You can remove the self-loops and parallel edges (see below) which will likely result in a graph that doesn’t have the exact degree sequence specified.

The density of self-loops and parallel edges tends to decrease as the number of nodes increases. However, typically the number of self-loops will approach a Poisson distribution with a nonzero mean, and similarly for the number of parallel edges. Consider a node with \( k \) stubs. The probability of being joined to another stub of the same node is basically \( (k - 1) / N \), where \( k \) is the degree and \( N \) is the number of nodes. So the probability of a self-loop scales like \( c / N \) for some constant \( c \). As \( N \) grows, this means we expect \( c \) self-loops. Similarly for parallel edges.

References

Examples

You can create a degree sequence following a particular distribution by using the one of the distribution functions in random_sequence (or one of your own). For example, to create an undirected multigraph on one hundred nodes with degree sequence chosen from the power law distribution:

```python
>>> sequence = nx.random_powerlaw_tree_sequence(100, tries=5000)
>>> G = nx.configuration_model(sequence)
>>> len(G)
100
>>> actual_degrees = [d for v, d in G.degree()]
>>> actual_degrees == sequence
True
```

The returned graph is a multigraph, which may have parallel edges. To remove any parallel edges from the returned graph:

```
>>> G = nx.Graph(G)
```

Similarly, to remove self-loops:

```
>>> G.remove_edges_from(nx.selfloop_edges(G))
```

### 5.8.2 networkx.generators.degree_seq.directed_configuration_model

**directed_configuration_model** *(in_degree_sequence, out_degree_sequence, create_using=None, seed=None)*

Return a directed_random graph with the given degree sequences. The configuration model generates a random directed pseudograph (graph with parallel edges and self loops) by randomly assigning edges to match the given degree sequences.

**Parameters**

- **in_degree_sequence** *(list of nonnegative integers)* – Each list entry corresponds to the in-degree of a node.
- **out_degree_sequence** *(list of nonnegative integers)* – Each list entry corresponds to the out-degree of a node.
- **create_using** *(graph, optional (default MultiDiGraph))* – Return graph of this type. The instance will be cleared.
- **seed** *(hashable object, optional)* – Seed for random number generator.

**Returns** *G* – A graph with the specified degree sequences. Nodes are labeled starting at 0 with an index corresponding to the position in deg_sequence.

**Return type** *MultiDiGraph*

**Raises** *NetworkXError* – If the degree sequences do not have the same sum.

**See also:**

*configuration_model()*

**Notes**

Algorithm as described by Newman¹.

A non-graphical degree sequence (not realizable by some simple graph) is allowed since this function returns graphs with self loops and parallel edges. An exception is raised if the degree sequences does not have the same sum.

This configuration model construction process can lead to duplicate edges and loops. You can remove the self-loops and parallel edges (see below) which will likely result in a graph that doesn’t have the exact degree sequence specified. This “finite-size effect” decreases as the size of the graph increases.

References

Examples

One can modify the in- and out-degree sequences from an existing directed graph in order to create a new directed graph. For example, here we modify the directed path graph:

```python
>>> D = nx.DiGraph([(0, 1), (1, 2), (2, 3)])
>>> din = list(d for n, d in D.in_degree())
>>> dout = list(d for n, d in D.out_degree())
>>> din.append(1)
>>> dout[0] = 2
>>> # We now expect an edge from node 0 to a new node, node 3.
... D = nx.directed_configuration_model(din, dout)
```

The returned graph is a directed multigraph, which may have parallel edges. To remove any parallel edges from the returned graph:

```python
>>> D = nx.DiGraph(D)
```

Similarly, to remove self-loops:

```python
>>> D.remove_edges_from(nx.selfloop_edges(D))
```

5.8.3 networkx.generators.degree_seq.expected_degree_graph

**expected_degree_graph** (*w*, *seed=None*, *selfloops=True*)

Return a random graph with given expected degrees.

Given a sequence of expected degrees \( W = (w_0, w_1, \ldots, w_{n-1}) \) of length \( n \) this algorithm assigns an edge between node \( u \) and node \( v \) with probability

\[
    p_{uv} = \frac{w_u w_v}{\sum_k w_k}.
\]

Parameters

- *w* (list) – The list of expected degrees.
- *selfloops* (bool, default=True) – Set to False to remove the possibility of self-loop edges.
- *seed* (hashable object, optional) – The seed for the random number generator.

Returns

Return type *Graph*

Examples

```python
>>> z=[10 for i in range(100)]
>>> G=nx.expected_degree_graph(z)
```
Notes

The nodes have integer labels corresponding to index of expected degrees input sequence.

The complexity of this algorithm is $O(n + m)$ where $n$ is the number of nodes and $m$ is the expected number of edges.

The model in¹ includes the possibility of self-loop edges. Set selfloops=False to produce a graph without self loops.

For finite graphs this model doesn’t produce exactly the given expected degree sequence. Instead the expected degrees are as follows.

For the case without self loops (selfloops=False),

$$E[\text{deg}(u)] = \sum_{v \neq u} p_{uv} = w_u \left(1 - \frac{w_u}{\sum_k w_k}\right).$$

NetworkX uses the standard convention that a self-loop edge counts 2 in the degree of a node, so with self loops (selfloops=True),

$$E[\text{deg}(u)] = \sum_{v \neq u} p_{uv} + 2p_{uu} = w_u \left(1 + \frac{w_u}{\sum_k w_k}\right).$$

References

5.8.4 networkx.generators.degree_seq.havel_hakimi_graph

havel_hakimi_graph (deg_sequence, create_using=None)

Return a simple graph with given degree sequence constructed using the Havel-Hakimi algorithm.

Parameters

- deg_sequence (list of integers) – Each integer corresponds to the degree of a node (need not be sorted).
- create_using (graph, optional (default Graph)) – Return graph of this type. The instance will be cleared. Directed graphs are not allowed.

Raises NetworkXException – For a non-graphical degree sequence (i.e. one not realizable by some simple graph).

Notes

The Havel-Hakimi algorithm constructs a simple graph by successively connecting the node of highest degree to other nodes of highest degree, resorting remaining nodes by degree, and repeating the process. The resulting graph has a high degree-associativity. Nodes are labeled 1, ..., len(deg_sequence), corresponding to their position in deg_sequence.

The basic algorithm is from Hakimi¹ and was generalized by Kleitman and Wang².

References

5.8.5 networkx.generators.degree_seq.directed_havel_hakimi_graph

directed_havel_hakimi_graph (in_deg_sequence, out_deg_sequence, create_using=None)

Return a directed graph with the given degree sequences.

Parameters

• in_deg_sequence (list of integers) – Each list entry corresponds to the in-degree of a node.
• out_deg_sequence (list of integers) – Each list entry corresponds to the out-degree of a node.
• create_using (graph, optional (default DiGraph)) – Return graph of this type. The instance will be cleared.

Returns G – A graph with the specified degree sequences. Nodes are labeled starting at 0 with an index corresponding to the position in deg_sequence

Return type DiGraph

Raises NetworkXError – If the degree sequences are not digraphical.

See also: configuration_model()

Notes

Algorithm as described by Kleitman and Wang¹.

References

5.8.6 networkx.generators.degree_seq.degree_sequence_tree

degree_sequence_tree (deg_sequence, create_using=None)

Make a tree for the given degree sequence.

A tree has #nodes-#edges=1 so the degree sequence must have len(deg_sequence)-sum(deg_sequence)/2=1

5.8.7 networkx.generators.degree_seq.random_degree_sequence_graph

random_degree_sequence_graph (sequence, seed=None, tries=10)

Return a simple random graph with the given degree sequence.

If the maximum degree \(d_m\) in the sequence is \(O(m^{1/4})\) then the algorithm produces almost uniform random graphs in \(O(md_m)\) time where \(m\) is the number of edges.

Parameters

• sequence (list of integers) – Sequence of degrees
• seed (hashable object, optional) – Seed for random number generator
• tries (int, optional) – Maximum number of tries to create a graph

Returns `G` – A graph with the specified degree sequence. Nodes are labeled starting at 0 with an index corresponding to the position in the sequence.

Return type `Graph`

Raises

- `NetworkXUnfeasible` – If the degree sequence is not graphical.
- `NetworkXError` – If a graph is not produced in specified number of tries

See also:

`is_graphical()`, `configuration_model()`

Notes

The generator algorithm\(^1\) is not guaranteed to produce a graph.

References

Examples

```python
>>> sequence = [1, 2, 2, 3]
>>> G = nx.random_degree_sequence_graph(sequence)
>>> sorted(d for n, d in G.degree())
[1, 2, 2, 3]
```

5.9 Random Clustered

Generate graphs with given degree and triangle sequence.

| random_clustered_graph(joint_degree_sequence) | Generate a random graph with the given joint independent edge degree and triangle degree sequence. |

5.9.1 networkx.generators.random_clustered.random_clustered_graph

`random_clustered_graph(joint_degree_sequence, create_using=None, seed=None)`

Generate a random graph with the given joint independent edge degree and triangle degree sequence.

This uses a configuration model-like approach to generate a random graph (with parallel edges and self-loops) by randomly assigning edges to match the given joint degree sequence.

The joint degree sequence is a list of pairs of integers of the form \([(d_{1,i},d_{1,t}),\ldots,(d_{n,i},d_{n,t})]\). According to this list, vertex \(u\) is a member of \(d_{u,t}\) triangles and has \(d_{u,i}\) other edges. The number \(d_{u,i}\) is the triangle degree of \(u\) and the number \(d_{u,i}\) is the independent edge degree.

Parameters

- `joint_degree_sequence (list of integer pairs)` – Each list entry corresponds to the independent edge degree and triangle degree of a node.

---

\(^1\) Moshen Bayati, Jeong Han Kim, and Amin Saberi, A sequential algorithm for generating random graphs. Algorithmica, Volume 58, Number 4, 860-910, DOI: 10.1007/s00453-009-9340-1
NetworkX Reference, Release 2.2rc1.dev20180319181321

- **create_using** *(graph, optional (default MultiGraph))* – Return graph of this type. The instance will be cleared.

- **seed** *(hashable object, optional)* – The seed for the random number generator.

Returns G – A graph with the specified degree sequence. Nodes are labeled starting at 0 with an index corresponding to the position in deg_sequence.

Return type **MultiGraph**

Raises **NetworkXError** – If the independent edge degree sequence sum is not even or the triangle degree sequence sum is not divisible by 3.

Notes

As described by Miller\(^1\) (see also Newman\(^2\) for an equivalent description).

A non-graphical degree sequence (not realizable by some simple graph) is allowed since this function returns graphs with self loops and parallel edges. An exception is raised if the independent degree sequence does not have an even sum or the triangle degree sequence sum is not divisible by 3.

This configuration model-like construction process can lead to duplicate edges and loops. You can remove the self-loops and parallel edges (see below) which will likely result in a graph that doesn’t have the exact degree sequence specified. This “finite-size effect” decreases as the size of the graph increases.

References

Examples

```python
>>> deg = [(1, 0), (1, 0), (1, 0), (2, 0), (1, 0), (2, 1), (0, 1), (0, 1)]
>>> G = nx.random_clustered_graph(deg)
```

To remove parallel edges:

```python
>>> G = nx.Graph(G)
```

To remove self loops:

```python
>>> G.remove_edges_from(nx.selfloop_edges(G))
```

5.10 Directed

Generators for some directed graphs, including growing network (GN) graphs and scale-free graphs.

- **gn_graph** *(n[, kernel, create_using, seed])* – Return the growing network (GN) digraph with n nodes.

- **gnr_graph** *(n, p[, create_using, seed])* – Return the growing network with redirection (GNR) digraph with n nodes and redirection probability p.

Continued on next page

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\(^1\) Joel C. Miller. “Percolation and epidemics in random clustered networks”. In: Physical review. E, Statistical, nonlinear, and soft matter physics 80 (2 Part 1 August 2009).

Table 10 – continued from previous page

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<th>Description</th>
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<td><code>gnc_graph(n[, create_using, seed])</code></td>
<td>Return the growing network with copying (GNC) digraph with ( n ) nodes.</td>
</tr>
<tr>
<td><code>random_k_out_graph(n, k, alpha[, ...])</code></td>
<td>Returns a random ( k )-out graph with preferential attachment.</td>
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<td><code>scale_free_graph(n[, alpha, beta, gamma, ...])</code></td>
<td>Returns a scale-free directed graph.</td>
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5.10.1 networkx.generators.directed.gn_graph

`gn_graph(n, kernel=None, create_using=None, seed=None)`

Return the growing network (GN) digraph with \( n \) nodes.

The GN graph is built by adding nodes one at a time with a link to one previously added node. The target node for the link is chosen with probability based on degree. The default attachment kernel is a linear function of the degree of a node.

The graph is always a (directed) tree.

**Parameters**

- \( n \) (int) – The number of nodes for the generated graph.
- kernel (function) – The attachment kernel.
- create_using (graph, optional (default DiGraph)) – Return graph of this type. The instance will be cleared.
- seed (hashable object, optional) – The seed for the random number generator.

**Examples**

To create the undirected GN graph, use the to_directed() method:

```python
>>> D = nx.gn_graph(10)  # the GN graph
>>> G = D.to_undirected()  # the undirected version
```

To specify an attachment kernel, use the kernel keyword argument:

```python
>>> D = nx.gn_graph(10, kernel=lambda x: x ** 1.5)  # A_k = k^1.5
```

**References**

5.10.2 networkx.generators.directed.gnr_graph

`gnr_graph(n, p, create_using=None, seed=None)`

Return the growing network with redirection (GNR) digraph with \( n \) nodes and redirection probability \( p \).

The GNR graph is built by adding nodes one at a time with a link to one previously added node. The previous target node is chosen uniformly at random. With probability \( p \) the link is instead “redirected” to the successor node of the target.

The graph is always a (directed) tree.

**Parameters**

- \( n \) (int) – The number of nodes for the generated graph.
- \( p \) (float) – The redirection probability.
• create_using (graph, optional (default DiGraph)) – Return graph of this type. The instance will be cleared.
• seed (hashable object, optional) – The seed for the random number generator.

Examples

To create the undirected GNR graph, use the to_directed() method:

```python
>>> D = nx.gnr_graph(10, 0.5)  # the GNR graph
>>> G = D.to_undirected()  # the undirected version
```

References

5.10.3 networkx.generators.directed.gnc_graph

gnc_graph (n, create_using=None, seed=None)

Return the growing network with copying (GNC) digraph with n nodes.

The GNC graph is built by adding nodes one at a time with a link to one previously added node (chosen uniformly at random) and to all of that node’s successors.

Parameters

• n (int) – The number of nodes for the generated graph.
• create_using (graph, optional (default DiGraph)) – Return graph of this type. The instance will be cleared.
• seed (hashable object, optional) – The seed for the random number generator.

References

5.10.4 networkx.generators.directed.random_k_out_graph

random_k_out_graph (n, k, alpha, self_loops=True, seed=None)

Returns a random k-out graph with preferential attachment.

A random k-out graph with preferential attachment is a multidigraph generated by the following algorithm.

1. Begin with an empty digraph, and initially set each node to have weight alpha.
2. Choose a node \( u \) with out-degree less than \( k \) uniformly at random.
3. Choose a node \( v \) from with probability proportional to its weight.
4. Add a directed edge from \( u \) to \( v \), and increase the weight of \( v \) by one.
5. If each node has out-degree \( k \), halt, otherwise repeat from step 2.

For more information on this model of random graph, see [1].

Parameters

• n (int) – The number of nodes in the returned graph.
• k (int) – The out-degree of each node in the returned graph.
• alpha (float) – A positive float representing the initial weight of each vertex. A higher number means that in step 3 above, nodes will be chosen more like a true uniformly random sample, and a lower number means that nodes are more likely to be chosen as their in-degree increases. If this parameter is not positive, a ValueError is raised.

• self_loops (bool) – If True, self-loops are allowed when generating the graph.

• seed (int) – If provided, this is used as the seed for the random number generator.

Returns A k-out-regular multidigraph generated according to the above algorithm.

Return type MultiDiGraph

Raises ValueError – If alpha is not positive.

Notes

The returned multidigraph may not be strongly connected, or even weakly connected.

References


5.10.5 networkx.generators.directed.scale_free_graph

scale_free_graph (n, alpha=0.41, beta=0.54, gamma=0.05, delta_in=0.2, delta_out=0, create_using=None, seed=None)

Returns a scale-free directed graph.

Parameters

• n (integer) – Number of nodes in graph

• alpha (float) – Probability for adding a new node connected to an existing node chosen randomly according to the in-degree distribution.

• beta (float) – Probability for adding an edge between two existing nodes. One existing node is chosen randomly according the in-degree distribution and the other chosen randomly according to the out-degree distribution.

• gamma (float) – Probability for adding a new node connected to an existing node chosen randomly according to the out-degree distribution.

• delta_in (float) – Bias for choosing nodes from in-degree distribution.

• delta_out (float) – Bias for choosing nodes from out-degree distribution.

• create_using (graph, optional (default MultiDiGraph)) – Use this graph instance to start the process (default=3-cycle).

• seed (integer, optional) – Seed for random number generator

Examples

Create a scale-free graph on one hundred nodes:
>>> G = nx.scale_free_graph(100)

Notes

The sum of alpha, beta, and gamma must be 1.

References

5.11 Geometric

Generators for geometric graphs.

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<td>random_geometric_graph(n, radius[, dim, pos, p])</td>
<td>Returns a random geometric graph in the unit cube of dimensions dim.</td>
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<td>soft_random_geometric_graph(n, radius[, ...])</td>
<td>Returns a soft random geometric graph in the unit cube of dimensions dim.</td>
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<tr>
<td>geographical_threshold_graph(n, theta[, ...])</td>
<td>Returns a geographical threshold graph.</td>
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<tr>
<td>waxman_graph(n[, beta, alpha, L, domain, metric])</td>
<td>Return a Waxman random graph.</td>
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<tr>
<td>navigable_small_world_graph(n[, p, q, r, ...])</td>
<td>Return a navigable small-world graph.</td>
</tr>
<tr>
<td>thresholded_random_geometric_graph(n[, ...[, ...]])</td>
<td>Returns a thresholded random geometric graph in the unit cube of dimensions dim.</td>
</tr>
</tbody>
</table>

5.11.1 networkx.generators.geometric.random_geometric_graph

random_geometric_graph (n, radius, dim=2, pos=None, p=2)

Returns a random geometric graph in the unit cube of dimensions dim.

The random geometric graph model places n nodes uniformly at random in the unit cube. Two nodes are joined by an edge if the distance between the nodes is at most radius.

Edges are determined using a KDTree when SciPy is available. This reduces the time complexity from $O(n^2)$ to $O(n)$.

Parameters

- n (int or iterable) – Number of nodes or iterable of nodes
- radius (float) – Distance threshold value
- dim (int, optional) – Dimension of graph
- pos (dict, optional) – A dictionary keyed by node with node positions as values.
- p (float, optional) – Which Minkowski distance metric to use. p has to meet the condition $1 \leq p \leq \infty$.
  
  If this argument is not specified, the $L^2$ metric (the Euclidean distance metric), $p = 2$ is used. This should not be confused with the $p$ of an Erdős-Rényi random graph, which represents probability.

Returns A random geometric graph, undirected and without self-loops. Each node has a node attribute 'pos' that stores the position of that node in Euclidean space as provided by the pos keyword argument or, if pos was not provided, as generated by this function.
Return type  *Graph*

**Examples**

Create a random geometric graph on twenty nodes where nodes are joined by an edge if their distance is at most 0.1:

```python
>>> G = nx.random_geometric_graph(20, 0.1)
```

**Notes**

This uses a $k$-d tree to build the graph.

The `pos` keyword argument can be used to specify node positions so you can create an arbitrary distribution and domain for positions.

For example, to use a 2D Gaussian distribution of node positions with mean $(0, 0)$ and standard deviation 2:

```python
>>> import random
>>> n = 20
>>> pos = {i: (random.gauss(0, 2), random.gauss(0, 2)) for i in range(n)}
>>> G = nx.random_geometric_graph(n, 0.2, pos=pos)
```

**References**

5.11.2  networkx.generators.geometric.soft_random_geometric_graph

`soft_random_geometric_graph(n, radius, dim=2, pos=None, p=2, p_dist=None)`

Returns a soft random geometric graph in the unit cube of dimensions `dim`.

The soft random geometric graph [1] model places $n$ nodes uniformly at random in the unit cube. Two nodes of distance, `dist`, computed by the $p$-Minkowski distance metric are joined by an edge with probability `$p_{dist}$` if the computed distance metric value of the nodes is at most `radius`, otherwise they are not joined.

Edges within `radius` of each other are determined using a KDTree when SciPy is available. This reduces the time complexity from $O(n^2)$ to $O(n)$.

**Parameters**

- `n (int or iterable)` – Number of nodes or iterable of nodes
- `radius (float)` – Distance threshold value
- `dim (int, optional)` – Dimension of graph
- `pos (dict, optional)` – A dictionary keyed by node with node positions as values.
- `p (float, optional)` – Which Minkowski distance metric to use. `p` has to meet the condition $1 \leq p \leq \infty$.

If this argument is not specified, the $L^2$ metric (the Euclidean distance metric), $p = 2$ is used.

This should not be confused with the $p$ of an Erdős-Rényi random graph, which represents probability.
• **p_dist** *(function, optional)* – A probability density function computing the probability of connecting two nodes that are of distance, dist, computed by the Minkowski distance metric. The probability density function, \(p\_dist\), must be any function that takes the metric value as input and outputs a single probability value between 0-1. The scipy.stats package has many probability distribution functions implemented and tools for custom probability distribution definitions [2], and passing the .pdf method of scipy.stats distributions can be used here. If the probability function, \(p\_dist\), is not supplied, the default function is an exponential distribution with rate parameter \(\lambda = 1\).

**Returns** A soft random geometric graph, undirected and without self-loops. Each node has a node attribute 'pos' that stores the position of that node in Euclidean space as provided by the pos keyword argument or, if pos was not provided, as generated by this function.

**Return type** *Graph*

**Examples**

Default Graph:

\[G = nx.soft_random_geometric_graph(50, 0.2)\]

Custom Graph:

Create a soft random geometric graph on 100 uniformly distributed nodes where nodes are joined by an edge with probability computed from an exponential distribution with rate parameter \(\lambda = 1\) if their Euclidean distance is at most 0.2.

**Notes**

This uses a \(k\)-d tree to build the graph.

The pos keyword argument can be used to specify node positions so you can create an arbitrary distribution and domain for positions.

For example, to use a 2D Gaussian distribution of node positions with mean (0, 0) and standard deviation 2

The scipy.stats package can be used to define the probability distribution with the .pdf method used as \(p\_dist\).

```python
>>> import random
>>> import math

>>> n = 100
>>> pos = {i: (random.gauss(0, 2), random.gauss(0, 2)) for i in range(n)}
>>> def p_dist(dist):
...    return math.exp(-dist)

>>> G = nx.soft_random_geometric_graph(n, 0.2, pos=pos, p_dist=p_dist)
```

**References**

5.11.3 *networkx.generators.geometric.geographical_threshold_graph*

geographical_threshold_graph \((n, \ \theta, \ \text{dim}=2, \ pos=\text{None, weight=\text{None, metric=\text{None,}} \ p\_dist=\text{None}})\)

Returns a geographical threshold graph.
The geographical threshold graph model places $n$ nodes uniformly at random in a rectangular domain. Each node $u$ is assigned a weight $w_u$. Two nodes $u$ and $v$ are joined by an edge if

$$(w_u + w_v)h(r) \geq \theta$$

where $r$ is the distance between $u$ and $v$, $h(r)$ is a probability of connection as a function of $r$, and $\theta$ as the threshold parameter. $h(r)$ corresponds to the $p_{\text{dist}}$ parameter.

**Parameters**

- **n** (*int or iterable*) – Number of nodes or iterable of nodes
- **theta** (*float*) – Threshold value
- **dim** (*int, optional*) – Dimension of graph
- **pos** (*dict*) – Node positions as a dictionary of tuples keyed by node.
- **weight** (*dict*) – Node weights as a dictionary of numbers keyed by node.
- **metric** (*function*) – A metric on vectors of numbers (represented as lists or tuples). This must be a function that accepts two lists (or tuples) as input and yields a number as output. The function must also satisfy the four requirements of a metric. Specifically, if $d$ is the function and $x, y, z$ are vectors in the graph, then $d$ must satisfy
  1. $d(x, y) \geq 0$,
  2. $d(x, y) = 0$ if and only if $x = y$,
  3. $d(x, y) = d(y, x)$,
  4. $d(x, z) \leq d(x, y) + d(y, z)$.

If this argument is not specified, the Euclidean distance metric is used.
- **p_dist** (*function, optional*) – A probability density function computing the probability of connecting two nodes that are of distance, $r$, computed by metric. The probability density function, $p_{\text{dist}}$, must be any function that takes the metric value as input and outputs a single probability value between 0-1. The scipy.stats package has many probability distribution functions implemented and tools for custom probability distribution definitions [2], and passing the .pdf method of scipy.stats distributions can be used here. If the probability function, $p_{\text{dist}}$, is not supplied, the default exponential function :math: r^{-2}$ is used.

**Returns**

A random geographic threshold graph, undirected and without self-loops.

Each node has a node attribute $\text{pos}$ that stores the position of that node in Euclidean space as provided by the $\text{pos}$ keyword argument or, if $\text{pos}$ was not provided, as generated by this function. Similarly, each node has a node attribute $\text{weight}$ that stores the weight of that node as provided or as generated.

**Return type** *Graph*

**Examples**

Specify an alternate distance metric using the $\text{metric}$ keyword argument. For example, to use the taxicab metric instead of the default Euclidean metric:

```python
>>> dist = lambda x, y: sum(abs(a - b) for a, b in zip(x, y))
>>> G = nx.geographical_threshold_graph(10, 0.1, metric=dist)
```
Notes

If weights are not specified they are assigned to nodes by drawing randomly from the exponential distribution with rate parameter $\lambda = 1$. To specify weights from a different distribution, use the weight keyword argument:

```python
>>> import random
>>> n = 20
>>> w = {i: random.expovariate(5.0) for i in range(n)}
>>> G = nx.geographical_threshold_graph(20, 50, weight=w)
```

If node positions are not specified they are randomly assigned from the uniform distribution.

Starting in NetworkX 2.1 the parameter alpha is deprecated and replaced with the customizable p_dist function parameter, which defaults to $r^{-2}$ if p_dist is not supplied. To reproduce networks of earlier NetworkX versions, a custom function needs to be defined and passed as the p_dist parameter. For example, if the parameter alpha = 2 was used in NetworkX 2.0, the custom function def custom_dist(r): r**-2 can be passed in versions >=2.1 as the parameter p_dist = custom_dist to produce an equivalent network. Note the change in sign from +2 to -2 in this parameter change.

References

5.11.4 networkx.generators.geometric.waxman_graph

waxman_graph($n$, beta=0.4, alpha=0.1, L=None, domain=(0, 0, 1, 1), metric=None)

Return a Waxman random graph.

The Waxman random graph model places $n$ nodes uniformly at random in a rectangular domain. Each pair of nodes at distance $d$ is joined by an edge with probability

$$p = \beta \exp(-d/\alpha L).$$

This function implements both Waxman models, using the L keyword argument.

- Waxman-1: if L is not specified, it is set to be the maximum distance between any pair of nodes.
- Waxman-2: if L is specified, the distance between a pair of nodes is chosen uniformly at random from the interval [0, L].

Parameters

- $n$ (int or iterable) – Number of nodes or iterable of nodes
- beta (float) – Model parameter
- alpha (float) – Model parameter
- L (float, optional) – Maximum distance between nodes. If not specified, the actual distance is calculated.
- domain (four-tuple of numbers, optional) – Domain size, given as a tuple of the form (x_min, y_min, x_max, y_max).
- metric (function) – A metric on vectors of numbers (represented as lists or tuples). This must be a function that accepts two lists (or tuples) as input and yields a number as output. The function must also satisfy the four requirements of a metric. Specifically, if $d$ is the function and $x, y, z$ are vectors in the graph, then $d$ must satisfy
  1. $d(x, y) \geq 0$,
2. \(d(x, y) = 0\) if and only if \(x = y\),
3. \(d(x, y) = d(y, x)\),
4. \(d(x, z) \leq d(x, y) + d(y, z)\).

If this argument is not specified, the Euclidean distance metric is used.

**Returns** A random Waxman graph, undirected and without self-loops. Each node has a node attribute 'pos' that stores the position of that node in Euclidean space as generated by this function.

**Return type** *Graph*

**Examples**

Specify an alternate distance metric using the **metric** keyword argument. For example, to use the “taxicab metric” instead of the default Euclidean metric:

```python
>>> dist = lambda x, y: sum(abs(a - b) for a, b in zip(x, y))
>>> G = nx.waxman_graph(10, 0.5, 0.1, metric=dist)
```

**Notes**

Starting in NetworkX 2.0 the parameters alpha and beta align with their usual roles in the probability distribution. In earlier versions their positions in the expression were reversed. Their position in the calling sequence reversed as well to minimize backward incompatibility.

**References**

5.11.5 *networkx.generators.geometric.navigable_small_world_graph*

*navigable_small_world_graph* \((n, p=1, q=1, r=2, \text{dim}=2, \text{seed}=None)\)

Return a navigable small-world graph.

A navigable small-world graph is a directed grid with additional long-range connections that are chosen randomly.

[... ] we begin with a set of nodes [... ] that are identified with the set of lattice points in an \(n \times n\) square, \(\{(i, j) : i \in \{1, 2, \ldots, n\}, j \in \{1, 2, \ldots, n\}\}\), and we define the **lattice distance** between two nodes \((i, j)\) and \((k, l)\) to be the number of “lattice steps” separating them: \(d((i, j), (k, l)) = |k - i| + |l - j|\).

For a universal constant \(p \geq 1\), the node \(u\) has a directed edge to every other node within lattice distance \(p\)—these are its **local contacts**. For universal constants \(q \geq 0\) and \(r \geq 0\) we also construct directed edges from \(u\) to \(q\) other nodes (the **long-range contacts**) using independent random trials; the \(i^{th}\) directed edge from :math:`u` has endpoint \(v\) with probability proportional to \(d(u, v)^{-r}\).

**Parameters**

- **n** (*int*) – The length of one side of the lattice; the number of nodes in the graph is therefore \(n^2\).

---

• \( p (\text{int}) \) – The diameter of short range connections. Each node is joined with every other node within this lattice distance.
• \( q (\text{int}) \) – The number of long-range connections for each node.
• \( r (\text{float}) \) – Exponent for decaying probability of connections. The probability of connecting to a node at lattice distance \( d \) is \( 1/d^r \).
• \( \text{dim} (\text{int}) \) – Dimension of grid
• \( \text{seed} (\text{int}, \text{optional}) \) – Seed for random number generator (default=None).

References

5.11.6 networkx.generators.geometric.thresholded_random_geometric_graph

thresholded_random_geometric_graph \((n, \text{radius}, \text{theta}, \text{dim}=2, \text{pos}=\text{None}, \text{weight}=\text{None}, p=2)\)

Returns a thresholded random geographic graph in the unit cube of dimensions \( \text{dim} \).

The thresholded random geographic graph [1] model places \( n \) nodes uniformly at random in the unit cube. Each node \( u \) is assigned a weight \( w_u \). Two nodes \( u \) and \( v \) are joined by an edge if they are within the maximum connection distance, \( \text{radius} \) computed by the \( p \)-Minkowski distance and the summation of weights \( w_u + w_v \) is greater than or equal to the threshold parameter \( \text{theta} \).

Edges within \( \text{radius} \) of each other are determined using a KDTree when SciPy is available. This reduces the time complexity from \( O(n^2) \) to \( O(n) \).

Parameters

• \( n (\text{int or iterable}) \) – Number of nodes or iterable of nodes
• \( \text{radius} (\text{float}) \) – Distance threshold value
• \( \text{theta} (\text{float}) \) – Threshold value
• \( \text{dim} (\text{int}, \text{optional}) \) – Dimension of graph
• \( \text{pos} (\text{dict}, \text{optional}) \) – A dictionary keyed by node with node positions as values.
• \( \text{weight} (\text{dict}, \text{optional}) \) – Node weights as a dictionary of numbers keyed by node.
• \( p (\text{float}, \text{optional}) \) – Which Minkowski distance metric to use. \( p \) has to meet the condition \( 1 \leq p \leq \infty \).

If this argument is not specified, the \( L^2 \) metric (the Euclidean distance metric), \( p = 2 \) is used. This should not be confused with the \( p \) of an Erdős-Rényi random graph, which represents probability.

Returns

A thresholded random geographic graph, undirected and without self-loops.

Each node has a node attribute \'pos\' that stores the position of that node in Euclidean space as provided by the \( \text{pos} \) keyword argument or, if \( \text{pos} \) was not provided, as generated by this function. Similarly, each node has a node attribute \'weight\' that stores the weight of that node as provided or as generated.

Return type \( \text{Graph} \)
Examples

Default Graph:
G = nx.thresholded_random_geometric_graph(50, 0.2, 0.1)

Custom Graph:
Create a thresholded random geometric graph on 50 uniformly distributed nodes where nodes are joined by an edge if their sum weights drawn from an exponential distribution with rate = 5 are >= theta = 0.1 and their Euclidean distance is at most 0.2.

Notes

This uses a k-d tree to build the graph.
The pos keyword argument can be used to specify node positions so you can create an arbitrary distribution and domain for positions.

For example, to use a 2D Gaussian distribution of node positions with mean (0, 0) and standard deviation 2.

If weights are not specified they are assigned to nodes by drawing randomly from the exponential distribution with rate parameter $\lambda = 1$. To specify weights from a different distribution, use the weight keyword argument:

```python
>>> import random
>>> import math

>>> n = 50
>>> pos = {i: (random.gauss(0, 2), random.gauss(0, 2)) for i in range(n)}
>>> w = {i: random.expovariate(5.0) for i in range(n)}
>>> G = nx.thresholded_random_geometric_graph(n, 0.2, 0.1, pos=pos, weight=w)
```

References

5.12 Line Graph

Functions for generating line graphs.

- `line_graph(G[, create_using])` Returns the line graph of the graph or digraph G.
- `inverse_line_graph(G)` Returns the inverse line graph of graph G.

5.12.1 networkx.generators.line.line_graph

`line_graph(G, create_using=None)`

Returns the line graph of the graph or digraph G.

The line graph of a graph $G$ has a node for each edge in $G$ and an edge joining those nodes if the two edges in $G$ share a common node. For directed graphs, nodes are adjacent exactly when the edges they represent form a directed path of length two.

The nodes of the line graph are 2-tuples of nodes in the original graph (or 3-tuples for multigraphs, with the key of the edge as the third element).
For information about self-loops and more discussion, see the Notes section below.

**Parameters**

- **G (graph)** – A NetworkX Graph, DiGraph, MultiGraph, or MultiDiGraph.

**Returns**

- **L** – The line graph of G.

**Return type**

- **graph**

**Examples**

```python
>>> import networkx as nx
>>> G = nx.star_graph(3)
>>> L = nx.line_graph(G)
>>> print(sorted(map(sorted, L.edges())))  # makes a 3-clique, K3

[(0, 1), (0, 2)], [(0, 1), (0, 3)], [(0, 2), (0, 3)]
```

**Notes**

Graph, node, and edge data are not propagated to the new graph. For undirected graphs, the nodes in G must be sortable, otherwise the constructed line graph may not be correct.

**Self-loops in undirected graphs**

For an undirected graph G without multiple edges, each edge can be written as a set \{u, v\}. Its line graph L has the edges of G as its nodes. If x and y are two nodes in L, then \(\{x, y\}\) is an edge in L if and only if the intersection of x and y is nonempty. Thus, the set of all edges is determined by the set of all pairwise intersections of edges in G.

Trivially, every edge in G would have a nonzero intersection with itself, and so every node in L should have a self-loop. This is not so interesting, and the original context of line graphs was with simple graphs, which had no self-loops or multiple edges. The line graph was also meant to be a simple graph and thus, self-loops in L are not part of the standard definition of a line graph. In a pairwise intersection matrix, this is analogous to excluding the diagonal entries from the line graph definition.

Self-loops and multiple edges in G add nodes to L in a natural way, and do not require any fundamental changes to the definition. It might be argued that the self-loops we excluded before should now be included. However, the self-loops are still “trivial” in some sense and thus, are usually excluded.

**Self-loops in directed graphs**

For a directed graph G without multiple edges, each edge can be written as a tuple \((u, v)\). Its line graph L has the edges of G as its nodes. If x and y are two nodes in L, then \((x, y)\) is an edge in L if and only if the tail of x matches the head of y, for example, if \(x = (a, b)\) and \(y = (b, c)\) for some vertices a, b, and c in G.

Due to the directed nature of the edges, it is no longer the case that every edge in G should have a self-loop in L. Now, the only time self-loops arise is if a node in G itself has a self-loop. So such self-loops are no longer “trivial” but instead, represent essential features of the topology of G. For this reason, the historical development of line digraphs is such that self-loops are included. When the graph G has multiple edges, once again only superficial changes are required to the definition.

**References**

5.12.2 networkx.generators.line.inverse_line_graph

`inverse_line_graph(G)`

Returns the inverse line graph of graph G.

If H is a graph, and G is the line graph of H, such that \( H = L(G) \). Then H is the inverse line graph of G.

Not all graphs are line graphs and these do not have an inverse line graph. In these cases this generator returns a NetworkXError.

**Parameters**

- \( G \) (graph) – A NetworkX Graph

**Returns**

- H – The inverse line graph of G.

**Return type**

graph

**Raises**

- `NetworkXNotImplemented` – If G is directed or a multigraph
- `NetworkXError` – If G is not a line graph

**Notes**

This is an implementation of the Roussopolous algorithm.

**References**


5.13 Ego Graph

Ego graph.

```
`ego_graph(G, n[, radius, center, ...])`
```

Returns induced subgraph of neighbors centered at node n within a given radius.

5.13.1 networkx.generators.ego.ego_graph

`ego_graph(G, n, radius=1, center=True, undirected=False, distance=None)`

Returns induced subgraph of neighbors centered at node n within a given radius.

**Parameters**

- \( G \) (graph) – A NetworkX Graph or DiGraph
- \( n \) (node) – A single node
- radius (number, optional) – Include all neighbors of distance<=radius from n.
• **center** *(bool, optional)* – If False, do not include center node in graph

• **undirected** *(bool, optional)* – If True use both in- and out-neighbors of directed graphs.

• **distance** *(key, optional)* – Use specified edge data key as distance. For example, setting distance='weight' will use the edge weight to measure the distance from the node n.

**Notes**

For directed graphs D this produces the “out” neighborhood or successors. If you want the neighborhood of predecessors first reverse the graph with D.reverse(). If you want both directions use the keyword argument undirected=True.

Node, edge, and graph attributes are copied to the returned subgraph.

### 5.14 Stochastic

Functions for generating stochastic graphs from a given weighted directed graph.

```python
stochastic_graph(G[, copy, weight]) Returns a right-stochastic representation of directed graph G.
```

#### 5.14.1 networkx.generators.stochastic.stochastic_graph

```python
stochastic_graph(G, copy=True, weight='weight') Returns a right-stochastic representation of directed graph G.
```

A right-stochastic graph is a weighted digraph in which for each node, the sum of the weights of all the out-edges of that node is 1. If the graph is already weighted (for example, via a ‘weight’ edge attribute), the reweighting takes that into account.

**Parameters**

- **G** *(directed graph)* – A DiGraph or MultiDiGraph.

- **copy (boolean, optional)** – If this is True, then this function returns a new graph with the stochastic reweighting. Otherwise, the original graph is modified in-place (and also returned, for convenience).

- **weight (edge attribute key (optional, default='weight'))** – Edge attribute key used for reading the existing weight and setting the new weight. If no attribute with this key is found for an edge, then the edge weight is assumed to be 1. If an edge has a weight, it must be a a positive number.

### 5.15 Intersection

Generators for random intersection graphs.

```python
uniform_random_intersection_graph(n, m, p[, ...]) Return a uniform random intersection graph.
```

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<table>
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<th>Function</th>
<th>Description</th>
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<tr>
<td>$k_{\text{random}_intersection_graph}(n, m, k)$</td>
<td>Return a intersection graph with randomly chosen attribute sets for each node that are of equal size (k).</td>
</tr>
<tr>
<td>$general_{\text{random}_intersection_graph}(n, m, p)$</td>
<td>Return a random intersection graph with independent probabilities for connections between node and attribute sets.</td>
</tr>
</tbody>
</table>

5.15.1 networkx.generators.intersection.uniform_random_intersection_graph

$uniform_{\text{random}\_intersection\_graph}(n, m, p, seed=\text{None})$

Return a uniform random intersection graph.

**Parameters**
- $n$ (int) – The number of nodes in the first bipartite set (nodes)
- $m$ (int) – The number of nodes in the second bipartite set (attributes)
- $p$ (float) – Probability of connecting nodes between bipartite sets
- $seed$ (int, optional) – Seed for random number generator (default=None).

**See also:**
- gnp_random_graph()

**References**

5.15.2 networkx.generators.intersection.k_random_intersection_graph

$k_{\text{random}\_intersection\_graph}(n, m, k)$

Return a intersection graph with randomly chosen attribute sets for each node that are of equal size (k).

**Parameters**
- $n$ (int) – The number of nodes in the first bipartite set (nodes)
- $m$ (int) – The number of nodes in the second bipartite set (attributes)
- $k$ (float) – Size of attribute set to assign to each node.
- $seed$ (int, optional) – Seed for random number generator (default=None).

**See also:**
- gnp_random_graph(), uniform_random_intersection_graph()

**References**

5.15.3 networkx.generators.intersection.general_random_intersection_graph

$general_{\text{random}\_intersection\_graph}(n, m, p)$

Return a random intersection graph with independent probabilities for connections between node and attribute sets.

**Parameters**
- $n$ (int) – The number of nodes in the first bipartite set (nodes)
- $m$ (int) – The number of nodes in the second bipartite set (attributes)
• \( p \) (list of floats of length \( m \)) – Probabilities for connecting nodes to each attribute
• \( \text{seed} \) (int, optional) – Seed for random number generator (default=None).

See also:
gnp_random_graph(), uniform_random_intersection_graph()

References

5.16 Social Networks

Famous social networks.

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<th>Description</th>
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<td>karate_club_graph()</td>
<td>Return Zachary’s Karate Club graph.</td>
</tr>
<tr>
<td>davis_southern_women_graph()</td>
<td>Return Davis Southern women social network.</td>
</tr>
<tr>
<td>florentine_families_graph()</td>
<td>Return Florentine families graph.</td>
</tr>
</tbody>
</table>

5.16.1 networkx.generators.social.karate_club_graph

karate_club_graph()

Return Zachary’s Karate Club graph.

Each node in the returned graph has a node attribute ‘club’ that indicates the name of the club to which the member represented by that node belongs, either ‘Mr. Hi’ or ‘Officer’.

Examples

To get the name of the club to which a node belongs:

```python
>>> import networkx as nx
>>> G = nx.karate_club_graph()
>>> G.nodes[5]['club']
'Mr. Hi'
>>> G.nodes[9]['club']
'Officer'
```

References

5.16.2 networkx.generators.social.davis_southern_women_graph

davis_southern_women_graph()

Return Davis Southern women social network.

This is a bipartite graph.
References

5.16.3 networkx.generators.social.florentine_families_graph

florentine_families_graph()
Return Florentine families graph.

References

5.17 Community

Generators for classes of graphs used in studying social networks.

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<th>Function</th>
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<td>caveman_graph(l, k)</td>
<td>Returns a caveman graph of l cliques of size k.</td>
</tr>
<tr>
<td>connected_caveman_graph(l, k)</td>
<td>Returns a connected caveman graph of l cliques of size k.</td>
</tr>
<tr>
<td>relaxed_caveman_graph(l, k, p[, seed])</td>
<td>Return a relaxed caveman graph.</td>
</tr>
<tr>
<td>random_partition_graph(sizes, p_in, p_out[, ...])</td>
<td>Return the random partition graph with a partition of sizes.</td>
</tr>
<tr>
<td>planted_partition_graph(l, k, p_in, p_out[, ...])</td>
<td>Return the planted l-partition graph.</td>
</tr>
<tr>
<td>gaussian_random_partition_graph(n, s, v, ...)</td>
<td>Generate a Gaussian random partition graph.</td>
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<tr>
<td>ring_of_cliques(num_cliques, clique_size)</td>
<td>Defines a “ring of cliques” graph.</td>
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<tr>
<td>windmill_graph(n, k)</td>
<td>Generate a windmill graph.</td>
</tr>
</tbody>
</table>

5.17.1 networkx.generators.community.caveman_graph

caveman_graph(l, k)
Returns a caveman graph of l cliques of size k.

Parameters

- l (int) – Number of cliques
- k (int) – Size of cliques

Returns G – caveman graph

Return type NetworkX Graph

Notes

This returns an undirected graph, it can be converted to a directed graph using nx.to_directed(), or a multigraph using nx.MultiGraph(nx.caveman_graph(l, k)). Only the undirected version is described in\(^1\) and it is unclear which of the directed generalizations is most useful.

Examples

```python
>>> G = nx.caveman_graph(3, 3)
```

See also:

connected_caveman_graph()

References

5.17.2 networkx.generators.community.connected_caveman_graph

connected_caveman_graph(l, k)
Returns a connected caveman graph of l cliques of size k.

The connected caveman graph is formed by creating n cliques of size k, then a single edge in each clique is rewired to a node in an adjacent clique.

Parameters

• l (int) – number of cliques
• k (int) – size of cliques

Returns G – connected caveman graph

Return type NetworkX Graph

Notes

This returns an undirected graph, it can be converted to a directed graph using nx.to_directed(), or a multigraph using nx.MultiGraph(nx.caveman_graph(l, k)). Only the undirected version is described in1 and it is unclear which of the directed generalizations is most useful.

Examples

>>> G = nx.connected_caveman_graph(3, 3)

References

5.17.3 networkx.generators.community.relaxed_caveman_graph

relaxed_caveman_graph(l, k, p, seed=None)
Return a relaxed caveman graph.

A relaxed caveman graph starts with l cliques of size k. Edges are then randomly rewired with probability p to link different cliques.

Parameters

• l (int) – Number of groups
• k (int) – Size of cliques
• p (float) – Probability of rewiring each edge.
• seed (int, optional) – Seed for random number generator(default=None)

Returns G – Relaxed Caveman Graph

Return type NetworkX Graph

Raises NetworkXError: – If p is not in [0,1]

Examples

```python
>>> G = nx.relaxed_caveman_graph(2, 3, 0.1, seed=42)
```

References

5.17.4 networkx.generators.community.random_partition_graph

random_partition_graph(sizes, p_in, p_out, seed=None, directed=False)

Return the random partition graph with a partition of sizes.

A partition graph is a graph of communities with sizes defined by s in sizes. Nodes in the same group are connected with probability p_in and nodes of different groups are connected with probability p_out.

Parameters

- sizes (list of ints) – Sizes of groups
- p_in (float) – probability of edges with in groups
- p_out (float) – probability of edges between groups
- directed (boolean optional, default=False) – Whether to create a directed graph
- seed (int optional, default None) – A seed for the random number generator

Returns G – random partition graph of size sum(gs)

Return type NetworkX Graph or DiGraph

Raises NetworkXError – If p_in or p_out is not in [0,1]

Examples

```python
>>> G = nx.random_partition_graph([10,10,10],.25,.01)
>>> len(G)
30
>>> partition = G.graph['partition']
>>> len(partition)
3
```

Notes

This is a generalization of the planted-l-partition described in\(^1\). It allows for the creation of groups of any size. The partition is store as a graph attribute ‘partition’.

---

References

5.17.5 networkx.generators.community.planted_partition_graph

\texttt{planted\_partition\_graph}(l, k, p\textsubscript{in}, p\textsubscript{out}, seed=None, directed=False)

Return the planted l-partition graph.

This model partitions a graph with \(n = l \times k\) vertices in \(l\) groups with \(k\) vertices each. Vertices of the same group are linked with a probability \(p\textsubscript{in}\), and vertices of different groups are linked with probability \(p\textsubscript{out}\).

Parameters

- \(l\) (\texttt{int}) – Number of groups
- \(k\) (\texttt{int}) – Number of vertices in each group
- \(p\textsubscript{in}\) (\texttt{float}) – probability of connecting vertices within a group
- \(p\textsubscript{out}\) (\texttt{float}) – probability of connected vertices between groups
- \texttt{seed} (\texttt{int, optional}) – Seed for random number generator (default=None)
- \texttt{directed} (\texttt{bool, optional} (default=False)) – If True return a directed graph

Returns \(G\) – planted \(l\)-partition graph

Return type NetworkX Graph or DiGraph

Raises NetworkXError: – If \(p\textsubscript{in}, p\textsubscript{out}\) are not in \([0,1]\) or

Examples

```python
>>> G = nx.planted_partition_graph(4, 3, 0.5, 0.1, seed=42)
```

See also:

random\_partition\_model()

References

5.17.6 networkx.generators.community.gaussian_random_partition_graph

\texttt{gaussian\_random\_partition\_graph}(n, s, v, p\textsubscript{in}, p\textsubscript{out}, directed=False, seed=None)

Generate a Gaussian random partition graph.

A Gaussian random partition graph is created by creating \(k\) partitions each with a size drawn from a normal distribution with mean \(s\) and variance \(s/v\). Nodes are connected within clusters with probability \(p\textsubscript{in}\) and between clusters with probability \(p\textsubscript{out}\)[1]

Parameters

- \(n\) (\texttt{int}) – Number of nodes in the graph
- \(s\) (\texttt{float}) – Mean cluster size
- \(v\) (\texttt{float}) – Shape parameter. The variance of cluster size distribution is \(s/v\).
- \(p\textsubscript{in}\) (\texttt{float}) – Probability of intra cluster connection.
- \(p\textsubscript{out}\) (\texttt{float}) – Probability of inter cluster connection.
**gaussian_random_partition_graph**

- **directed** *(boolean, optional default=False)* – Whether to create a directed graph or not
- **seed** *(int)* – Seed value for random number generator

**Returns**
- G – gaussian random partition graph

**Return type** NetworkX Graph or DiGraph

**Raises**
- NetworkXError – If s is > n If p_in or p_out is not in [0,1]

**Notes**

Note the number of partitions is dependent on s,v and n, and that the last partition may be considerably smaller, as it is sized to simply fill out the nodes [1]

**See also:**
- random_partition_graph()

**Examples**

```python
>>> G = nx.gaussian_random_partition_graph(100, 10, 10, .25, .1)
>>> len(G)
100
```

**References**

5.17.7 networkx.generators.community.ring_of_cliques

**ring_of_cliques** *(num_cliques, clique_size)*

 Defines a “ring of cliques” graph.

A ring of cliques graph is consisting of cliques, connected through single links. Each clique is a complete graph.

**Parameters**

- **num_cliques** *(int)* – Number of cliques
- **clique_size** *(int)* – Size of cliques

**Returns**
- G – ring of cliques graph

**Return type** NetworkX Graph

**Raises**
- NetworkXError – If the number of cliques is lower than 2 or if the size of cliques is smaller than 2.

**Examples**

```python
>>> G = nx.ring_of_cliques(8, 4)
```

**See also:**
- connected_caveman_graph()
Notes

The `connected_caveman_graph` graph removes a link from each clique to connect it with the next clique. Instead, the `ring_of_cliques` graph simply adds the link without removing any link from the cliques.

5.17.8 networkx.generators.community.windmill_graph

`windmill_graph(n, k)`

Generate a windmill graph. A windmill graph is a graph of \( n \) cliques each of size \( k \) that are all joined at one node. It can be thought of as taking a disjoint union of \( n \) cliques of size \( k \), selecting one point from each, and contracting all of the selected points. Alternatively, one could generate \( n \) cliques of size \( k-1 \) and one node that is connected to all other nodes in the graph.

Parameters

- \( n \) (int) – Number of cliques
- \( k \) (int) – Size of cliques

Returns \( G \) – windmill graph with \( n \) cliques of size \( k \)

Return type : NetworkX Graph

Raises NetworkXError – If the number of cliques is less than two If the size of the cliques are less than two

Examples

```python
>>> G = nx.windmill_graph(4, 5)
```

Notes

The node labeled 0 will be the node connected to all other nodes. Note that windmill graphs are usually denoted \( Wd(k, n) \), so the parameters are in the opposite order as the parameters of this method.

5.18 Trees

Functions for generating trees.

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<tbody>
<tr>
<td><code>random_tree(n, seed)</code></td>
<td>Returns a uniformly random tree on ( n ) nodes.</td>
</tr>
<tr>
<td><code>prefix_tree(paths)</code></td>
<td>Creates a directed prefix tree from the given list of iterables.</td>
</tr>
</tbody>
</table>

5.18.1 networkx.generators.trees.random_tree

`random_tree(n, seed=None)`

Returns a uniformly random tree on \( n \) nodes.

Parameters

- \( n \) (int) – A positive integer representing the number of nodes in the tree.
• **seed** (*int*) – A seed for the random number generator.

**Returns** A tree, given as an undirected graph, whose nodes are numbers in the set \(\{0, \ldots, n - 1\}\).

**Return type** NetworkX graph

**Raises** NetworkXPointlessConcept – If \(n\) is zero (because the null graph is not a tree).

### Notes

The current implementation of this function generates a uniformly random Prüfer sequence then converts that to a tree via the `from_pruefer_sequence()` function. Since there is a bijection between Prüfer sequences of length \(n - 2\) and trees on \(n\) nodes, the tree is chosen uniformly at random from the set of all trees on \(n\) nodes.

#### 5.18.2 networkx.generators.trees.prefix_tree

**prefix_tree** (*paths*)

Creates a directed prefix tree from the given list of iterables.

**Parameters**

- **paths** (*iterable of lists*) – An iterable over “paths”, which are themselves lists of nodes. Common prefixes among these paths are converted into common initial segments in the generated tree.

- Most commonly, this may be an iterable over lists of integers, or an iterable over Python strings.

**Returns**

A directed graph representing an arborescence consisting of the prefix tree generated by *paths*. Nodes are directed “downward”, from parent to child. A special “synthetic” root node is added to be the parent of the first node in each path. A special “synthetic” leaf node, the “nil” node, is added to be the child of all nodes representing the last element in a path. (The addition of this nil node technically makes this not an arborescence but a directed acyclic graph; removing the nil node makes it an arborescence.)

Each node has an attribute ‘source’ whose value is the original element of the path to which this node corresponds. The ‘source’ of the root node is None, and the ‘source’ of the nil node is NIL.

The root node is the only node of in-degree zero in the graph, and the nil node is the only node of out-degree zero. For convenience, the nil node can be accessed via the NIL attribute; for example:

```python
>>> from networkx.generators.trees import NIL
>>> paths = ['ab', 'abs', 'ad']
>>> T = nx.prefix_tree(paths)
>>> T.predecessors(NIL)
```

**Return type** *DiGraph*

### Notes

The prefix tree is also known as a trie.
Examples

Create a prefix tree from a list of strings with some common prefixes:

```python
>>> strings = ['ab', 'abs', 'ad']
>>> T, root = nx.prefix_tree(strings)
```

Continuing the above example, to recover the original paths that generated the prefix tree, traverse up the tree from the NIL node to the root:

```python
>>> from networkx.generators.trees import NIL
>>> strings = ['ab', 'abs', 'ad']
>>> T, root = nx.prefix_tree(strings)
>>> recovered = []
>>> for v in T.predecessors(NIL):
...     s = ''
...     while v != root:
...         # Prepend the character `v` to the accumulator `s`.
...         s = str(T.node[v]['source']) + s
...         # Each non-nil, non-root node has exactly one parent.
...         v = next(T.predecessors(v))
...     recovered.append(s)
>>> sorted(recovered)
['ab', 'abs', 'ad']
```

5.19 Non Isomorphic Trees

Implementation of the Wright, Richmond, Odlyzko and McKay (WROM) algorithm for the enumeration of all non-isomorphic free trees of a given order. Rooted trees are represented by level sequences, i.e., lists in which the i-th element specifies the distance of vertex i to the root.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>nonisomorphic_trees(order[, create])</code></td>
<td>Returns a list of nonisomporphic trees</td>
</tr>
<tr>
<td><code>number_of_nonisomorphic_trees(order)</code></td>
<td>Returns the number of nonisomorphic trees</td>
</tr>
</tbody>
</table>

5.19.1 networkx.generators.nonisomorphic_trees.nonisomorphic_trees

`nonisomorphic_trees (order, create='graph')`

Returns a list of nonisomporphic trees

Parameters

- `order (int)` – order of the desired tree(s)
- `create (graph or matrix (default="Graph"))` – If graph is selected a list of trees will be returned, if matrix is selected a list of adjacency matrix will be returned

Returns

- `G (List of NetworkX Graphs)`
- `M (List of Adjacency matrices)`
5.19.2 networkx.generators.nonisomorphic_trees.number_of_nonisomorphic_trees

number_of_nonisomorphic_trees(order)

Returns the number of nonisomorphic trees

Parameters:
- order (int): order of the desired tree(s)

Returns:
- length

Return type:
- Number of nonisomorphic graphs for the given order

References

5.20 Triads

Functions that generate the triad graphs, that is, the possible digraphs on three nodes.

triad_graph(triad_name)

Returns the triad graph with the given name.

Each string in the following tuple is a valid triad name:

('003', '012', '102', '021D', '021U', '021C', '111D', '111U',
 '030T', '030C', '201', '120D', '120U', '120C', '210', '300')

Each triad name corresponds to one of the possible valid digraphs on three nodes.

Parameters:
- triad_name (string): The name of a triad, as described above.

Returns:
- The digraph on three nodes with the given name. The nodes of the graph are the single-character strings 'a', 'b', and 'c'.

Return type:
- DiGraph

Raises:
- ValueError: If triad_name is not the name of a triad.

See also:
- triadic_census()

5.21 Joint Degree Sequence

Generate graphs with a given joint degree

is_valid_joint_degree(joint_degrees)

Checks whether the given joint degree dictionary is realizable as a simple graph.

Continued on next page
Table 21 – continued from previous page

| joint_degree_graph(joint_degrees[, seed]) | Generates a random simple graph with the given joint degree dictionary. |

5.21.1 networkx.generators.joint_degree_seq.is_valid_joint_degree

is_valid_joint_degree(joint_degrees)
Checks whether the given joint degree dictionary is realizable as a simple graph.

A **joint degree dictionary** is a dictionary of dictionaries, in which entry `joint_degrees[k][l]` is an integer representing the number of edges joining nodes of degree `k` with nodes of degree `l`. Such a dictionary is realizable as a simple graph if and only if the following conditions are satisfied.

- Each entry must be an integer,
- The total number of nodes of degree `k`, computed by `sum(joint_degrees[k].values()) / k`, must be an integer,
- The total number of edges joining nodes of degree `k` with nodes of degree `l` cannot exceed the total number of possible edges,
- Each diagonal entry `joint_degrees[k][k]` must be even (this is a convention assumed by the `joint_degree_graph()` function).

**Parameters**

- joint_degrees (dictionary of dictionary of integers) – A joint degree dictionary in which entry `joint_degrees[k][l]` is the number of edges joining nodes of degree `k` with nodes of degree `l`.

**Returns**

Whether the given joint degree dictionary is realizable as a simple graph.

**Return type**

bool

References

5.21.2 networkx.generators.joint_degree_seq.joint_degree_graph

joint_degree_graph(joint_degrees, seed=None)
Generates a random simple graph with the given joint degree dictionary.

**Parameters**

- joint_degrees (dictionary of dictionary of integers) – A joint degree dictionary in which entry `joint_degrees[k][l]` is the number of edges joining nodes of degree `k` with nodes of degree `l`.
- seed (hashable object, optional) – Seed for random number generator.

**Returns**

G – A graph with the specified joint degree dictionary.

**Return type**

Graph

**Raises**

NetworkXError – If `joint_degrees` dictionary is not realizable.
Notes

In each iteration of the “while loop” the algorithm picks two disconnected nodes \( v \) and \( w \), of degree \( k \) and \( l \) correspondingly, for which \( \text{joint}_{-}\text{degrees}[k][l] \) has not reached its target yet. It then adds edge \((v, w)\) and increases the number of edges in graph \( G \) by one.

The intelligence of the algorithm lies in the fact that it is always possible to add an edge between such disconnected nodes \( v \) and \( w \), even if one or both nodes do not have free stubs. That is made possible by executing a “neighbor switch”, an edge rewiring move that releases a free stub while keeping the joint degree of \( G \) the same.

The algorithm continues for \( E \) (number of edges) iterations of the “while loop”, at which point all entries of the given \( \text{joint}_{-}\text{degrees}[k][l] \) have reached their target values and the construction is complete.

References

Examples

```python
>>> import networkx as nx
>>> joint_degrees = {1: {4: 1}, ...
... 2: {2: 2, 3: 2, 4: 2}, ...
... 3: {2: 2, 4: 1}, ...
... 4: {1: 1, 2: 2, 3: 1}}
>>> G=nx.joint_degree_graph(joint_degrees)
```

5.22 Mycielski

Functions related to the Mycielski Operation and the Mycielskian family of graphs.

<table>
<thead>
<tr>
<th>mycielskian ((G, \text{iterations}))</th>
<th>Returns the Mycielskian of a simple, undirected graph ( G )</th>
</tr>
</thead>
<tbody>
<tr>
<td>mycielski_graph ((n))</td>
<td>Generator for the ( n )th Mycielski Graph.</td>
</tr>
</tbody>
</table>

5.22.1 networkx.generators.mycielski.mycielskian

\texttt{mycielskian} \((G, \text{iterations}=1)\)

Returns the Mycielskian of a simple, undirected graph \( G \)

The Mycielskian of graph preserves a graph’s triangle free property while increasing the chromatic number by 1.

The Mycielski Operation on a graph, \( G = (V, E) \), constructs a new graph with \( 2|V| + 1 \) nodes and \( 3|E| + |V| \) edges.

The construction is as follows:

Let \( V = 0, ..., n - 1 \). Construct another vertex set \( U = n, ..., 2n \) and a vertex, \( w \). Construct a new graph, \( M \), with vertices \( U \cup V \cup w \). For edges, \((u, v) \in E\) add edges \((u, v), (u, v + n)\), and \((u + n, v)\) to \( M \). Finally, for all vertices \( u \in U \), add edge \((u, w)\) to \( M \).

The Mycielski Operation can be done multiple times by repeating the above process iteratively.

More information can be found at https://en.wikipedia.org/wiki/Mycielskian
Parameters

- G (graph) – A simple, undirected NetworkX graph
- iterations (int) – The number of iterations of the Mycielski operation to perform on G. Defaults to 1. Must be a non-negative integer.

Returns  M – The Mycielskian of G after the specified number of iterations.

Return type  graph

Notes

Graph, node, and edge data are not necessarily propagated to the new graph.

5.22.2  networkx.generators.mycielski.mycielski_graph

mycielski_graph (n)

Generator for the n_th Mycielski Graph.

The Mycielski family of graphs is an infinite set of graphs. \( M_1 \) is the singleton graph, \( M_2 \) is two vertices with an edge, and, for \( i > 2 \), \( M_i \) is the Mycielskian of \( M_{i-1} \).

More information can be found at http://mathworld.wolfram.com/MycielskiGraph.html

Parameters  n (int) – The desired Mycielski Graph.

Returns  M – The n_th Mycielski Graph

Return type  graph

Notes

The first graph in the Mycielski sequence is the singleton graph. The Mycielskian of this graph is not the \( P_2 \) graph, but rather the \( P_2 \) graph with an extra, isolated vertex. The second Mycielski graph is the \( P_2 \) graph, so the first two are hard coded. The remaining graphs are generated using the Mycielski operation.
6.1 Graph Matrix

Adjacency matrix and incidence matrix of graphs.

```python
adjacency_matrix(G[, nodelist, weight])
```
Return adjacency matrix of G.

```python
incidence_matrix(G[, nodelist, edgelist, ...])
```
Return incidence matrix of G.

6.1.1 networkx.linalg.graphmatrix.adjacency_matrix

```python
adjacency_matrix(G, nodelist=None, weight='weight')
```
Return adjacency matrix of G.

**Parameters**

- **G (graph)** – A NetworkX graph
- **nodelist (list, optional)** – The rows and columns are ordered according to the nodes in nodelist. If nodelist is None, then the ordering is produced by G.nodes().
- **weight (string or None, optional (default='weight'))** – The edge data key used to provide each value in the matrix. If None, then each edge has weight 1.

**Returns**

- **A** – Adjacency matrix representation of G.
- **Return type** SciPy sparse matrix

**Notes**

For directed graphs, entry i,j corresponds to an edge from i to j.

If you want a pure Python adjacency matrix representation try networkx.convert.to_dict_of_dicts which will return a dictionary-of-dictionaries format that can be addressed as a sparse matrix.

For MultiGraph/MultiDiGraph with parallel edges the weights are summed. See to_numpy_matrix for other options.

The convention used for self-loop edges in graphs is to assign the diagonal matrix entry value to the edge weight attribute (or the number 1 if the edge has no weight attribute). If the alternate convention of doubling the edge weight is desired the resulting Scipy sparse matrix can be modified as follows:
```python
>>> import scipy as sp
>>> G = nx.Graph([(1,1)])
>>> A = nx.adjacency_matrix(G)
>>> print(A.todense())
[[1]]
>>> A.setdiag(A.diagonal()*2)
>>> print(A.todense())
[[2]]
```

See also:

to_numpy_matrix(), to_scipy_sparse_matrix(), to_dict_of_dicts()

6.1.2 networkx.linalg.graphmatrix.incidence_matrix

```
incidence_matrix(G, nodelist=None, edgelist=None, oriented=False, weight=None)
```

Return incidence matrix of G.

The incidence matrix assigns each row to a node and each column to an edge. For a standard incidence matrix a 1 appears wherever a row’s node is incident on the column’s edge. For an oriented incidence matrix each edge is assigned an orientation (arbitrarily for undirected and aligning to direction for directed). A -1 appears for the tail of an edge and 1 for the head of the edge. The elements are zero otherwise.

Parameters

- **G** (graph) – A NetworkX graph
- **nodelist** (list, optional (default= all nodes in G)) – The rows are ordered according to the nodes in nodelist. If nodelist is None, then the ordering is produced by G.nodes().
- **edgelist** (list, optional (default= all edges in G)) – The columns are ordered according to the edges in edgelist. If edgelist is None, then the ordering is produced by G.edges().
- **oriented** (bool, optional (default=False)) – If True, matrix elements are +1 or -1 for the head or tail node respectively of each edge. If False, +1 occurs at both nodes.
- **weight** (string or None, optional (default=None)) – The edge data key used to provide each value in the matrix. If None, then each edge has weight 1. Edge weights, if used, should be positive so that the orientation can provide the sign.

Returns  

**A** – The incidence matrix of G.

Return type  

SciPy sparse matrix

Notes

For MultiGraph/MultiDiGraph, the edges in edgelist should be (u,v,key) 3-tuples.

“Networks are the best discrete model for so many problems in applied mathematics”

---

References

6.2 Laplacian Matrix

Laplacian matrix of graphs.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>laplacian_matrix(G, nodelist, weight)</td>
<td>Return the Laplacian matrix of G.</td>
</tr>
<tr>
<td>normalized_laplacian_matrix(G, nodelist, ...)</td>
<td>Return the normalized Laplacian matrix of G.</td>
</tr>
<tr>
<td>directed_laplacian_matrix(G, nodelist, ...)</td>
<td>Return the directed Laplacian matrix of G.</td>
</tr>
</tbody>
</table>

6.2.1 networkx.linalg.laplacianmatrix.laplacian_matrix

`laplacian_matrix(G, nodelist=None, weight='weight')`

Return the Laplacian matrix of G.

The graph Laplacian is the matrix \( L = D - A \), where A is the adjacency matrix and D is the diagonal matrix of node degrees.

Parameters

- `G` (graph) – A NetworkX graph
- `nodelist` (list, optional) – The rows and columns are ordered according to the nodes in nodelist. If nodelist is None, then the ordering is produced by G.nodes().
- `weight` (string or None, optional (default='weight')) – The edge data key used to compute each value in the matrix. If None, then each edge has weight 1.

Returns `L` – The Laplacian matrix of G.

Return type SciPy sparse matrix

Notes

For MultiGraph/MultiDiGraph, the edges weights are summed.

See also:

to_numpy_matrix(), normalized_laplacian_matrix()

6.2.2 networkx.linalg.laplacianmatrix.normalized_laplacian_matrix

`normalized_laplacian_matrix(G, nodelist=None, weight='weight')`

Return the normalized Laplacian matrix of G.

The normalized graph Laplacian is the matrix

\[ N = D^{-1/2}LD^{-1/2} \]

where \( L \) is the graph Laplacian and \( D \) is the diagonal matrix of node degrees.

Parameters

- `G` (graph) – A NetworkX graph
• **nodelist** *(list, optional)* – The rows and columns are ordered according to the nodes in nodelist. If nodelist is None, then the ordering is produced by G.nodes().

• **weight** *(string or None, optional (default='weight'))* – The edge data key used to compute each value in the matrix. If None, then each edge has weight 1.

**Returns**

N – The normalized Laplacian matrix of G.

**Return type**

NumPy matrix

**Notes**

For MultiGraph/MultiDiGraph, the edges weights are summed. See to_numpy_matrix for other options.

If the Graph contains selfloops, D is defined as \( \text{diag}(\text{sum}(A,1)) \), where A is the adjacency matrix \(^2\).

See also:

*laplacian_matrix()*

**References**

6.2.3 networkx.linalg.laplacianmatrix.directed_laplacian_matrix

directed_laplacian_matrix *(G, nodelist=None, weight='weight', walk_type=None, alpha=0.95)*

Return the directed Laplacian matrix of G.

The graph directed Laplacian is the matrix

\[
L = I - \left( \Phi^{1/2} P \Phi^{-1/2} + \Phi^{-1/2} P^T \Phi^{1/2} \right) / 2
\]

where \( I \) is the identity matrix, \( P \) is the transition matrix of the graph, and \( \Phi \) a matrix with the Perron vector of \( P \) in the diagonal and zeros elsewhere.

Depending on the value of walk_type, \( P \) can be the transition matrix induced by a random walk, a lazy random walk, or a random walk with teleportation (PageRank).

**Parameters**

• **G** *(DiGraph)* – A NetworkX graph

• **nodelist** *(list, optional)* – The rows and columns are ordered according to the nodes in nodelist. If nodelist is None, then the ordering is produced by G.nodes().

• **weight** *(string or None, optional (default='weight'))* – The edge data key used to compute each value in the matrix. If None, then each edge has weight 1.

• **walk_type** *(string or None, optional (default=None))* – If None, \( P \) is selected depending on the properties of the graph. Otherwise is one of 'random', 'lazy', or 'pagerank'

• **alpha** *(real)* – \((1 - \alpha)\) is the teleportation probability used with pagerank

**Returns**

L – Normalized Laplacian of G.

**Return type**

NumPy array

**Raises**

• NetworkXError – If NumPy cannot be imported

---

• NetworkXNotImplemented – If G is not a DiGraph

Notes

Only implemented for DiGraphs

See also:

laplacian_matrix()

References

6.3 Spectrum

Eigenvalue spectrum of graphs.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>laplacian_spectrum(G[, weight])</td>
<td>Return eigenvalues of the Laplacian of G</td>
</tr>
<tr>
<td>adjacency_spectrum(G[, weight])</td>
<td>Return eigenvalues of the adjacency matrix of G.</td>
</tr>
</tbody>
</table>

6.3.1 networkx.linalg.spectrum.laplacian_spectrum

laplacian_spectrum(G, weight='weight')

Return eigenvalues of the Laplacian of G

Parameters

- G (graph) – A NetworkX graph
- weight (string or None, optional (default='weight')) – The edge data key used to compute each value in the matrix. If None, then each edge has weight 1.

Returns evals – Eigenvalues

Return type NumPy array

Notes

For MultiGraph/MultiDiGraph, the edges weights are summed. See to_numpy_matrix for other options.

See also:

laplacian_matrix()

6.3.2 networkx.linalg.spectrum.adjacency_spectrum

adjacency_spectrum(G, weight='weight')

Return eigenvalues of the adjacency matrix of G.

Parameters

- G (graph) – A NetworkX graph
- weight (string or None, optional (default='weight')) – The edge data key used to compute each value in the matrix. If None, then each edge has weight 1.
Returns `evals` – Eigenvalues

Return type NumPy array

Notes

For MultiGraph/MultiDiGraph, the edges weights are summed. See to_numpy_matrix for other options.

See also:

adjacency_matrix()

6.4 Algebraic Connectivity

Algebraic connectivity and Fiedler vectors of undirected graphs.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>algebraic_connectivity(G[, weight, ...])</code></td>
<td>Return the algebraic connectivity of an undirected graph.</td>
</tr>
<tr>
<td><code>fiedler_vector(G[, weight, normalized, tol, ...])</code></td>
<td>Return the Fiedler vector of a connected undirected graph.</td>
</tr>
<tr>
<td><code>spectral_ordering(G[, weight, normalized, ...])</code></td>
<td>Compute the spectral_ordering of a graph.</td>
</tr>
</tbody>
</table>

6.4.1 networkx.linalg.algebraicconnectivity.algebraic_connectivity

`algebraic_connectivity(G[, weight='weight', normalized=False, tol=1e-08, method='tracemin_pcg'])`

Return the algebraic connectivity of an undirected graph.

The algebraic connectivity of a connected undirected graph is the second smallest eigenvalue of its Laplacian matrix.

Parameters

- `G` (*NetworkX graph*) – An undirected graph.
- `weight` (*object, optional (default: None]*) – The data key used to determine the weight of each edge. If None, then each edge has unit weight.
- `normalized` (*bool, optional (default: False]*) – Whether the normalized Laplacian matrix is used.
- `tol` (*float, optional (default: 1e-8]*) – Tolerance of relative residual in eigenvalue computation.
- `method` (*string, optional (default: 'tracemin_pcg]*) – Method of eigenvalue computation. It must be one of the tracemin options shown below (TraceMIN), ‘lanczos’ (Lanczos iteration) or ‘lobpcg’ (LOBPCG).

The TraceMIN algorithm uses a linear system solver. The following values allow specifying the solver to be used.

<table>
<thead>
<tr>
<th>Value</th>
<th>Solver</th>
</tr>
</thead>
<tbody>
<tr>
<td>'tracemin_pcg'</td>
<td>Preconditioned conjugate gradient method</td>
</tr>
<tr>
<td>'tracemin_chol'</td>
<td>Cholesky factorization</td>
</tr>
<tr>
<td>'tracemin_lu'</td>
<td>LU factorization</td>
</tr>
</tbody>
</table>

Returns `algebraic_connectivity` – Algebraic connectivity.
Return type  float

Raises

- NetworkXNotImplemented – If G is directed.
- NetworkXError – If G has less than two nodes.

Notes

Edge weights are interpreted by their absolute values. For MultiGraph’s, weights of parallel edges are summed. Zero-weighted edges are ignored.

To use Cholesky factorization in the TraceMIN algorithm, the scikits.sparse package must be installed.

See also:

laplacian_matrix()

6.4.2 networkx.linalg.algebraicconnectivity.fiedler_vector

fiedler_vector (G, weight='weight', normalized=False, tol=1e-08, method='tracemin_pcg')

Return the Fiedler vector of a connected undirected graph.

The Fiedler vector of a connected undirected graph is the eigenvector corresponding to the second smallest eigenvalue of the Laplacian matrix of the graph.

Parameters

- G (NetworkX graph) – An undirected graph.
- weight (object, optional (default: None)) – The data key used to determine the weight of each edge. If None, then each edge has unit weight.
- normalized (bool, optional (default: False)) – Whether the normalized Laplacian matrix is used.
- tol (float, optional (default: 1e-8)) – Tolerance of relative residual in eigenvalue computation.
- method (string, optional (default: 'tracemin_pcg')) – Method of eigenvalue computation. It must be one of the tracemin options shown below (TraceMIN), ‘lanczos’ (Lanczos iteration) or ‘lobpcg’ (LOBPCG).

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<td>Cholesky factorization</td>
</tr>
<tr>
<td>'tracemin_lu'</td>
<td>LU factorization</td>
</tr>
</tbody>
</table>

Returns fiedler_vector – Fiedler vector.

Return type  NumPy array of floats.

Raises

- NetworkXNotImplemented – If G is directed.
- NetworkXError – If G has less than two nodes or is not connected.
Notes

Edge weights are interpreted by their absolute values. For MultiGraph’s, weights of parallel edges are summed. Zero-weighted edges are ignored.

To use Cholesky factorization in the TraceMIN algorithm, the scikit.sparse package must be installed.

See also:

laplacian_matrix()

6.4.3 networkx.linalg.algebraicconnectivity.spectral_ordering

spectral_ordering (G, weight='weight', normalized=False, tol=1e-08, method='tracemin_pcg')

Compute the spectral ordering of a graph.

The spectral ordering of a graph is an ordering of its nodes where nodes in the same weakly connected components appear contiguous and ordered by their corresponding elements in the Fiedler vector of the component.

Parameters

• G (NetworkX graph) – A graph.
• weight (object, optional (default: None)) – The data key used to determine the weight of each edge. If None, then each edge has unit weight.
• normalized (bool, optional (default: False)) – Whether the normalized Laplacian matrix is used.
• tol (float, optional (default: 1e-8)) – Tolerance of relative residual in eigenvalue computation.
• method (string, optional (default: ‘tracemin_pcg’)) – Method of eigenvalue computation. It must be one of the tracemin options shown below (TraceMIN), ‘lanczos’ (Lanczos iteration) or ‘lobpcg’ (LOBPCG).

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<td>Cholesky factorization</td>
</tr>
<tr>
<td>‘tracemin_lu’</td>
<td>LU factorization</td>
</tr>
</tbody>
</table>

Returns spectral_ordering – Spectral ordering of nodes.

Return type NumPy array of floats.

Raises NetworkXError – If G is empty.

Notes

Edge weights are interpreted by their absolute values. For MultiGraph’s, weights of parallel edges are summed. Zero-weighted edges are ignored.

To use Cholesky factorization in the TraceMIN algorithm, the scikit.sparse package must be installed.

See also:
6.5 Attribute Matrices

Functions for constructing matrix-like objects from graph attributes.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>attr_matrix(G[, edge_attr, node_attr, ...])</code></td>
<td>Returns a NumPy matrix using attributes from G.</td>
</tr>
<tr>
<td><code>attr_sparse_matrix(G[, edge_attr, ...])</code></td>
<td>Returns a SciPy sparse matrix using attributes from G.</td>
</tr>
</tbody>
</table>

6.5.1 networkx.linalg.attrmatrix.attr_matrix

The `attr_matrix` function returns a NumPy matrix using attributes from the graph G.

Parameters

- **G** *(graph)* – The NetworkX graph used to construct the NumPy matrix.
- **edge_attr** *(str, optional)* – Each element of the matrix represents a running total of the specified edge attribute for edges whose node attributes correspond to the rows/cols of the matrix. The attribute must be present for all edges in the graph. If no attribute is specified, then we just count the number of edges whose node attributes correspond to the matrix element.
- **node_attr** *(str, optional)* – Each row and column in the matrix represents a particular value of the node attribute. The attribute must be present for all nodes in the graph. Note, the values of this attribute should be reliably hashable. So, float values are not recommended. If no attribute is specified, then the rows and columns will be the nodes of the graph.
- **normalized** *(bool, optional)* – If True, then each row is normalized by the summation of its values.
- **rc_order** *(list, optional)* – A list of the node attribute values. This list specifies the ordering of rows and columns of the array. If no ordering is provided, then the ordering will be random (and also, a return value).

Other Parameters

- **dtype** *(NumPy data-type, optional)* – A valid NumPy dtype used to initialize the array. Keep in mind certain dtypes can yield unexpected results if the array is to be normalized. The parameter is passed to numpy.zeros(). If unspecified, the NumPy default is used.
- **order** *(‘C’, ‘F’), optional* – Whether to store multidimensional data in C- or Fortran-contiguous (row- or column-wise) order in memory. This parameter is passed to numpy.zeros(). If unspecified, the NumPy default is used.

Returns

- **M** *(NumPy matrix)* – The attribute matrix.
• **ordering** (list) – If `rc_order` was specified, then only the matrix is returned. However, if `rc_order` was None, then the ordering used to construct the matrix is returned as well.

### Examples

Construct an adjacency matrix:

```python
>>> try:
...   import numpy as np
... except TypeError:
...   pass

>>> G = nx.Graph()
>>> G.add_edge(0, 1, thickness=1, weight=3)
>>> G.add_edge(0, 2, thickness=2)
>>> G.add_edge(1, 2, thickness=3)

>>> nx.attr_matrix(G, rc_order=[0, 1, 2])
matrix([[0., 1., 1.],
        [1., 0., 1.],
        [1., 1., 0.]])
```

Alternatively, we can obtain the matrix describing edge thickness.

```python
>>> nx.attr_matrix(G, edge_attr='thickness', rc_order=[0, 1, 2])
matrix([[0., 1., 2.],
        [1., 0., 3.],
        [2., 3., 0.]])
```

We can also color the nodes and ask for the probability distribution over all edges \((u,v)\) describing:

\[
Pr(v \text{ has color } Y \mid u \text{ has color } X)
\]

```python
>>> G.nodes[0]['color'] = 'red'
>>> G.nodes[1]['color'] = 'red'
>>> G.nodes[2]['color'] = 'blue'
>>> rc = ['red', 'blue']

>>> nx.attr_matrix(G, node_attr='color', normalized=True, rc_order=rc)
matrix([[0.33333333, 0.66666667],
        [1. , 0. ]])
```

For example, the above tells us that for all edges \((u,v)\):

\[
Pr(v \text{ is red } \mid u \text{ is red}) = 1/3 \quad Pr(v \text{ is blue } \mid u \text{ is red}) = 2/3
\]

\[
Pr(v \text{ is red } \mid u \text{ is blue}) = 1 \quad Pr(v \text{ is blue } \mid u \text{ is blue}) = 0
\]

Finally, we can obtain the total weights listed by the node colors.

```python
>>> nx.attr_matrix(G, edge_attr='weight', node_attr='color', rc_order=rc)
matrix([[3., 2.],
        [2., 0.]])
```

Thus, the total weight over all edges \((u,v)\) with \(u\) and \(v\) having colors:

- (red, red) is 3 # the sole contribution is from edge (0,1) (red, blue) is 2 # contributions from edges (0,2) and (1,2) (blue, red) is 2 # same as (red, blue) since graph is undirected (blue, blue) is 0 # there are no edges with blue endpoints
6.5.2 networkx.linalg.attrmatrix.attr_sparse_matrix

`attr_sparse_matrix(G, edge_attr=None, node_attr=None, normalized=False, rc_order=None, dtype=None)`

Returns a SciPy sparse matrix using attributes from G.

If only G is passed in, then the adjacency matrix is constructed.

Let A be a discrete set of values for the node attribute `node_attr`. Then the elements of A represent the rows and columns of the constructed matrix. Now, iterate through every edge `e=(u,v)` in G and consider the value of the edge attribute `edge_attr`. If `ua` and `va` are the values of the node attribute `node_attr` for u and v, respectively, then the value of the edge attribute is added to the matrix element at `(ua, va)`.

**Parameters**

- `G` (**graph**) – The NetworkX graph used to construct the NumPy matrix.

- `edge_attr` (**str, optional**) – Each element of the matrix represents a running total of the specified edge attribute for edges whose node attributes correspond to the rows/cols of the matrix. The attribute must be present for all edges in the graph. If no attribute is specified, then we just count the number of edges whose node attributes correspond to the matrix element.

- `node_attr` (**str, optional**) – Each row and column in the matrix represents a particular value of the node attribute. The attribute must be present for all nodes in the graph. Note, the values of this attribute should be reliably hashable. So, float values are not recommended. If no attribute is specified, then the rows and columns will be the nodes of the graph.

- `normalized` (**bool, optional**) – If True, then each row is normalized by the summation of its values.

- `rc_order` (**list, optional**) – A list of the node attribute values. This list specifies the ordering of rows and columns of the array. If no ordering is provided, then the ordering will be random (and also, a return value).

**Other Parameters**

- `dtype` (**NumPy data-type, optional**) – A valid NumPy dtype used to initialize the array. Keep in mind certain dtypes can yield unexpected results if the array is to be normalized. The parameter is passed to numpy.zeros(). If unspecified, the NumPy default is used.

**Returns**

- `M` (**SciPy sparse matrix**) – The attribute matrix.

- `ordering` (**list**) – If `rc_order` was specified, then only the matrix is returned. However, if `rc_order` was None, then the ordering used to construct the matrix is returned as well.

**Examples**

Construct an adjacency matrix:

```python
>>> G = nx.Graph()
>>> G.add_edge(0,1,thickness=1,weight=3)
>>> G.add_edge(0,2,thickness=2)
>>> G.add_edge(1,2,thickness=3)
>>> M = nx.attr_sparse_matrix(G, rc_order=[0,1,2])
>>> M.todense()
matrix([[ 0., 1., 1.],
        [ 1., 0., 1.],
        [ 1., 1., 0.]])
```
Alternatively, we can obtain the matrix describing edge thickness.

```python
>>> M = nx.attr_sparse_matrix(G, edge_attr='thickness', rc_order=[0,1,2])
>>> M.todense()
matrix([[ 0., 1., 2.],
        [ 1., 0., 3.],
        [ 2., 3., 0.]])
```

We can also color the nodes and ask for the probability distribution over all edges (u,v) describing:

\[ \Pr(v \text{ has color } Y \mid u \text{ has color } X) \]

```python
>>> G.nodes[0]['color'] = 'red'
>>> G.nodes[1]['color'] = 'red'
>>> G.nodes[2]['color'] = 'blue'
>>> rc = ['red', 'blue']
>>> M = nx.attr_sparse_matrix(G, node_attr='color', normalized=True, rc_order=rc)
>>> M.todense()
matrix([[ 0.33333333, 0.66666667],
        [ 1. , 0. ]])
```

For example, the above tells us that for all edges (u,v):

\[ \Pr( v \text{ is red } \mid u \text{ is red}) = 1/3 \]
\[ \Pr( v \text{ is blue } \mid u \text{ is red}) = 2/3 \]
\[ \Pr( v \text{ is red } \mid u \text{ is blue}) = 1 \]
\[ \Pr( v \text{ is blue } \mid u \text{ is blue}) = 0 \]

Finally, we can obtain the total weights listed by the node colors.

```python
>>> M = nx.attr_sparse_matrix(G, edge_attr='weight', node_attr='color', rc_order=rc)
>>> M.todense()
matrix([[ 3., 2.],
        [ 2., 0.]])
```

Thus, the total weight over all edges (u,v) with u and v having colors:

- (red, red) is 3 # the sole contribution is from edge (0,1) (red, blue) is 2 # contributions from edges (0,2) and (1,2) (blue, red) is 2 # same as (red, blue) since graph is undirected (blue, blue) is 0 # there are no edges with blue endpoints
7.1 To NetworkX Graph

Functions to convert NetworkX graphs to and from other formats.

The preferred way of converting data to a NetworkX graph is through the graph constructor. The constructor calls the to_networkx_graph() function which attempts to guess the input type and convert it automatically.

Examples

Create a graph with a single edge from a dictionary of dictionaries

```python
>>> d={0: {1: 1}} # dict-of-dicts single edge (0,1)
>>> G=nx.Graph(d)
```

See also:

nx_agraph, nx_pydot

---

7.1.1 networkx.convert.to_networkx_graph

**to_networkx_graph** *(data[, create_using,...]) Make a NetworkX graph from a known data structure.*

```python
>>> d = {0: {1: {'weight':1}}} # dict-of-dicts single edge (0,1)
>>> G = nx.Graph(d)
```

The preferred way to call this is automatically from the class constructor

```python
>>> G = nx.Graph(d)
```

instead of the equivalent

```python
>>> G = nx.from_dict_of_dicts(d)
```

Parameters

- **data** *(object to be converted)* –

  Current known types are: any NetworkX graph dict-of-dicts dict-of-lists list of edges
  Pandas DataFrame (row per edge) numpy matrix numpy ndarray scipy sparse matrix pygraphviz agraph
• **create_using** *(NetworkX graph)* – Use specified graph for result. Otherwise a new graph is created.

• **multigraph_input** *(bool (default False))* – If True and data is a dict_of_dicts, try to create a multigraph assuming dict_of_dict_of_lists. If data and create_using are both multigraphs then create a multigraph from a multigraph.

## 7.2 Dictionaries

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<td>Return adjacency representation of graph as a dictionary of dictionaries.</td>
</tr>
<tr>
<td><code>from_dict_of_dicts</code></td>
<td>Return a graph from a dictionary of dictionaries.</td>
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</tbody>
</table>

### 7.2.1 networkx.convert.to_dict_of_dicts

**to_dict_of_dicts** *(G, nodelist=None, edge_data=None)*

Return adjacency representation of graph as a dictionary of dictionaries.

**Parameters**

- **G** *(graph)* – A NetworkX graph
- **nodelist** *(list)* – Use only nodes specified in nodelist
- **edge_data** *(list, optional)* – If provided, the value of the dictionary will be set to edge_data for all edges. This is useful to make an adjacency matrix type representation with 1 as the edge data. If edgedata is None, the edgedata in G is used to fill the values. If G is a multigraph, the edgedata is a dict for each pair (u,v).

### 7.2.2 networkx.convert.from_dict_of_dicts

**from_dict_of_dicts** *(d, create_using=None, multigraph_input=False)*

Return a graph from a dictionary of dictionaries.

**Parameters**

- **d** *(dictionary of dictionaries)* – A dictionary of dictionaries adjacency representation.
- **create_using** *(NetworkX graph)* – Use specified graph for result. Otherwise a new graph is created.
- **multigraph_input** *(bool (default False))* – When True, the values of the inner dict are assumed to be containers of edge data for multiple edges. Otherwise this routine assumes the edge data are singletons.

### Examples

```python
>>> dod = {0: {1: {'weight': 1}}}
# single edge (0,1)
>>> G = nx.from_dict_of_dicts(dod)
```

or

```python
>>> G = nx.Graph(dod)
# use Graph constructor
```
7.3 Lists

<table>
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<th>Function</th>
<th>Description</th>
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<td>Return adjacency representation of graph as a dictionary of lists.</td>
</tr>
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<td><code>from_dict_of_lists(d[, create_using])</code></td>
<td>Return a graph from a dictionary of lists.</td>
</tr>
<tr>
<td><code>to_edgelist(G[, nodelist])</code></td>
<td>Return a list of edges in the graph.</td>
</tr>
<tr>
<td><code>from_edgelist(edgelist[, create_using])</code></td>
<td>Return a graph from a list of edges.</td>
</tr>
</tbody>
</table>

7.3.1 networkx.convert.to_dict_of_lists

`to_dict_of_lists(G, nodelist=None)`

Return adjacency representation of graph as a dictionary of lists.

Parameters

- `G (graph)` – A NetworkX graph
- `nodelist (list)` – Use only nodes specified in nodelist

Notes

Completely ignores edge data for MultiGraph and MultiDiGraph.

7.3.2 networkx.convert.from_dict_of_lists

`from_dict_of_lists(d, create_using=None)`

Return a graph from a dictionary of lists.

Parameters

- `d (dictionary of lists)` – A dictionary of lists adjacency representation.
- `create_using (NetworkX graph)` – Use specified graph for result. Otherwise a new graph is created.

Examples

```python
>>> dol = {0: [1]}  # single edge (0,1)
>>> G = nx.from_dict_of_lists(dol)
```

or

```python
>>> G = nx.Graph(dol)  # use Graph constructor
```

7.3.3 networkx.convert.to_edgelist

`to_edgelist(G, nodelist=None)`

Return a list of edges in the graph.

Parameters

- `G (graph)` – A NetworkX graph
7.3.4 networkx.convert.from_edgelist

from_edgelist (edgelist, create_using=None)
Return a graph from a list of edges.

Parameters

• edgelist (list or iterator) – Edge tuples
• create_using (NetworkX graph) – Use specified graph for result. Otherwise a new graph is created.

Examples

```python
>>> edgelist = [(0, 1)]  # single edge (0,1)
>>> G = nx.from_edgelist(edgelist)
```
or
```
>>> G = nx.Graph(edgelist)  # use Graph constructor
```

7.4 Numpy

Functions to convert NetworkX graphs to and from numpy/scipy matrices.

The preferred way of converting data to a NetworkX graph is through the graph constructor. The constructor calls the to_networkx_graph() function which attempts to guess the input type and convert it automatically.

Examples

Create a 10 node random graph from a numpy matrix

```python
>>> import numpy as np
>>> a = np.reshape(np.random.random_integers(0, 1, size=100), (10, 10))
>>> D = nx.DiGraph(a)
```
or equivalently
```
>>> D = nx.to_networkx_graph(a, create_using=nx.DiGraph())
```

See also:

nx_agraph, nx_pydot

to_numpy_matrix(G[, nodelist, dtype, order, ...]) Return the graph adjacency matrix as a NumPy matrix.
to_recarray(G[, nodelist, dtype, order]) Return the graph adjacency matrix as a NumPy recarray.
from_matrix(A[, parallel_edges, ...]) Return a graph from numpy matrix.
7.4.1 networkx.convert_matrix.to_numpy_matrix

to_numpy_matrix(\(G\), nodelist=None, dtype=None, order=None, multigraph_weight=<built-in function sum>, weight='weight', nonedge=0.0)

Return the graph adjacency matrix as a NumPy matrix.

Parameters

- \(G\) (graph) – The NetworkX graph used to construct the NumPy matrix.
- nodelist (list, optional) – The rows and columns are ordered according to the nodes in nodelist. If nodelist is None, then the ordering is produced by G.nodes().
- dtype (NumPy data type, optional) – A valid single NumPy data type used to initialize the array. This must be a simple type such as int or numpy.float64 and not a compound data type (see to_numpy_recarray) If None, then the NumPy default is used.
- order (\{'C', 'F'\}, optional) – Whether to store multidimensional data in C- or Fortran-contiguous (row- or column-wise) order in memory. If None, then the NumPy default is used.
- multigraph_weight (\{'sum', 'min', 'max'\}, optional) – An operator that determines how weights in multigraphs are handled. The default is to sum the weights of the multiple edges.
- weight (string or None optional (default = 'weight')) – The edge attribute that holds the numerical value used for the edge weight. If an edge does not have that attribute, then the value 1 is used instead.
- nonedge (float (default = 0.0)) – The matrix values corresponding to nonedges are typically set to zero. However, this could be undesirable if there are matrix values corresponding to actual edges that also have the value zero. If so, one might prefer nonedges to have some other value, such as nan.

Returns M – Graph adjacency matrix

Return type NumPy matrix

See also:
to_numpy_recarray(), from_numpy_matrix()

Notes

The matrix entries are assigned to the weight edge attribute. When an edge does not have a weight attribute, the value of the entry is set to the number 1. For multiple (parallel) edges, the values of the entries are determined by the multigraph_weight parameter. The default is to sum the weight attributes for each of the parallel edges.

When nodelist does not contain every node in \(G\), the matrix is built from the subgraph of \(G\) that is induced by the nodes in nodelist.

The convention used for self-loop edges in graphs is to assign the diagonal matrix entry value to the weight attribute of the edge (or the number 1 if the edge has no weight attribute). If the alternate convention of doubling the edge weight is desired the resulting Numpy matrix can be modified as follows:

```python
>>> import numpy as np
>>> G = nx.Graph([(1, 1)])
>>> A = nx.to_numpy_matrix(G)
>>> A
matrix([[ 1.]])
```

(continues on next page)
Examples

```python
>>> G = nx.MultiDiGraph()
>>> G.add_edge(0, 1, weight=2)
0
>>> G.add_edge(1, 0)
0
>>> G.add_edge(2, 2, weight=3)
0
>>> G.add_edge(2, 2)
1
>>> nx.to_numpy_matrix(G, nodelist=[0, 1, 2])
matrix([[ 0., 2., 0.],
        [ 1., 0., 0.],
        [ 0., 0., 4.]])
```

7.4.2 networkx.convert_matrix.to_numpy_recarray

to_numpy_recarray (G, nodelist=None, dtype=None, order=None)

Return the graph adjacency matrix as a NumPy recarray.

Parameters

- **G** *(graph)* – The NetworkX graph used to construct the NumPy matrix.
- **nodelist** *(list, optional)* – The rows and columns are ordered according to the nodes in nodelist. If nodelist is None, then the ordering is produced by G.nodes().
- **dtype** *(NumPy data-type, optional)* – A valid NumPy named dtype used to initialize the NumPy recarray. The data type names are assumed to be keys in the graph edge attribute dictionary.
- **order** *(‘C’, ‘F’), optional)* – Whether to store multidimensional data in C- or Fortran-contiguous (row- or column-wise) order in memory. If None, then the NumPy default is used.

Returns

- **M** – The graph with specified edge data as a NumPy recarray

Return type

NumPy recarray

Notes

When nodelist does not contain every node in G, the matrix is built from the subgraph of G that is induced by the nodes in nodelist.
Examples

```python
>>> G = nx.Graph()
>>> G.add_edge(1, 2, weight=7.0, cost=5)
>>> A = nx.to_numpy_recarray(G, dtype=[('weight', float), ('cost', int)])
>>> print(A.weight)
[[ 0.  7.]
 [ 7.  0.]]
>>> print(A.cost)
[[ 0  5]
 [ 5  0]]
```

7.4.3 `networkx.convert_matrix.from_numpy_matrix`

`from_numpy_matrix(A, parallel_edges=False, create_using=None)`

Return a graph from numpy matrix.

The numpy matrix is interpreted as an adjacency matrix for the graph.

Parameters

- `A` (numpy matrix) – An adjacency matrix representation of a graph
- `parallel_edges` (Boolean) – If this is True, `create_using` is a multigraph, and `A` is an integer matrix, then entry \((i, j)\) in the matrix is interpreted as the number of parallel edges joining vertices \(i\) and \(j\) in the graph. If it is False, then the entries in the adjacency matrix are interpreted as the weight of a single edge joining the vertices.
- `create_using` (NetworkX graph) – Use specified graph for result. The default is `Graph()`

Notes

If `create_using` is an instance of `networkx.MultiGraph` or `networkx.MultiDiGraph`, `parallel_edges` is True, and the entries of `A` are of type `int`, then this function returns a multigraph (of the same type as `create_using`) with parallel edges.

If `create_using` is an undirected multigraph, then only the edges indicated by the upper triangle of the matrix `A` will be added to the graph.

If the numpy matrix has a single data type for each matrix entry it will be converted to an appropriate Python data type.

If the numpy matrix has a user-specified compound data type the names of the data fields will be used as attribute keys in the resulting NetworkX graph.

See also:

`to_numpy_matrix()`, `to_numpy_recarray()`

Examples

Simple integer weights on edges:

```python
>>> import numpy as np
>>> A = np.matrix([[1, 1], [2, 1]])
>>> G = nx.from_numpy_matrix(A)
```
If `create_using` is a multigraph and the matrix has only integer entries, the entries will be interpreted as weighted edges joining the vertices (without creating parallel edges):

```python
>>> A = np.matrix([[1, 1], [1, 2]])
>>> G = nx.from_numpy_matrix(A, create_using=nx.MultiGraph())
>>> G[1][1]
AtlasView({0: {'weight': 2}})
```

If `create_using` is a multigraph and the matrix has only integer entries but `parallel_edges` is True, then the entries will be interpreted as the number of parallel edges joining those two vertices:

```python
>>> A = np.matrix([[1, 1], [1, 2]])
>>> temp = nx.MultiGraph()
>>> G = nx.from_numpy_matrix(A, parallel_edges=True, create_using=temp)
>>> G[1][1]
AtlasView({0: {'weight': 1}, 1: {'weight': 1}})
```

User defined compound data type on edges:

```python
>>> dt = [('weight', float), ('cost', int)]
>>> A = np.matrix([[1.0, 2]], dtype=dt)
>>> G = nx.from_numpy_matrix(A)
>>> list(G.edges())
[(0, 0)]
>>> G[0][0]['cost']
2
>>> G[0][0]['weight']
1.0
```

### 7.5 Scipy

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<td><code>to_scipy_sparse_matrix(G[, nodelist, dtype, ...])</code></td>
<td>Return the graph adjacency matrix as a SciPy sparse matrix.</td>
</tr>
<tr>
<td><code>from_scipy_sparse_matrix(A[, ...])</code></td>
<td>Creates a new graph from an adjacency matrix given as a SciPy sparse matrix.</td>
</tr>
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</table>

#### 7.5.1 networkx.convert_matrix.to_scipy_sparse_matrix

`to_scipy_sparse_matrix(G, nodelist=None, dtype=None, weight='weight', format='csr')`

Return the graph adjacency matrix as a SciPy sparse matrix.

**Parameters**

- **G** (*graph*) – The NetworkX graph used to construct the NumPy matrix.
- **nodelist** (*list, optional*) – The rows and columns are ordered according to the nodes in nodelist. If nodelist is None, then the ordering is produced by G.nodes().
- **dtype** (*NumPy data-type, optional*) – A valid NumPy dtype used to initialize the array. If None, then the NumPy default is used.
- **weight** (*string or None optional (default='weight')*) – The edge attribute that holds the numerical value used for the edge weight. If None then all edge weights are 1.
- **format** (*str in {'bsr', 'csr', 'csc', 'coo', 'lil', 'dia', 'dok'}*) – The type of the matrix to be
Returns \( M \) – Graph adjacency matrix.

Notes

The matrix entries are populated using the edge attribute held in parameter weight. When an edge does not have that attribute, the value of the entry is 1.

For multiple edges the matrix values are the sums of the edge weights.

When \( \text{nodelist} \) does not contain every node in \( G \), the matrix is built from the subgraph of \( G \) that is induced by the nodes in \( \text{nodelist} \).

Uses \( \text{coo\_matrix} \) format. To convert to other formats specify the \( \text{format=} \) keyword.

The convention used for self-loop edges in graphs is to assign the diagonal matrix entry value to the weight attribute of the edge (or the number 1 if the edge has no weight attribute). If the alternate convention of doubling the edge weight is desired the resulting \( \text{Scipy\ sparse\ matrix} \) can be modified as follows:

```python
>>> import scipy as sp
g = nx.Graph([(1, 1)])
A = nx.to_scipy_sparse_matrix(G)
print(A.todense())
[[1]]
A.setdiag(A.diagonal() * 2)
print(A.todense())
[[2]]
```

Examples

```python
>>> G = nx.MultiDiGraph()
>>> G.add_edge(0, 1, weight=2)
0
>>> G.add_edge(1, 0)
0
>>> G.add_edge(2, 2, weight=3)
0
>>> G.add_edge(2, 2)
1
>>> S = nx.to_scipy_sparse_matrix(G, nodelist=[0, 1, 2])
>>> print(S.todense())
[[0 2 0]
 [1 0 0]
 [0 0 4]]
```

References

7.5.2 networkx.convert_matrix.from_scipy_sparse_matrix

from_scipy_sparse_matrix(A, parallel_edges=False, create_using=None, edge_attribute='weight')

Creates a new graph from an adjacency matrix given as a SciPy sparse matrix.

Parameters

- A (scipy sparse matrix) – An adjacency matrix representation of a graph
- parallel_edges (Boolean) – If this is True, create_using is a multigraph, and A is an integer matrix, then entry \((i, j)\) in the matrix is interpreted as the number of parallel edges joining vertices \(i\) and \(j\) in the graph. If it is False, then the entries in the adjacency matrix are interpreted as the weight of a single edge joining the vertices.
- create_using (NetworkX graph) – Use specified graph for result. The default is Graph()
- edge_attribute (string) – Name of edge attribute to store matrix numeric value. The data will have the same type as the matrix entry (int, float, (real,imag)).

Notes

If create_using is an instance of networkx.MultiGraph or networkx.MultiDiGraph, parallel_edges is True, and the entries of A are of type int, then this function returns a multigraph (of the same type as create_using) with parallel edges. In this case, edge_attribute will be ignored.

If create_using is an undirected multigraph, then only the edges indicated by the upper triangle of the matrix \(A\) will be added to the graph.

Examples

```python
>>> import scipy as sp
>>> A = sp.sparse.eye(2, 2, 1)
>>> G = nx.from_scipy_sparse_matrix(A)
```

If create_using is a multigraph and the matrix has only integer entries, the entries will be interpreted as weighted edges joining the vertices (without creating parallel edges):

```python
>>> A = sp.sparse.csr_matrix([[1, 1], [1, 2]])
>>> G = nx.from_scipy_sparse_matrix(A, create_using=nx.MultiGraph())
>>> G[1][1]
AtlasView({0: {'weight': 2}})
```

If create_using is a multigraph and the matrix has only integer entries but parallel_edges is True, then the entries will be interpreted as the number of parallel edges joining those two vertices:

```python
>>> A = sp.sparse.csr_matrix([[1, 1], [1, 2]])
>>> G = nx.from_scipy_sparse_matrix(A, parallel_edges=True,
... create_using=nx.MultiGraph())
>>> G[1][1]
AtlasView({0: {'weight': 1}, 1: {'weight': 1}})
```
## 7.6 Pandas

### to_pandas_adjacency

```
\text{to}_\text{pandas}_\text{adjacency}(G[, \text{nodelist, dtype, }\ldots]) \quad \text{Return the graph adjacency matrix as a Pandas DataFrame.}
```

### from_pandas_adjacency

```
\text{from}_\text{pandas}_\text{adjacency}(df[, \text{create\_using}]) \quad \text{Return a graph from Pandas DataFrame.}
```

### to_pandas_edgelist

```
\text{to}_\text{pandas}_\text{edgelist}(G[, \text{source, target, }\ldots]) \quad \text{Return the graph edge list as a Pandas DataFrame.}
```

### from_pandas_edgelist

```
\text{from}_\text{pandas}_\text{edgelist}(df[, \text{source, target, }\ldots]) \quad \text{Return a graph from Pandas DataFrame containing an edge list.}
```

### 7.6.1 networkx.convert_matrix.to_pandas_adjacency

```
\text{to}_\text{pandas}_\text{adjacency}(G, \text{nodelist=None, dtype=None, order=None, multigraph_weight=<built-in\ function\ sum>, weight='weight', nonedge=0.0)}
```

Return the graph adjacency matrix as a Pandas DataFrame.

#### Parameters

- **G** (*graph*) – The NetworkX graph used to construct the Pandas DataFrame.
- **nodelist** (*list*, *optional*) – The rows and columns are ordered according to the nodes in `nodelist`. If `nodelist` is None, then the ordering is produced by `G.nodes()`.
- **multigraph_weight** (*{sum, min, max}*, *optional*) – An operator that determines how weights in multigraphs are handled. The default is to sum the weights of the multiple edges.
- **weight** (*string or None*, *optional*) – The edge attribute that holds the numerical value used for the edge weight. If an edge does not have that attribute, then the value 1 is used instead.
- **nonedge** (*float*, *optional*) – The matrix values corresponding to nonedges are typically set to zero. However, this could be undesirable if there are matrix values corresponding to actual edges that also have the value zero. If so, one might prefer nonedges to have some other value, such as `nan`.

#### Returns

- **df** – Graph adjacency matrix

#### Return type

Pandas DataFrame

#### Notes

The DataFrame entries are assigned to the weight edge attribute. When an edge does not have a weight attribute, the value of the entry is set to the number 1. For multiple (parallel) edges, the values of the entries are determined by the ‘multigraph_weight’ parameter. The default is to sum the weight attributes for each of the parallel edges.

When `nodelist` does not contain every node in `G`, the matrix is built from the subgraph of `G` that is induced by the nodes in `nodelist`.

The convention used for self-loop edges in graphs is to assign the diagonal matrix entry value to the weight attribute of the edge (or the number 1 if the edge has no weight attribute). If the alternate convention of doubling the edge weight is desired the resulting Pandas DataFrame can be modified as follows:

```python
>>> import pandas as pd
>>> import numpy as np
>>> G = nx.Graph([(1, 1)])
>>> df = nx.to_pandas_adjacency(G, dtype=int)
>>> df
1
lMatrixXd
```

(continues on next page)
>>> df.values[np.diag_indices_from(df)] *= 2
>>> df
  1
1  2

Examples

>>> G = nx.MultiDiGraph()
>>> G.add_edge(0, 1, weight=2)
0
>>> G.add_edge(1, 0)
0
>>> G.add_edge(2, 2, weight=3)
0
>>> G.add_edge(2, 2)
1
>>> nx.to_pandas_adjacency(G, nodelist=[0, 1, 2], dtype=int)
  0  1  2
0  0  2  0
1  1  0  0
2  0  0  4

7.6.2 networkx.convert_matrix.from_pandas_adjacency

from_pandas_adjacency (df, create_using=None)

Return a graph from Pandas DataFrame.

The Pandas DataFrame is interpreted as an adjacency matrix for the graph.

Parameters

• df (Pandas DataFrame) – An adjacency matrix representation of a graph
• create_using (NetworkX graph) – Use specified graph for result. The default is Graph()

Notes

If the numpy matrix has a single data type for each matrix entry it will be converted to an appropriate Python data type.

If the numpy matrix has a user-specified compound data type the names of the data fields will be used as attribute keys in the resulting NetworkX graph.

See also:

to_pandas_adjacency()

Examples

Simple integer weights on edges:
>>> import pandas as pd
>>> df = pd.DataFrame([[1, 1], [2, 1]])
>>> df
   0  1
0  1  1
1  2  1
>>> G = nx.from_pandas_adjacency(df)
>>> G.name = 'Graph from pandas adjacency matrix'
>>> print(nx.info(G))
Name: Graph from pandas adjacency matrix
Type: Graph
Number of nodes: 2
Number of edges: 3
Average degree: 3.0000

7.6.3 networkx.convert_matrix.to_pandas_edgelist
to_pandas_edgelist (G, source='source', target='target', nodelist=None, dtype=None, order=None)
Return the graph edge list as a Pandas DataFrame.

Parameters

- G (graph) – The NetworkX graph used to construct the Pandas DataFrame.
- source (str or int, optional) – A valid column name (string or integer) for the source nodes (for the directed case).
- target (str or int, optional) – A valid column name (string or integer) for the target nodes (for the directed case).
- nodelist (list, optional) – Use only nodes specified in nodelist

Returns df – Graph edge list

Return type Pandas DataFrame

Examples

>>> G = nx.Graph([('A', 'B', {'cost': 1, 'weight': 7}), ...
                  ('C', 'E', {'cost': 9, 'weight': 10})])
>>> df = nx.to_pandas_edgelist(G, nodelist=['A', 'C'])
>>> df
   cost  source target  weight
0     1        A        B       7
1     9        C        E      10

7.6.4 networkx.convert_matrix.from_pandas_edgelist
from_pandas_edgelist (df, source='source', target='target', edge_attr=None, create_using=None)
Return a graph from Pandas DataFrame containing an edge list.

The Pandas DataFrame should contain at least two columns of node names and zero or more columns of node attributes. Each row will be processed as one edge instance.

7.6. Pandas  547
Note: This function iterates over DataFrame.values, which is not guaranteed to retain the data type across columns in the row. This is only a problem if your row is entirely numeric and a mix of ints and floats. In that case, all values will be returned as floats. See the DataFrame.iterrows documentation for an example.

Parameters

- df (Pandas DataFrame) – An edge list representation of a graph
- source (str or int) – A valid column name (string or integer) for the source nodes (for the directed case).
- target (str or int) – A valid column name (string or integer) for the target nodes (for the directed case).
- edge_attr (str or int, iterable, True) – A valid column name (str or integer) or list of column names that will be used to retrieve items from the row and add them to the graph as edge attributes. If True, all of the remaining columns will be added.
- create_using (NetworkX graph) – Use specified graph for result. The default is Graph()

See also:

to_pandas_edgelist()

Examples

Simple integer weights on edges:

```python
>>> import pandas as pd
>>> import numpy as np
>>> r = np.random.RandomState(seed=5)
>>> ints = r.random_integers(1, 10, size=(3,2))
>>> a = ['A', 'B', 'C']
>>> b = ['D', 'A', 'E']
>>> df = pd.DataFrame(ints, columns=['weight', 'cost'])
>>> df[0] = a
>>> df['b'] = b
>>> df
   weight  cost   b
0       4      7   A
1       7      1   B
2      10      9   C
>>> G = nx.from_pandas_edgelist(df, 0, 'b', ['weight', 'cost'])
>>> G['E']['C']['weight']
10
>>> G['E']['C']['cost']
9
>>> edges = pd.DataFrame({'source': [0, 1, 2],
...                       'target': [2, 2, 3],
...                       'weight': [3, 4, 5],
...                       'color': ['red', 'blue', 'blue']})
>>> G = nx.from_pandas_edgelist(edges, edge_attr=True)
>>> G[0][2]['color']
'red'
```
8.1 Relabeling

convert_node_labels_to_integers(G[, ...]) Return a copy of the graph G with the nodes relabeled using consecutive integers.

relabel_nodes(G, mapping[, copy]) Relabel the nodes of the graph G.

8.1.1 networkx.relabel.convert_node_labels_to_integers

convert_node_labels_to_integers (G, first_label=0, ordering='default', label_attribute=None)
Return a copy of the graph G with the nodes relabeled using consecutive integers.

Parameters

• G (graph) – A NetworkX graph

• first_label (int, optional (default=0)) – An integer specifying the starting offset in numbering nodes. The new integer labels are numbered first_label, ... , n-1+first_label.

• ordering (string) – “default” : inherit node ordering from G.nodes() “sorted” : inherit node ordering from sorted(G.nodes()) “increasing degree” : nodes are sorted by increasing degree “decreasing degree” : nodes are sorted by decreasing degree

• label_attribute (string, optional (default=None)) – Name of node attribute to store old label. If None no attribute is created.

Notes

Node and edge attribute data are copied to the new (relabeled) graph.

There is no guarantee that the relabeling of nodes to integers will give the same two integers for two (even identical graphs). Use the ordering argument to try to preserve the order.

See also:
relabel_nodes()

8.1.2 networkx.relabel.relabel_nodes

relabel_nodes (G, mapping, copy=True)
Relabel the nodes of the graph G.

Parameters
• **G (graph)** – A NetworkX graph
• **mapping (dictionary)** – A dictionary with the old labels as keys and new labels as values. A partial mapping is allowed.
• **copy (bool (optional, default=True))** – If True return a copy, or if False relabel the nodes in place.

## Examples

To create a new graph with nodes relabeled according to a given dictionary:

```python
>>> G = nx.path_graph(3)
>>> sorted(G)
[0, 1, 2]
>>> mapping = {0: 'a', 1: 'b', 2: 'c'}
>>> H = nx.relabel_nodes(G, mapping)
>>> sorted(H)
['a', 'b', 'c']
```

Nodes can be relabeled with any hashable object, including numbers and strings:

```python
>>> import string

>>> G = nx.path_graph(26)  # nodes are integers 0 through 25
>>> sorted(G)[:3]
[0, 1, 2]
>>> mapping = dict(zip(G, string.ascii_lowercase))  # nodes are characters a through z
>>> sorted(G)[:3]
['a', 'b', 'c']
>>> mapping = dict(zip(G, range(1, 27)))  # nodes are integers 1 through 26
>>> sorted(G)[:3]
[1, 2, 3]
```

To perform a partial in-place relabeling, provide a dictionary mapping only a subset of the nodes, and set the `copy` keyword argument to False:

```python
>>> G = nx.path_graph(3)  # nodes 0-1-2
>>> mapping = {0: 'a', 1: 'b'}  # 0->'a' and 1->'b'
>>> G = nx.relabel_nodes(G, mapping, copy=False)
>>> sorted(G, key=str)
[2, 'a', 'b']
```

A mapping can also be given as a function:

```python
>>> G = nx.path_graph(3)
>>> H = nx.relabel_nodes(G, lambda x: x ** 2)
>>> list(H)
[0, 1, 4]
```

## Notes

Only the nodes specified in the mapping will be relabeled.
The keyword setting copy=False modifies the graph in place. Relabel_nodes avoids naming collisions by building a directed graph from mapping which specifies the order of relabelings. Naming collisions, such as a->b, b->c, are ordered such that “b” gets renamed to “c” before “a” gets renamed “b”. In cases of circular mappings (e.g. a->b, b->a), modifying the graph is not possible in-place and an exception is raised. In that case, use copy=True.

See also:

convert_node_labels_to_integers()
CHAPTER
NINE

READING AND WRITING GRAPHS

9.1 Adjacency List

9.1.1 Adjacency List

Read and write NetworkX graphs as adjacency lists.

Adjacency list format is useful for graphs without data associated with nodes or edges and for nodes that can be meaningfully represented as strings.

Format

The adjacency list format consists of lines with node labels. The first label in a line is the source node. Further labels in the line are considered target nodes and are added to the graph along with an edge between the source node and target node.

The graph with edges a-b, a-c, d-e can be represented as the following adjacency list (anything following the # in a line is a comment):

```
a b c # source target target
d e
```

---

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>read_adjlist(path[, comments, delimiter, ...])</td>
<td>Read graph in adjacency list format from path.</td>
</tr>
<tr>
<td>write_adjlist(G, path[, comments, ...])</td>
<td>Write graph G in single-line adjacency-list format to path.</td>
</tr>
<tr>
<td>parse_adjlist(lines[, comments, delimiter, ...])</td>
<td>Parse lines of a graph adjacency list representation.</td>
</tr>
<tr>
<td>generate_adjlist(G[, delimiter])</td>
<td>Generate a single line of the graph G in adjacency list format.</td>
</tr>
</tbody>
</table>

9.1.2 networkx.readwrite.adjlist.read_adjlist

read_adjlist (path, comments='#', delimiter=None, create_using=None, nodetype=None, encoding='utf-8')

Read graph in adjacency list format from path.

Parameters

- **path (string or file)** – Filename or file handle to read. Filenames ending in .gz or .bz2 will be uncompressed.
- **create_using (NetworkX graph container)** – Use given NetworkX graph for holding nodes or edges.
• **nodetype** (*Python type, optional*) – Convert nodes to this type.
• **comments** (*string, optional*) – Marker for comment lines
• **delimiter** (*string, optional*) – Separator for node labels. The default is whitespace.

**Returns**  

G – The graph corresponding to the lines in adjacency list format.

**Return type**  

NetworkX graph

### Examples

```python
>>> G=nx.path_graph(4)
>>> nx.write_adjlist(G, "test.adjlist")
>>> G=nx.read_adjlist("test.adjlist")
```

The path can be a filehandle or a string with the name of the file. If a filehandle is provided, it has to be opened in ‘rb’ mode.

```python
>>> fh=open("test.adjlist", 'rb')
>>> G=nx.read_adjlist(fh)
```

Filenames ending in .gz or .bz2 will be compressed.

```python
>>> nx.write_adjlist(G,"test.adjlist.gz")
>>> G=nx.read_adjlist("test.adjlist.gz")
```

The optional nodetype is a function to convert node strings to nodetype. For example

```python
>>> G=nx.read_adjlist("test.adjlist", nodetype=int)
```

will attempt to convert all nodes to integer type.

Since nodes must be hashable, the function nodetype must return hashable types (e.g. int, float, str, frozenset - or tuples of those, etc.)

The optional create_using parameter is a NetworkX graph container. The default is Graph(), an undirected graph. To read the data as a directed graph use

```python
>>> G=nx.read_adjlist("test.adjlist", create_using=nx.DiGraph())
```

### Notes

This format does not store graph or node data.

**See also:**

write_adjlist()
• **G** *(NetworkX graph)*
• **path** *(string or file)* – Filename or file handle for data output. Filenames ending in .gz or .bz2 will be compressed.
• **comments** *(string, optional)* – Marker for comment lines
• **delimiter** *(string, optional)* – Separator for node labels
• **encoding** *(string, optional)* – Text encoding.

**Examples**

```python
>>> G = nx.path_graph(4)
>>> nx.write_adjlist(G, "test.adjlist")
```

The path can be a filehandle or a string with the name of the file. If a filehandle is provided, it has to be opened in ‘wb’ mode.

```python
>>> fh = open("test.adjlist", 'wb')
>>> nx.write_adjlist(G, fh)
```

**Notes**

This format does not store graph, node, or edge data.

**See also:**

`read_adjlist()`, `generate_adjlist()`

### 9.1.4 networkx.readwrite.adjlist.parse_adjlist

**parse_adjlist** *(lines, comments='#', delimiter=None, create_using=None, nodetype=None)*

Parse lines of a graph adjacency list representation.

**Parameters**

- **lines** *(list or iterator of strings)* – Input data in adjlist format
- **create_using** *(NetworkX graph container)* – Use given NetworkX graph for holding nodes or edges.
- **nodetype** *(Python type, optional)* – Convert nodes to this type.
- **comments** *(string, optional)* – Marker for comment lines
- **delimiter** *(string, optional)* – Separator for node labels. The default is whitespace.

**Returns**

- **G** – The graph corresponding to the lines in adjacency list format.

**Return type**

NetworkX graph

**Examples**
>>> lines = ['1 2 5',
...        '2 3 4',
...        '3 5',
...        '4',
...        '5']
>>> G = nx.parse_adjlist(lines, nodetype=int)
>>> nodes = [1, 2, 3, 4, 5]
>>> all(node in G for node in nodes)
True
>>> edges = [(1, 2), (1, 5), (2, 3), (2, 4), (3, 5)]
>>> all((u, v) in G.edges() or (v, u) in G.edges() for (u, v) in edges)
True

See also:
read_adjlist()

9.1.5 networkx.readwrite.adjlist.generate_adjlist

generate_adjlist (G, delimiter=' ')
Generate a single line of the graph G in adjacency list format.

Parameters
- • G (NetworkX graph)
- • delimiter (string, optional) – Separator for node labels

Returns lines – Lines of data in adjlist format.

Return type string

Examples

```python
>>> G = nx.lollipop_graph(4, 3)
>>> for line in nx.generate_adjlist(G):
...     print(line)
0 1 2 3
1 2 3
2 3
3 4
4 5
5 6
6
```

See also:
write_adjlist(), read_adjlist()

9.2 Multiline Adjacency List

9.2.1 Multi-line Adjacency List
Read and write NetworkX graphs as multi-line adjacency lists.
The multi-line adjacency list format is useful for graphs with nodes that can be meaningfully represented as strings. With this format simple edge data can be stored but node or graph data is not.

**Format**

The first label in a line is the source node label followed by the node degree d. The next d lines are target node labels and optional edge data. That pattern repeats for all nodes in the graph.

The graph with edges a-b, a-c, d-e can be represented as the following adjacency list (anything following the # in a line is a comment):

```plaintext
# example.multiline-adjlist
a 2
b
c
d 1
e
```

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>read_multiline_adjlist</code></td>
<td>Read graph in multi-line adjacency list format from path.</td>
</tr>
<tr>
<td><code>write_multiline_adjlist</code></td>
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<tr>
<td><code>parse_multiline_adjlist</code></td>
<td>Parse lines of a multi-line adjacency list representation of a graph.</td>
</tr>
<tr>
<td><code>generate_multiline_adjlist</code></td>
<td>Generate a single line of the graph G in multi-line adjacency list format.</td>
</tr>
</tbody>
</table>

### 9.2.2 networkx.readwrite.multiline_adjlist.read_multiline_adjlist

`read_multiline_adjlist` *(path[, comments,...])*  
Read graph in multi-line adjacency list format from path.

- **Parameters**
  - *path* *(string or file)* – Filename or file handle to read. Filenames ending in .gz or .bz2 will be uncompressed.
  - *create_using* *(NetworkX graph container)* – Use given NetworkX graph for holding nodes or edges.
  - *nodetype* *(Python type, optional)* – Convert nodes to this type.
  - *edgetype* *(Python type, optional)* – Convert edge data to this type.
  - *comments* *(string, optional)* – Marker for comment lines
  - *delimiter* *(string, optional)* – Separator for node labels. The default is whitespace.

- **Returns** G
- **Return type** NetworkX graph

### Examples

```python
>>> G=nx.path_graph(4)
>>> nx.write_multiline_adjlist(G,"test.adjlist")
>>> G=nx.read_multiline_adjlist("test.adjlist")
```
The path can be a file or a string with the name of the file. If a file is provided, it has to be opened in `rb` mode.

```python
>>> fh=open("test.adjlist", 'rb')
>>> G=nx.read_multiline_adjlist(fh)
```

Filenames ending in `.gz` or `.bz2` will be compressed.

```python
>>> nx.write_multiline_adjlist(G,"test.adjlist.gz")
>>> G=nx.read_multiline_adjlist("test.adjlist.gz")
```

The optional nodetype is a function to convert node strings to nodetype. For example

```python
>>> G=nx.read_multiline_adjlist("test.adjlist", nodetype=int)
```

will attempt to convert all nodes to integer type.

The optional edgetype is a function to convert edge data strings to edgetype.

```python
>>> G=nx.read_multiline_adjlist("test.adjlist")
```

The optional create_using parameter is a NetworkX graph container. The default is Graph(), an undirected graph. To read the data as a directed graph use

```python
>>> G=nx.read_multiline_adjlist("test.adjlist", create_using=nx.DiGraph())
```

**Notes**

This format does not store graph, node, or edge data.

**See also:**

`write_multiline_adjlist()`

### 9.2.3 networkx.readwrite.multiline_adjlist.write_multiline_adjlist

`write_multiline_adjlist(G, path, delimiter=' ', comments='#', encoding='utf-8')`

Write the graph `G` in multiline adjacency list format to `path`

**Parameters**

- `G` *(NetworkX graph)*
- `comments` *(string, optional)* – Marker for comment lines
- `delimiter` *(string, optional)* – Separator for node labels
- `encoding` *(string, optional)* – Text encoding.

**Examples**

```python
>>> G=nx.path_graph(4)
>>> nx.write_multiline_adjlist(G,"test.adjlist")
```

The path can be a file handle or a string with the name of the file. If a file handle is provided, it has to be opened in `wb` mode.
```python
>>> fh=open("test.adjlist","wb")
>>> nx.write_multiline_adjlist(G,fh)

Filenames ending in .gz or .bz2 will be compressed.

```n
```python
>>> nx.write_multiline_adjlist(G,"test.adjlist.gz")

See also:

callread_multiline_adjlist()
```

### 9.2.4 networkx.readwrite.multiline_adjlist.parse_multiline_adjlist

`parse_multiline_adjlist(lines, comments='#', delimiter=None, create_using=None, nodetype=None, edgetype=None)`

Parse lines of a multiline adjacency list representation of a graph.

**Parameters**

- `lines` *(list or iterator of strings)* – Input data in multiline adjlist format
- `create_using` *(NetworkX graph container)* – Use given NetworkX graph for holding nodes or edges.
- `nodetype` *(Python type, optional)* – Convert nodes to this type.
- `comments` *(string, optional)* – Marker for comment lines
- `delimiter` *(string, optional)* – Separator for node labels. The default is whitespace.

**Returns** `G` – The graph corresponding to the lines in multiline adjacency list format.

**Return type** NetworkX graph

**Examples**

```python
>>> lines = ['1 2',
...          '2 { weight:3, name: 'Frodo'}',
...          '3 /',
...          '2 1',
...          '5 { weight:6, name: 'Saruman'}']
>>> G = nx.parse_multiline_adjlist(iter(lines), nodetype=int)
>>> list(G)
[1, 2, 3, 5]
```

### 9.2.5 networkx.readwrite.multiline_adjlist.generate_multiline_adjlist

`generate_multiline_adjlist(G, delimiter=' ')

Generate a single line of the graph G in multiline adjacency list format.

**Parameters**

- `G` *(NetworkX graph)*
- `delimiter` *(string, optional)* – Separator for node labels

**Returns** `lines` – Lines of data in multiline adjlist format.
Return type  string

Examples

```python
>>> G = nx.lollipop_graph(4, 3)
>>> for line in nx.generate_multiline_adjlist(G):
...    print(line)
0 3
1 {}
2 {}
3 {}
1 2
2 {}
3 {}
2 1
3 {}
3 1
4 {}
4 1
5 {}
5 1
6 {}
6 0
```

See also:

`write_multiline_adjlist()`, `read_multiline_adjlist()`

## 9.3 Edge List

### 9.3.1 Edge Lists

Read and write NetworkX graphs as edge lists.

The multi-line adjacency list format is useful for graphs with nodes that can be meaningfully represented as strings. With the edgelist format simple edge data can be stored but node or graph data is not. There is no way of representing isolated nodes unless the node has a self-loop edge.

**Format**

You can read or write three formats of edge lists with these functions.

Node pairs with no data:

```
1 2
```

Python dictionary as data:

```
1 2 {'weight': 7, 'color': 'green'}
```

Arbitrary data:

```
1 2 7 green
```
### read_edgelist

**read_edgelist** *(path[, comments, delimiter, ...])*

Read a graph from a list of edges.

- **Parameters**
  - *path* (file or string) – File or filename to read. If a file is provided, it must be opened in ‘rb’ mode. Filenames ending in .gz or .bz2 will be uncompressed.
  - *comments* (string, optional) – The character used to indicate the start of a comment.
  - *delimiter* (string, optional) – The string used to separate values. The default is whitespace.
  - *create_using* (Graph container, optional) – Use specified container to build graph. The default is networkx.Graph, an undirected graph.
  - *nodetype* (int, float, str, Python type, optional) – Convert node data from strings to specified type.
  - *data* (bool or list of (label, type) tuples) – Tuples specifying dictionary key names and types for edge data.
  - *edgetype* (int, float, str, Python type, optional) – Convert edge data from strings to specified type and use as ‘weight’.
  - *encoding* (string, optional) – Specify which encoding to use when reading file.

- **Returns**
  - *G* – A networkx Graph or other type specified with create_using.

- **Return type**
  - graph

#### Examples

```python
>>> import networkx as nx
>>> G=nx.path_graph(4)
>>> nx.write_edgelist(G, 'test.edgelist')

>>> fh=open('test.edgelist', 'rb')
>>> G=nx.read_edgelist(fh)
>>> fh.close()

>>> G=nx.read_edgelist('test.edgelist', nodetype=int)

>>> G=nx.read_edgelist('test.edgelist', create_using=nx.DiGraph())
```

Edgelist with data in a list:
>>> textline = '1 2 3'
>>> fh = open('test.edgelist','w')
>>> d = fh.write(textline)
>>> fh.close()
>>> G = nx.read_edgelist('test.edgelist', nodetype=int, data=(("weight",float),))
>>> list(G)
[1, 2]
>>> list(G.edges(data=True))
[(1, 2, {'weight': 3.0})]

See parse_edgelist() for more examples of formatting.

See also:

parse_edgelist()

Notes

Since nodes must be hashable, the function nodetype must return hashable types (e.g. int, float, str, frozenset -
or tuples of those, etc.)

9.3.3 networkx.readwrite.edgelist.write_edgelist

write_edgelist (G, path, comments='#', delimiter=' ', data=True, encoding='utf-8')
Write graph as a list of edges.

Parameters

- G (graph) – A NetworkX graph
- path (file or string) – File or filename to write. If a file is provided, it must be opened in
  'wb' mode. Filenames ending in .gz or .bz2 will be compressed.
- comments (string, optional) – The character used to indicate the start of a comment
- delimiter (string, optional) – The string used to separate values. The default is whitespace.
- data (bool or list, optional) – If False write no edge data. If True write a string representation
  of the edge data dictionary.. If a list (or other iterable) is provided, write the keys specified
  in the list.
- encoding (string, optional) – Specify which encoding to use when writing file.

Examples

>>> G=nx.path_graph(4)
>>> nx.write_edgelist(G, "test.edgelist")
>>> G=nx.path_graph(4)
>>> fh=open("test.edgelist",'wb')
>>> nx.write_edgelist(G, fh)
>>> nx.write_edgelist(G, "test.edgelist.gz")
>>> nx.write_edgelist(G, "test.edgelist.gz", data=False)
NetworkX Reference, Release 2.2rc1.dev20180319181321

>>> G=nx.Graph()
>>> G.add_edge(1,2,weight=7,color='red')
>>> nx.write_edgelist(G,'test.edgelist',data=False)
>>> nx.write_edgelist(G,'test.edgelist',data=['color'])
>>> nx.write_edgelist(G,'test.edgelist',data=['color','weight'])

See also:

write_edgelist(), write_weighted_edgelist()

9.3.4 networkx.readwrite.edgelist.read_weighted_edgelist

read_weighted_edgelist (path, comments='#', delimiter=None, create_using=None, nodetype=None, encoding='utf-8')

Read a graph as list of edges with numeric weights.

Parameters

- **path** (file or string) – File or filename to read. If a file is provided, it must be opened in ‘rb’ mode. Filenames ending in .gz or .bz2 will be uncompressed.
- **comments** (string, optional) – The character used to indicate the start of a comment.
- **delimiter** (string, optional) – The string used to separate values. The default is whitespace.
- **create_using** (Graph container, optional) – Use specified container to build graph. The default is networkx.Graph, an undirected graph.
- **nodetype** (int, float, str, Python type, optional) – Convert node data from strings to specified type
- **encoding** (string, optional) – Specify which encoding to use when reading file.

Returns G – A networkx Graph or other type specified with create_using

Return type graph

Notes

Since nodes must be hashable, the function nodetype must return hashable types (e.g. int, float, str, frozenset - or tuples of those, etc.)

Example edgelist file format.

With numeric edge data:

```python
# read with
# >>> G=nx.read_weighted_edgelist(fh)
# source target data
a b 1
a c 3.14159
d e 42
```

9.3.5 networkx.readwrite.edgelist.write_weighted_edgelist

write_weighted_edgelist (G, path, comments='#', delimiter=' ', encoding='utf-8')

Write graph G as a list of edges with numeric weights.

9.3. Edge List 563
Parameters

- **G (graph)** – A NetworkX graph
- **path (file or string)** – File or filename to write. If a file is provided, it must be opened in ‘wb’ mode. Filenames ending in .gz or .bz2 will be compressed.
- **comments (string, optional)** – The character used to indicate the start of a comment
- **delimiter (string, optional)** – The string used to separate values. The default is whitespace.
- **encoding (string, optional)** – Specify which encoding to use when writing file.

Examples

```python
>>> G=nx.Graph()
>>> G.add_edge(1,2,weight=7)
>>> nx.write_weighted_edgelist(G, 'test.weighted.edgelist')
```

See also:

read_edgelist(), write_edgelist(), write_weighted_edgelist()

9.3.6 networkx.readwrite.edgelist.generate_edgelist

generate_edgelist (G, delimiter=' ', data=True)

Generate a single line of the graph G in edge list format.

Parameters

- **G (NetworkX graph)**
- **delimiter (string, optional)** – Separator for node labels
- **data (bool or list of keys)** – If False generate no edge data. If True use a dictionary representation of edge data. If a list of keys use a list of data values corresponding to the keys.

Returns lines – Lines of data in adjlist format.

Return type string

Examples

```python
>>> G = nx.lollipop_graph(4, 3)
>>> G[1][2][‘weight’] = 3
>>> G[3][4][‘capacity’] = 12
>>> for line in nx.generate_edgelist(G, data=True):
...     print(line)
0 1
0 2
0 3
1 2
1 3
2 3
3 4
4 5
5 6
```
```python
>>> for line in nx.generate_edgelist(G):
...     print(line)
0 1 {}
0 2 {}
0 3 {}
1 2 {'weight': 3}
1 3 {}
2 3 {}
3 4 {'capacity': 12}
4 5 {}
5 6 {}
```

```python
>>> for line in nx.generate_edgelist(G,data=['weight']):
...     print(line)
0 1
0 2
0 3
1 2 3
1 3
2 3
3 4
4 5
5 6
```

See also:
write_adjlist(), read_adjlist()

9.3.7 networkx.readwrite.edgelist.parse_edgelist

`parse_edgelist(lines, comments='#', delimiter=None, create_using=None, nodetype=None, data=True)`

Parse lines of an edge list representation of a graph.

**Parameters**

- `lines` *(list or iterator of strings)* – Input data in edgelist format
- `comments` *(string, optional)* – Marker for comment lines
- `delimiter` *(string, optional)* – Separator for node labels
- `create_using` *(NetworkX graph container, optional)* – Use given NetworkX graph for holding nodes or edges.
- `nodetype` *(Python type, optional)* – Convert nodes to this type.
- `data` *(bool or list of (label, type) tuples)* – If False generate no edge data or if True use a dictionary representation of edge data or a list tuples specifying dictionary key names and types for edge data.

**Returns**

- `G` – The graph corresponding to lines

**Return type**

NetworkX Graph

**Examples**

Edgelist with no data:
>>> lines = ["1 2",
... "2 3",
... "3 4"]
>>> G = nx.parse_edgelist(lines, nodetype = int)
>>> list(G)
[1, 2, 3, 4]
>>> list(G.edges())
[(1, 2), (2, 3), (3, 4)]

Edgelist with data in Python dictionary representation:

>>> lines = ["1 2 {'weight':3}"
... "2 3 {'weight':27}
... "3 4 {'weight':3.0}"
>>> G = nx.parse_edgelist(lines, nodetype = int)
>>> list(G)
[1, 2, 3, 4]
>>> list(G.edges(data=True))
[(1, 2, {'weight': 3}), (2, 3, {'weight': 27}), (3, 4, {'weight': 3.0})]

Edgelist with data in a list:

>>> lines = ["1 2 3",
... "2 3 27",
... "3 4 3.0"]
>>> G = nx.parse_edgelist(lines, nodetype = int, data=((\'weight\',float),))
>>> list(G)
[1, 2, 3, 4]
>>> list(G.edges(data=True))
[(1, 2, {'weight': 3.0}), (2, 3, {'weight': 27.0}), (3, 4, {'weight': 3.0})]

See also:
read_weighted_edgelist()

9.4 GEXF

Read and write graphs in GEXF format.

GEXF (Graph Exchange XML Format) is a language for describing complex network structures, their associated data and dynamics.

This implementation does not support mixed graphs (directed and undirected edges together).

9.4.1 Format

GEXF is an XML format. See https://gephi.org/gexf/format/schema.html for the specification and https://gephi.org/gexf/format/basic.html for examples.

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<tr>
<th>Function</th>
<th>Description</th>
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<td>Read graph in GEXF format from path.</td>
</tr>
<tr>
<td><code>write_gexf(G, path[, encoding, prettyprint, ...])</code></td>
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<td><code>relabel_gexf_graph(G)</code></td>
<td>Relabel graph using “label” node keyword for node label.</td>
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</table>
9.4.2 networkx.readwrite.gexf.read_gexf

read_gexf (path, node_type=None, relabel=False, version='1.2draft')

Read graph in GEXF format from path.

“GEXF (Graph Exchange XML Format) is a language for describing complex networks structures, their associated data and dynamics”\(^1\).

Parameters

- **path** (*file or string*) – File or file name to write. File names ending in .gz or .bz2 will be compressed.
- **node_type** (*Python type* (default: None)) – Convert node ids to this type if not None.
- **relabel** (*bool* (default: False)) – If True relabel the nodes to use the GEXF node “label” attribute instead of the node “id” attribute as the NetworkX node label.
- **version** (*string* (default: 1.2draft)) – Version of GEFX File Format (see https://gephi.org/gexf/format/schema.html). Supported values: “1.1draft”, “1.2draft”

Returns **graph** – If no parallel edges are found a Graph or DiGraph is returned. Otherwise a MultiGraph or MultiDiGraph is returned.

Return type **NetworkX graph**

Notes

This implementation does not support mixed graphs (directed and undirected edges together).

References

9.4.3 networkx.readwrite.gexf.write_gexf

write_gexf (G, path, encoding='utf-8', prettyprint=True, version='1.2draft')

Write G in GEXF format to path.

“GEXF (Graph Exchange XML Format) is a language for describing complex networks structures, their associated data and dynamics”\(^1\).

Node attributes are checked according to the version of the GEXF schemas used for parameters which are not user defined, e.g. visualization ‘viz’\(^2\). See example for usage.

Parameters

- **G** (*graph*) – A NetworkX graph
- **path** (*file or string*) – File or file name to write. File names ending in .gz or .bz2 will be compressed.
- **encoding** (*string* (optional, default: ‘utf-8’)) – Encoding for text data.
- **prettyprint** (*bool* (optional, default: True)) – If True use line breaks and indenting in output XML.

---

\(^1\) GEXF File Format, https://gephi.org/gexf/format/
\(^2\) GEXF viz schema 1.1, https://gephi.org/gexf/1.1draft/viz
Examples

```python
>>> G = nx.path_graph(4)
>>> nx.write_gexf(G, "test.gexf")
```

# visualization data >>> G.nodes[0]['viz'] = {'size': 54} >>> G.nodes[0]['viz']['position'] = {'x': 0, 'y': 1}
>>> G.nodes[0]['viz']['color'] = {'r': 0, 'g': 0, 'b': 256}

Notes

This implementation does not support mixed graphs (directed and undirected edges together).

The node id attribute is set to be the string of the node label. If you want to specify an id use set it as node data, e.g. node[‘a’][‘id’]=1 to set the id of node ‘a’ to 1.

References

9.4.4 networkx.readwrite.gexf.relabel_gexf_graph

`relabel_gexf_graph(G)`

Relabel graph using “label” node keyword for node label.

Parameters:
- `G` (graph) – A NetworkX graph read from GEXF data

Returns:
- `H` – A NetworkX graph with relabeled nodes

Return type:
- `graph`

Raises:
- `NetworkXError` – If node labels are missing or not unique while relabel=True.

Notes

This function relabels the nodes in a NetworkX graph with the “label” attribute. It also handles relabeling the specific GEXF node attributes “parents”, and “pid”.

9.5 GML

Read graphs in GML format.

“GML, the Graph Modelling Language, is our proposal for a portable file format for graphs. GML’s key features are portability, simple syntax, extensibility and flexibility. A GML file consists of a hierarchical key-value lists. Graphs can be annotated with arbitrary data structures. The idea for a common file format was born at the GD’95; this proposal is the outcome of many discussions. GML is the standard file format in the Graphlet graph editor system. It has been overtaken and adapted by several other systems for drawing graphs.”

GML files are stored using a 7-bit ASCII encoding with any extended ASCII characters (iso8859-1) appearing as HTML character entities. You will need to give some thought into how the exported data should interact with different languages and even different Python versions. Re-importing from gml is also a concern.

Without specifying a `stringizer/destringizer`, the code is capable of handling `int/float/str/dict/list` data as required by the GML specification. For other data types, you need to explicitly supply a `stringizer/destringizer`.
For better interoperability of data generated by Python 2 and Python 3, we’ve provided `literal_stringizer` and `literal_destringizer`.

For additional documentation on the GML file format, please see the GML website.

Several example graphs in GML format may be found on Mark Newman’s Network data page.

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<th>Description</th>
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<td>Read graph in GML format from path.</td>
</tr>
<tr>
<td><code>write_gml(G, path[, stringizer])</code></td>
<td>Write a graph G in GML format to the file or file handle path.</td>
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<td><code>parse_gml(lines[, label, destringizer])</code></td>
<td>Parse GML graph from a string or iterable.</td>
</tr>
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<td><code>generate_gml(G[, stringizer])</code></td>
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<td><code>literal_destringizer(rep)</code></td>
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</tr>
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<td><code>literal_stringizer(value)</code></td>
<td>Convert a value to a Python literal in GML representation.</td>
</tr>
</tbody>
</table>

### 9.5.1 networkx.readwrite.gml.read_gml

**read_gml** *(path, label='label', destringizer=None)*

Read graph in GML format from path.

**Parameters**

- **path** *(filename or filehandle)* – The filename or filehandle to read from.
- **label** *(string, optional)* – If not None, the parsed nodes will be renamed according to node attributes indicated by label. Default value: ‘label’.
- **destringizer** *(callable, optional)* – A destringizer that recovers values stored as strings in GML. If it cannot convert a string to a value, a `ValueError` is raised. Default value: None.

**Returns**  
G – The parsed graph.

**Return type** NetworkX graph

**Raises** NetworkXError – If the input cannot be parsed.

**See also:**

`write_gml()`, `parse_gml()`, `literal_destringizer()`

**Notes**

GML files are stored using a 7-bit ASCII encoding with any extended ASCII characters (iso8859-1) appearing as HTML character entities. Without specifying a stringizer/destringizer, the code is capable of handling int/float/str/dict/list data as required by the GML specification. For other data types, you need to explicitly supply a stringizer/destringizer.

For additional documentation on the GML file format, please see the GML website.

See the module docstring `networkx.readwrite.gml` for additional details.
Examples

```python
>>> G = nx.path_graph(4)
>>> nx.write_gml(G, 'test.gml')
>>> H = nx.read_gml('test.gml')
```

9.5.2 networkx.readwrite.gml.write_gml

`write_gml(G, path, stringizer=None)`

Write a graph $G$ in GML format to the file or file handle `path`.

**Parameters**

- `G` (*NetworkX* graph) – The graph to be converted to GML.
- `path` (*filename or filehandle*) – The filename or filehandle to write. Files whose names end with `.gz` or `.bz2` will be compressed.
- `stringizer` (*callable, optional*) – A *stringizer* which converts non-int/non-float/non-dict values into strings. If it cannot convert a value into a string, it should raise a `ValueError` to indicate that. Default value: None.

**Raises** *NetworkXError* – If `stringizer` cannot convert a value into a string, or the value to convert is not a string while `stringizer` is None.

See also: `read_gml()`, `generate_gml()`, `literal_stringizer()`

**Notes**

Graph attributes named ‘directed’, ‘multigraph’, ‘node’ or ‘edge’, node attributes named ‘id’ or ‘label’, edge attributes named ‘source’ or ‘target’ (or ‘key’ if $G$ is a multigraph) are ignored because these attribute names are used to encode the graph structure.

GML files are stored using a 7-bit ASCII encoding with any extended ASCII characters (iso8859-1) appearing as HTML character entities. Without specifying a stringizer/destringizer, the code is capable of handling `int/float/str/dict/list` data as required by the GML specification. For other data types, you need to explicitly supply a stringizer/destringizer.

For additional documentation on the GML file format, please see the [GML website](https://www.kernel.org/pub/software/scientific/python/networkx/documentation/gml.html).

See the module docstring `networkx.readwrite.gml` for additional details.

Examples

```python
>>> G = nx.path_graph(4)
>>> nx.write_gml(G, "test.gml")
```

Filenames ending in `.gz` or `.bz2` will be compressed.

```python
>>> nx.write_gml(G, "test.gml.gz")
```
9.5.3 networkx.readwrite.gml.parse_gml

parse_gml(lines, label='label', destringizer=None)  
Parse GML graph from a string or iterable.

Parameters

- lines (string or iterable of strings) – Data in GML format.
- label (string, optional) – If not None, the parsed nodes will be renamed according to node attributes indicated by label. Default value: ‘label’.
- destringizer (callable, optional) – A destringizer that recovers values stored as strings in GML. If it cannot convert a string to a value, a ValueError is raised. Default value: None.

Returns G – The parsed graph.

Return type NetworkX graph

Raises NetworkXError – If the input cannot be parsed.

See also: write_gml(), read_gml(), literal_destringizer()

Notes

This stores nested GML attributes as dictionaries in the NetworkX graph, node, and edge attribute structures.

GML files are stored using a 7-bit ASCII encoding with any extended ASCII characters (iso8859-1) appearing as HTML character entities. Without specifying a stringizer/destringizer, the code is capable of handling int/float/str/dict/list data as required by the GML specification. For other data types, you need to explicitly supply a stringizer/destringizer.

For additional documentation on the GML file format, please see the GML website.

See the module docstring networkx.readwrite.gml for additional details.

9.5.4 networkx.readwrite.gml.generate_gml

generate_gml(G, stringizer=None)  
Generate a single entry of the graph G in GML format.

Parameters

- G (NetworkX graph) – The graph to be converted to GML.
- stringizer (callable, optional) – A stringizer which converts non-int/non-float/non-dict values into strings. If it cannot convert a value into a string, it should raise a ValueError to indicate that. Default value: None.

Returns lines – Lines of GML data. Newlines are not appended.

Return type generator of strings

Raises NetworkXError – If stringizer cannot convert a value into a string, or the value to convert is not a string while stringizer is None.

See also: literal_stringizer()
Notes

Graph attributes named ‘directed’, ‘multigraph’, ‘node’ or ‘edge’, node attributes named ‘id’ or ‘label’, edge attributes named ‘source’ or ‘target’ (or ‘key’ if \( G \) is a multigraph) are ignored because these attribute names are used to encode the graph structure.

GML files are stored using a 7-bit ASCII encoding with any extended ASCII characters (iso8859-1) appearing as HTML character entities. Without specifying a stringizer/destringizer, the code is capable of handling int/float/str/dict/list data as required by the GML specification. For other data types, you need to explicitly supply a stringizer/destringizer.

For additional documentation on the GML file format, please see the GML website.

See the module docstring `networkx.readwrite.gml` for additional details.

Examples

```python
>>> G = nx.Graph()
>>> G.add_node("1")
>>> print("\n".join(nx.generate_gml(G)))
graph [node [id 0 label "1"]]

>>> G = nx.OrderedMultiGraph([("a", "b"), ("a", "b")])
>>> print("\n".join(nx.generate_gml(G)))
graph [multigraph 1 node [id 0 label "a"] node [id 1 label "b"] edge [source 0 target 1 key 0] edge [source 0 target 1 key 1]]
```

9.5.5 networkx.readwrite.gml.literal_destringizer

`literal_destringizer (rep)`

Convert a Python literal to the value it represents.

Parameters `rep` *(string)* – A Python literal.
Returns value – The value of the Python literal.

Return type object

Raises ValueError – If rep is not a Python literal.

9.5.6 networkx.readwrite.gml.literal_stringizer

literal_stringizer(value)

Convert a value to a Python literal in GML representation.

Parameters value (object) – The value to be converted to GML representation.

Returns rep – A double-quoted Python literal representing value. Unprintable characters are replaced by XML character references.

Return type string

Raises ValueError – If value cannot be converted to GML.

Notes

literal_stringizer is largely the same as repr in terms of functionality but attempts prefix unicode and bytes literals with u and b to provide better interoperability of data generated by Python 2 and Python 3.

The original value can be recovered using the networkx.readwrite.gml.literal_destringizer() function.

9.6 Pickle

9.6.1 Pickled Graphs

Read and write NetworkX graphs as Python pickles.

“The pickle module implements a fundamental, but powerful algorithm for serializing and de-serializing a Python object structure. “Pickling” is the process whereby a Python object hierarchy is converted into a byte stream, and “unpickling” is the inverse operation, whereby a byte stream is converted back into an object hierarchy.”

Note that NetworkX graphs can contain any hashable Python object as node (not just integers and strings). For arbitrary data types it may be difficult to represent the data as text. In that case using Python pickles to store the graph data can be used.

Format

See https://docs.python.org/2/library/pickle.html

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<thead>
<tr>
<th>Function</th>
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</tr>
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<tbody>
<tr>
<td>read_gpickle(path)</td>
<td>Read graph object in Python pickle format.</td>
</tr>
<tr>
<td>write_gpickle(G, path[, protocol])</td>
<td>Write graph in Python pickle format.</td>
</tr>
</tbody>
</table>
9.6.2 networkx.readwrite.gpickle.read_gpickle

read_gpickle(path)
Read graph object in Python pickle format.

Pickles are a serialized byte stream of a Python object. This format will preserve Python objects used as nodes or edges.

Parameters path (file or string) – File or filename to write. Filenames ending in .gz or .bz2 will be uncompressed.

Returns G – A NetworkX graph

Return type graph

Examples

```python
>>> G = nx.path_graph(4)
>>> nx.write_gpickle(G, "test.gpickle")
>>> G = nx.read_gpickle("test.gpickle")
```

References

9.6.3 networkx.readwrite.gpickle.write_gpickle

write_gpickle(G, path, protocol=2)
Write graph in Python pickle format.

Pickles are a serialized byte stream of a Python object. This format will preserve Python objects used as nodes or edges.

Parameters

• G (graph) – A NetworkX graph
• path (file or string) – File or filename to write. Filenames ending in .gz or .bz2 will be compressed.
• protocol (integer) – Pickling protocol to use. Default value: pickle.HIGHEST_PROTOCOL.

Examples

```python
>>> G = nx.path_graph(4)
>>> nx.write_gpickle(G, "test.gpickle")
```
References

9.7 GraphML

9.7.1 GraphML

Read and write graphs in GraphML format.

This implementation does not support mixed graphs (directed and undirected edges together), hyperedges, nested graphs, or ports.

“GraphML is a comprehensive and easy-to-use file format for graphs. It consists of a language core to describe the structural properties of a graph and a flexible extension mechanism to add application-specific data. Its main features include support of

• directed, undirected, and mixed graphs,
• hypergraphs,
• hierarchical graphs,
• graphical representations,
• references to external data,
• application-specific attribute data, and
• light-weight parsers.

Unlike many other file formats for graphs, GraphML does not use a custom syntax. Instead, it is based on XML and hence ideally suited as a common denominator for all kinds of services generating, archiving, or processing graphs.”

http://graphml.graphdrawing.org/

Format

GraphML is an XML format. See http://graphml.graphdrawing.org/specification.html for the specification and http://graphml.graphdrawing.org/primer/graphml-primer.html for examples.

```
read_graphml(path[, node_type, edge_key_type])  Read graph in GraphML format from path.
write_graphml(G, path[, encoding, ...])        Write G in GraphML XML format to path
```

9.7.2 networkx.readwrite.graphml.read_graphml

```
read_graphml (path, node_type=<type 'str'>, edge_key_type=<type 'int'>)
```

Read graph in GraphML format from path.

Parameters

• `path (file or string)` – File or filename to write. Filenames ending in .gz or .bz2 will be compressed.

• `node_type (Python type (default: str))` – Convert node ids to this type

• `edge_key_type (Python type (default: int))` – Convert graphml edge ids to this type as key of multi-edges
Returns graph – If no parallel edges are found a Graph or DiGraph is returned. Otherwise a MultiGraph or MultiDiGraph is returned.

Return type  NetworkX graph

Notes

Default node and edge attributes are not propagated to each node and edge. They can be obtained from G.graph and applied to node and edge attributes if desired using something like this:

```python
>>> default_color = G.graph['node_default']['color']
>>> for node, data in G.nodes(data=True):
...     if 'color' not in data:
...         data['color'] = default_color

>>> default_color = G.graph['edge_default']['color']
>>> for u, v, data in G.edges(data=True):
...     if 'color' not in data:
...         data['color'] = default_color
```

This implementation does not support mixed graphs (directed and undirected edges together), hypergraphs, nested graphs, or ports.

For multigraphs the GraphML edge “id” will be used as the edge key. If not specified then they “key” attribute will be used. If there is no “key” attribute a default NetworkX multigraph edge key will be provided.

Files with the yEd “yfiles” extension will can be read but the graphics information is discarded.

yEd compressed files (“file.graphmlz” extension) can be read by renaming the file to “file.graphml.gz”.

9.7.3  networkx.readwrite.graphml.write_graphml

write_graphml(G, path, encoding='utf-8', prettyprint=True, infer_numeric_types=False)

Write G in GraphML XML format to path

This function uses the LXML framework and should be faster than the version using the xml library.

Parameters

- G (graph) – A networkx graph
- path (file or string) – File or filename to write. Filenames ending in .gz or .bz2 will be compressed.
- encoding (string (optional)) – Encoding for text data.
- prettyprint (bool (optional)) – If True use line breaks and indenting in output XML.
- infer_numeric_types (boolean) – Determine if numeric types should be generalized. For example, if edges have both int and float ‘weight’ attributes, we infer in GraphML that both are floats.

Examples

```python
>>> G = nx.path_graph(4)
>>> nx.write_graphml_lxml(G, "fourpath.graphml")
```
Notes

This implementation does not support mixed graphs (directed and unidirected edges together) hyperedges, nested graphs, or ports.

9.8 JSON

9.8.1 JSON data

Generate and parse JSON serializable data for NetworkX graphs.

These formats are suitable for use with the d3.js examples https://d3js.org/

The three formats that you can generate with NetworkX are:

- node-link like in the d3.js example https://bl.ocks.org/mbostock/4062045
- tree like in the d3.js example https://bl.ocks.org/mbostock/4063550
- adjacency like in the d3.js example https://bost.ocks.org/mike/miserables/

```
node_link_data(G[, attrs])
```

Return data in node-link format that is suitable for JSON serialization and use in Javascript documents.

```
node_link_graph(data[, directed, ...])
```

Return graph from node-link data format.

```
adjacency_data(G[, attrs])
```

Return data in adjacency format that is suitable for JSON serialization and use in Javascript documents.

```
adjacency_graph(data[, directed, ...])
```

Return graph from adjacency data format.

```
tree_data(G, root[, attrs])
```

Return data in tree format that is suitable for JSON serialization and use in Javascript documents.

```
tree_graph(data[, attrs])
```

Return graph from tree data format.

```
jit_data(G[, indent])
```

Return data in JIT JSON format.

```
jit_graph(data[, create_using])
```

Read a graph from JIT JSON.

9.8.2 networkx.readwrite.json_graph.node_link_data

```
node_link_data(G, attrs=None)
```

Return data in node-link format that is suitable for JSON serialization and use in Javascript documents.

Parameters

- **G** (NetworkX graph)
- **attrs** (dict) – A dictionary that contains five keys ‘source’, ‘target’, ‘name’, ‘key’ and ‘link’. The corresponding values provide the attribute names for storing NetworkX-internal graph data. The values should be unique. Default value:

```
dict(source='source', target='target', name='id', key='key', link='links')
```

If some user-defined graph data use these attribute names as data keys, they may be silently dropped.

Returns **data** – A dictionary with node-link formatted data.

Return type **dict**
Raises NetworkXError – If values in attrs are not unique.

Examples

```python
>>> from networkx.readwrite import json_graph
>>> G = nx.Graph([('A', 'B')])
>>> data1 = json_graph.node_link_data(G)
>>> H = nx.gn_graph(2)
>>> data2 = json_graph.node_link_data(H, {'link': 'edges', 'source': 'from', 'target': 'to'})
```

To serialize with json

```python
>>> import json
>>> s1 = json.dumps(data1)
>>> s2 = json.dumps(data2, default={'link': 'edges', 'source': 'from', 'target': 'to'})
```

Notes

Graph, node, and link attributes are stored in this format. Note that attribute keys will be converted to strings in order to comply with JSON.

Attribute ‘key’ is only used for multigraphs.

See also:

- node_link_graph()
- adjacency_data()
- tree_data()

9.8.3 networkx.readwrite.json_graph.node_link_graph

node_link_graph(data, directed=False, multigraph=True, attrs=None)

Return graph from node-link data format.

Parameters

- data (dict) – node-link formatted graph data
- directed (bool) – If True, and direction not specified in data, return a directed graph.
- multigraph (bool) – If True, and multigraph not specified in data, return a multigraph.
- attrs (dict) – A dictionary that contains five keys ‘source’, ‘target’, ‘name’, ‘key’ and ‘link’. The corresponding values provide the attribute names for storing NetworkX-internal graph data. Default value:
  ```python
dict(source='source', target='target', name='id', key='key', link='links')
  ```

Returns G – A NetworkX graph object

Return type NetworkX graph

Examples
>>> from networkx.readwrite import json_graph
>>> G = nx.Graph([('A', 'B')])
>>> data = json_graph.node_link_data(G)
>>> H = json_graph.node_link_graph(data)

Notes

Attribute ‘key’ is only used for multigraphs.

See also:
node_link_data(), adjacency_data(), tree_data()

9.8.4 networkx.readwrite.json_graph.adjacency_data

adjacency_data(G, attrs={'id': 'id', 'key': 'key'})
Return data in adjacency format that is suitable for JSON serialization and use in Javascript documents.

Parameters

- G (NetworkX graph)
- attrs (dict) – A dictionary that contains two keys ‘id’ and ‘key’. The corresponding values provide the attribute names for storing NetworkX-internal graph data. The values should be unique. Default value: dict(id='id', key='key').

If some user-defined graph data use these attribute names as data keys, they may be silently dropped.

Returns data – A dictionary with adjacency formatted data.

Return type dict

Raises NetworkXError – If values in attrs are not unique.

Examples

```python
>>> from networkx.readwrite import json_graph
>>> G = nx.Graph([(1, 2)])
>>> data = json_graph.adjacency_data(G)
To serialize with json
```  ```python
>>> import json
>>> s = json.dumps(data)
```

Notes

Graph, node, and link attributes will be written when using this format but attribute keys must be strings if you want to serialize the resulting data with JSON.

The default value of attrs will be changed in a future release of NetworkX.

See also:
adjacency_graph(), node_link_data(), tree_data()  

9.8.5 networkx.readwrite.json_graph.adjacency_graph

adjacency_graph(data, directed=False, multigraph=True, attrs={'id': 'id', 'key': 'key'})

Return graph from adjacency data format.

Parameters  
- data (dict) – Adjacency list formatted graph data

Returns
- G (NetworkX graph) – A NetworkX graph object
- directed (bool) – If True, and direction not specified in data, return a directed graph.
- multigraph (bool) – If True, and multigraph not specified in data, return a multigraph.
- attrs (dict) – A dictionary that contains two keys ‘id’ and ‘key’. The corresponding values provide the attribute names for storing NetworkX-internal graph data. The values should be unique. Default value: dict(id='id', key='key').

Examples

```python
>>> from networkx.readwrite import json_graph
>>> G = nx.Graph([(1,2)])
>>> data = json_graph.adjacency_data(G)
>>> H = json_graph.adjacency_graph(data)
```

Notes

The default value of attrs will be changed in a future release of NetworkX.

See also:
adjacency_graph(), node_link_data(), tree_data()

9.8.6 networkx.readwrite.json_graph.tree_data

tree_data(G, root, attrs={'children': 'children', 'id': 'id'})

Return data in tree format that is suitable for JSON serialization and use in Javascript documents.

Parameters
- G (NetworkX graph) – G must be an oriented tree
- root (node) – The root of the tree
- attrs (dict) – A dictionary that contains two keys ‘id’ and ‘children’. The corresponding values provide the attribute names for storing NetworkX-internal graph data. The values should be unique. Default value: dict(id='id', children='children').

If some user-defined graph data use these attribute names as data keys, they may be silently dropped.

Returns data – A dictionary with node-link formatted data.

Return type dict
**Raises** NetworkXError – If values in attrs are not unique.

**Examples**

```python
>>> from networkx.readwrite import json_graph
>>> G = nx.DiGraph([(1, 2)])
>>> data = json_graph.tree_data(G, root=1)
```

To serialize with json

```python
>>> import json
>>> s = json.dumps(data)
```

**Notes**

Node attributes are stored in this format but keys for attributes must be strings if you want to serialize with JSON.

Graph and edge attributes are not stored.

The default value of attrs will be changed in a future release of NetworkX.

**See also:**

`tree_graph()`, `node_link_data()`, `node_link_data()`

### 9.8.7 networkx.readwrite.json_graph.tree_graph

**tree_graph** *(data, attrs={'children': 'children', 'id': 'id'})*

Return graph from tree data format.

**Parameters**

- **data** *(dict)* – Tree formatted graph data

**Returns**

- **G** *(NetworkX DiGraph)*

**Notes**

The default value of attrs will be changed in a future release of NetworkX.

**See also:**

9.8. JSON
9.8.8 networkx.readwrite.json_graph.jit_data

jit_data(G, indent=None)
Return data in JIT JSON format.

Parameters

- G (NetworkX Graph)
- indent (optional, default=None) – If indent is a non-negative integer, then JSON array elements and object members will be pretty-printed with that indent level. An indent level of 0, or negative, will only insert newlines. None (the default) selects the most compact representation.

Returns data

Return type JIT JSON string

9.8.9 networkx.readwrite.json_graph.jit_graph

jit_graph(data, create_using=None)
Read a graph from JIT JSON.

Parameters

- data (JSON Graph Object)
- create_using (Networkx Graph, optional (default: Graph())) – Return graph of this type.
  The provided instance will be cleared.

Returns G

Return type NetworkX Graph built from create_using if provided.

9.9 LEDA

Read graphs in LEDA format.

LEDA is a C++ class library for efficient data types and algorithms.

9.9.1 Format

See http://www.algorithmic-solutions.info/leda_guide/graphs/leda_native_graph_fileformat.html

read_leda(path[, encoding]) Read graph in LEDA format from path.
parse_leda(lines) Read graph in LEDA format from string or iterable.

9.9.2 networkx.readwrite.leda.read_leda

read_leda(path, encoding=’UTF-8’)
Read graph in LEDA format from path.
Parameters **path** *(file or string)* – File or filename to read. Filenames ending in `.gz` or `.bz2` will be uncompressed.

Returns **G**

Return type NetworkX graph

**Examples**

G=nx.read_leda('file.leda')

**References**

9.9.3 networkx.readwrite.leda.parse_leda

**parse_leda** *(lines)*

Read graph in LEDA format from string or iterable.

Parameters **lines** *(string or iterable)* – Data in LEDA format.

Returns **G**

Return type NetworkX graph

**Examples**

G=nx.parse_leda(string)

**References**

9.10 YAML

9.10.1 YAML

Read and write NetworkX graphs in YAML format.

“YAML is a data serialization format designed for human readability and interaction with scripting languages.” See http://www.yamll.org for documentation.

**Format**

http://pyyaml.org/wiki/PyYAML

| read_yaml(path) | Read graph in YAML format from path. |
| write_yaml(G_to_be_yaml,...) | Write graph G in YAML format to path. |
9.10.2 networkx.readwrite.nx_yaml.read_yaml

read_yaml(path)

Read graph in YAML format from path.

YAML is a data serialization format designed for human readability and interaction with scripting languages\(^1\).

**Parameters** path (file or string) – File or filename to read. Filenames ending in .gz or .bz2 will be uncompressed.

**Returns** G

**Return type** NetworkX graph

**Examples**

```python
>>> G=nx.path_graph(4)
>>> nx.write_yaml(G,'test.yaml')
>>> G=nx.read_yaml('test.yaml')
```

**References**

9.10.3 networkx.readwrite.nx_yaml.write_yaml

write_yaml(G_to_be_yaml, path_for_yaml_output, **kwds)

Write graph G in YAML format to path.

YAML is a data serialization format designed for human readability and interaction with scripting languages\(^1\).

**Parameters**

- G (graph) – A NetworkX graph
- path (file or string) – File or filename to write. Filenames ending in .gz or .bz2 will be compressed.

**Notes**

To use encoding on the output file include e.g. encoding='utf-8' in the keyword arguments.

**Examples**

```python
>>> G=nx.path_graph(4)
>>> nx.write_yaml(G,'test.yaml')
```

\(^1\) http://www.yaml.org
\(^1\) http://www.yaml.org
References

9.11 SparseGraph6

Functions for reading and writing graphs in the graph6 or sparse6 file formats.

According to the author of these formats,

graph6 and sparse6 are formats for storing undirected graphs in a compact manner, using only printable ASCII characters. Files in these formats have text type and contain one line per graph.

graph6 is suitable for small graphs, or large dense graphs. sparse6 is more space-efficient for large sparse graphs.

—graph6 and sparse6 homepage

9.11.1 Graph6

Functions for reading and writing graphs in the graph6 format.

The graph6 file format is suitable for small graphs or large dense graphs. For large sparse graphs, use the sparse6 format.

For more information, see the graph6 homepage.

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<tr>
<th>from_graph6_bytes(string)</th>
<th>Read a simple undirected graph in graph6 format from string.</th>
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<tr>
<td>read_graph6(path)</td>
<td>Read simple undirected graphs in graph6 format from path.</td>
</tr>
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<td>to_graph6_bytes(G[, nodes, header])</td>
<td>Convert a simple undirected graph to bytes in graph6 format.</td>
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<tr>
<td>write_graph6(G, path[, nodes, header])</td>
<td>Write a simple undirected graph to a path in graph6 format.</td>
</tr>
</tbody>
</table>

networkx.readwrite.graph6.from_graph6_bytes

from_graph6_bytes(string)

Read a simple undirected graph in graph6 format from string.

Parameters

string (string) – Data in graph6 format, without a trailing newline.

Returns

G

Return type

Graph

Raises

• NetworkXError – If the string is unable to be parsed in graph6 format
• ValueError – If any character c in the input string does not satisfy 63 <= ord(c) < 127.

Examples

>>> G = nx.from_graph6_bytes(b'A_')
>>> sorted(G.edges())
[(0, 1)]

9.11. SparseGraph6 585
See also:

read_graph6(), write_graph6()

References

networkx.readwrite.graph6.read_graph6

read_graph6 (path)
Read simple undirected graphs in graph6 format from path.

Parameters path (file or string) – File or filename to write.

Returns G – If the file contains multiple lines then a list of graphs is returned

Return type Graph or list of Graphs

Raises NetworkXError – If the string is unable to be parsed in graph6 format

Examples

You can read a graph6 file by giving the path to the file:

```
>>> import tempfile
>>> with tempfile.NamedTemporaryFile() as f:
...    _ = f.write(b'>>graph6<<A_
...    _ = f.seek(0)
...    G = nx.read_graph6(f.name)
>>> list(G.edges())
[(0, 1)]
```

You can also read a graph6 file by giving an open file-like object:

```
>>> import tempfile
>>> with tempfile.NamedTemporaryFile() as f:
...    _ = f.write(b'>>graph6<<A_
...    _ = f.seek(0)
...    G = nx.read_graph6(f)
>>> list(G.edges())
[(0, 1)]
```

See also:

from_graph6_bytes(), write_graph6()

References

networkx.readwrite.graph6.to_graph6_bytes

to_graph6_bytes (G, nodes=None, header=True)
Convert a simple undirected graph to bytes in graph6 format.

Parameters

• G (Graph (undirected))
• **nodes** (*list or iterable*) – Nodes are labeled 0...n-1 in the order provided. If None the ordering given by G.nodes() is used.

• **header** (*bool*) – If True add ‘>>graph6<<’ bytes to head of data.

**Raises**

• **NetworkXNotImplemented** – If the graph is directed or is a multigraph.

• **ValueError** – If the graph has at least \(2^{36}\) nodes; the graph6 format is only defined for graphs of order less than \(2^{36}\).

**Examples**

```plaintext
>>> nx.to_graph6_bytes(nx.path_graph(2))
b'>>graph6<<A_\n'
```

**See also:**

*from_graph6_bytes()*, *read_graph6()*, *write_graph6_bytes()*

**Notes**

The returned bytes end with a newline character.

The format does not support edge or node labels, parallel edges or self loops. If self loops are present they are silently ignored.

**References**

*networkx.readwrite.graph6.write_graph6*

**write_graph6** (*G*, *path*, **nodes**=None, **header**=True)

Write a simple undirected graph to a path in graph6 format.

**Parameters**

• **G** (*Graph (undirected))

• **path** (*str*) – The path naming the file to which to write the graph.

• **nodes** (*list or iterable*) – Nodes are labeled 0...n-1 in the order provided. If None the ordering given by G.nodes() is used.

• **header** (*bool*) – If True add ‘>>graph6<<’ string to head of data

**Raises**

• **NetworkXNotImplemented** – If the graph is directed or is a multigraph.

• **ValueError** – If the graph has at least \(2^{36}\) nodes; the graph6 format is only defined for graphs of order less than \(2^{36}\).
Examples

You can write a graph6 file by giving the path to a file:

```python
>>> import tempfile
>>> with tempfile.NamedTemporaryFile() as f:
...     nx.write_graph6(nx.path_graph(2), f.name)
...     _ = f.seek(0)
...     print(f.read())
b'>>graph6<<A\n'
```

See also:

`from_graph6_bytes()`, `read_graph6()`

Notes

The function writes a newline character after writing the encoding of the graph.

The format does not support edge or node labels, parallel edges or self loops. If self loops are present they are silently ignored.

References

9.11.2 Sparse6

Functions for reading and writing graphs in the sparse6 format.

The sparse6 file format is a space-efficient format for large sparse graphs. For small graphs or large dense graphs, use the graph6 file format.

For more information, see the sparse6 homepage.

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<th>Function</th>
<th>Description</th>
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<td><code>from_sparse6_bytes(string)</code></td>
<td>Read an undirected graph in sparse6 format from string.</td>
</tr>
<tr>
<td><code>read_sparse6(path)</code></td>
<td>Read an undirected graph in sparse6 format from path.</td>
</tr>
<tr>
<td><code>to_sparse6_bytes(G[, nodes, header])</code></td>
<td>Convert an undirected graph to bytes in sparse6 format.</td>
</tr>
<tr>
<td><code>write_sparse6(G, path[, nodes, header])</code></td>
<td>Write graph G to given path in sparse6 format.</td>
</tr>
</tbody>
</table>

`networkx.readwrite.sparse6.from_sparse6_bytes`

`from_sparse6_bytes(string)`

Read an undirected graph in sparse6 format from string.

Parameters

- `string` (string) – Data in sparse6 format

Returns

- `G` (Graph)

Return type

- `Graph`

Raises

- `NetworkXError` – If the string is unable to be parsed in sparse6 format
Examples

```python
>>> G = nx.from_sparse6_bytes(b':A_')
>>> sorted(G.edges())
[(0, 1), (0, 1), (0, 1)]
```

See also:

`read_sparse6()`, `write_sparse6()`

References

networkx.readwrite.sparse6.read_sparse6

`read_sparse6(path)`
Read an undirected graph in sparse6 format from path.

**Parameters**

- **path** *(file or string)* – File or filename to write.

**Returns**

- **G** – If the file contains multiple lines then a list of graphs is returned

**Return type**

Graph/Multigraph or list of Graphs/MultiGraphs

**Raises**

- **NetworkXError** – If the string is unable to be parsed in sparse6 format

Examples

You can read a sparse6 file by giving the path to the file:

```python
>>> import tempfile
>>> with tempfile.NamedTemporaryFile() as f:
...     _ = f.write(b'>>sparse6<<:An
...     _ = f.seek(0)
...     G = nx.read_sparse6(f.name)
>>> list(G.edges())
[(0, 1)]
```

You can also read a sparse6 file by giving an open file-like object:

```python
>>> import tempfile
>>> with tempfile.NamedTemporaryFile() as f:
...     _ = f.write(b'>>sparse6<<:An
...     _ = f.seek(0)
...     G = nx.read_sparse6(f)
>>> list(G.edges())
[(0, 1)]
```

See also:

`read_sparse6()`, `from_sparse6_bytes()`
References

networkx.readwrite.sparse6.to_sparse6_bytes

to_sparse6_bytes (G, nodes=None, header=True)
Convert an undirected graph to bytes in sparse6 format.

Parameters

• G (Graph (undirected))
• nodes (list or iterable) – Nodes are labeled 0…n-1 in the order provided. If None the
  ordering given by G.nodes() is used.
• header (bool) – If True add ‘>>>sparse6<<’ bytes to head of data.

Raises

• NetworkXNotImplemented – If the graph is directed.
• ValueError – If the graph has at least $2^{36}$ nodes; the sparse6 format is only de-
  fined for graphs of order less than $2^{36}$.

Examples

```python
>>> nx.to_sparse6_bytes(nx.path_graph(2))
b'>>>sparse6<<:An
'
```

See also:

to_sparse6_bytes(), read_sparse6(), write_sparse6_bytes()

Notes

The returned bytes end with a newline character.
The format does not support edge or node labels.

References

networkx.readwrite.sparse6.write_sparse6

write_sparse6 (G, path, nodes=None, header=True)
Write graph G to given path in sparse6 format.

Parameters

• G (Graph (undirected))
• path (file or string) – File or filename to write
• nodes (list or iterable) – Nodes are labeled 0…n-1 in the order provided. If None the
  ordering given by G.nodes() is used.
• header (bool) – If True add ‘>>>sparse6<<’ string to head of data

Raises NetworkXError – If the graph is directed
Examples

You can write a sparse6 file by giving the path to the file:

```python
>>> import tempfile
>>> with tempfile.NamedTemporaryFile() as f:
...    nx.write_sparse6(nx.path_graph(2), f.name)
...    print(f.read())
b'>>sparse6<<:An\n'
```

You can also write a sparse6 file by giving an open file-like object:

```python
>>> with tempfile.NamedTemporaryFile() as f:
...    nx.write_sparse6(nx.path_graph(2), f)
...    _ = f.seek(0)
...    print(f.read())
b'>>sparse6<<:An\n'
```

See also:

`read_sparse6()`, `from_sparse6_bytes()`

Notes

The format does not support edge or node labels.

References

9.12 Pajek

9.12.1 Pajek

Read graphs in Pajek format.

This implementation handles directed and undirected graphs including those with self loops and parallel edges.

Format


<table>
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<tr>
<th>Function</th>
<th>Description</th>
</tr>
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<tbody>
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<td><code>read_pajek(path[, encoding])</code></td>
<td>Read graph in Pajek format from path.</td>
</tr>
<tr>
<td><code>write_pajek(G, path[, encoding])</code></td>
<td>Write graph in Pajek format to path.</td>
</tr>
<tr>
<td><code>parse_pajek(lines)</code></td>
<td>Parse Pajek format graph from string or iterable.</td>
</tr>
</tbody>
</table>

9.12.2 networkx.readwrite.pajek.read_pajek

`read_pajek (path, encoding='UTF-8')`

Read graph in Pajek format from path.

Parameters

- **path (file or string)** – File or filename to write. Filenames ending in .gz or .bz2 will be uncompressed.
Returns \( G \)

**Return type** NetworkX MultiGraph or MultiDiGraph.

**Examples**

```python
>>> G=nx.path_graph(4)
>>> nx.write_pajek(G, "test.net")
>>> G=nx.read_pajek("test.net")
```

To create a Graph instead of a MultiGraph use

```python
>>> G1=nx.Graph(G)
```

**References**


## 9.12.3 `networkx.readwrite.pajek.write_pajek`

**write_pajek** \((G, \text{path}, \text{encoding}='UTF-8')\)

Write graph in Pajek format to path.

**Parameters**

- **G** *(graph)* – A Networkx graph
- **path** *(file or string)* – File or filename to write. Filenames ending in .gz or .bz2 will be compressed.

**Examples**

```python
>>> G=nx.path_graph(4)
>>> nx.write_pajek(G, "test.net")
```

**References**


## 9.12.4 `networkx.readwrite.pajek.parse_pajek`

**parse_pajek** *(lines)*

Parse Pajek format graph from string or iterable.

**Parameters**

- **lines** *(string or iterable)* – Data in Pajek format.

**Returns** \( G \)

**Return type** NetworkX graph
See also:

`read_pajek()`

## 9.13 GIS Shapefile

### 9.13.1 Shapefile

Generates a networkx.DiGraph from point and line shapefiles.

“The Esri Shapefile or simply a shapefile is a popular geospatial vector data format for geographic information systems software. It is developed and regulated by Esri as a (mostly) open specification for data interoperability among Esri and other software products.” See [https://en.wikipedia.org/wiki/Shapefile](https://en.wikipedia.org/wiki/Shapefile) for additional information.

### 9.13.2 `networkx.readwrite.nx_shp.read_shp`

`read_shp(path[, simplify, geom_attrs, strict])` Generates a networkx.

`write_shp(G, outdir)` Writes a networkx.

---

```
read_shp(path[, simplify, geom_attrs, strict])
write_shp(G, outdir)
```

### Parameters

- **path** *(file or string)* – File, directory, or filename to read.
- **simplify** *(bool)* – If True, simplify line geometries to start and end coordinates. If False, and line feature geometry has multiple segments, the non-geometric attributes for that feature will be repeated for each edge comprising that feature.
- **geom_attrs** *(bool)* – If True, include the Wkb, Wkt and Json geometry attributes with each edge.

**NOTE:** if these attributes are available, write_shp will use them to write the geometry. If nodes store the underlying coordinates for the edge geometry as well (as they do when they are read via this method) and they change, your geomety will be out of sync.

- **strict** *(bool)* – If True, raise NetworkXError when feature geometry is missing or GeometryType is not supported. If False, silently ignore missing or unsupported geometry in features.

### Returns

- **G**

### Return type

NetworkX graph

### Raises

- **ImportError** – If ogr module is not available.
- **RuntimeError** – If file cannot be open or read.

---

• `NetworkXError` – If `strict=True` and feature is missing geometry or `GeometryType` is not supported.

Examples

```python
>>> G=nx.read_shp('test.shp')
```

References

9.13.3 `networkx.readwrite.nx_shp.write_shp`

`write_shp(G, outdir)`

Writes a `networkx.DiGraph` to two shapefiles, edges and nodes. Nodes and edges are expected to have a Well Known Binary (Wkb) or Well Known Text (Wkt) key in order to generate geometries. Also acceptable are nodes with a numeric tuple key `(x,y)`.

“The Esri Shapefile or simply a shapefile is a popular geospatial vector data format for geographic information systems software⁠¹.”

Parameters

- `outdir (directory path)` – Output directory for the two shapefiles.

Returns

- `Return type` None

Examples

```python
nx.write_shp(digraph, '/shapefiles') # doctest +SKIP
```

References

---

¹ https://en.wikipedia.org/wiki/Shapefile
NetworkX provides basic functionality for visualizing graphs, but its main goal is to enable graph analysis rather than perform graph visualization. In the future, graph visualization functionality may be removed from NetworkX or only available as an add-on package.

Proper graph visualization is hard, and we highly recommend that people visualize their graphs with tools dedicated to that task. Notable examples of dedicated and fully-featured graph visualization tools are Cytoscape, Gephi, Graphviz and, for LaTeX typesetting, PGF/TikZ. To use these and other such tools, you should export your NetworkX graph into a format that can be read by those tools. For example, Cytoscape can read the GraphML format, and so `networkx.write_graphml(G)` might be an appropriate choice.

## 10.1 Matplotlib

### 10.1.1 Matplotlib

Draw networks with matplotlib.

**See also:**

- [matplotlib](http://matplotlib.org/)
- [pygraphviz](http://pygraphviz.github.io/)

```python

draw(G[, pos, ax])        # Draw the graph G with Matplotlib.
draw_networkx(G[, pos, arrows, with_labels]) # Draw the graph G using Matplotlib.
draw_networkx_nodes(G, pos[, nodelist, …])  # Draw the nodes of the graph G.
draw_networkx_edges(G, pos[, edgelist, …])  # Draw the edges of the graph G.
draw_networkx_labels(G, pos[, labels, …])   # Draw node labels on the graph G.
draw_networkx_edge_labels(G, pos[, …])      # Draw edge labels.
draw_circular(G, **kwargs)            # Draw the graph G with a circular layout.
draw_kamada_kawai(G, **kwargs)        # Draw the graph G with a Kamada-Kawai force-directed layout.
draw_random(G, **kwargs)              # Draw the graph G with a random layout.
draw_spectral(G, **kwargs)            # Draw the graph G with a spectral layout.
draw_spring(G, **kwargs)              # Draw the graph G with a spring layout.
draw_shell(G, **kwargs)               # Draw networkx graph with shell layout.
```
10.1.2 networkx.drawing.nx_pylab.draw

draw \((G, pos=None, ax=None, **kwds)\)
Draw the graph \(G\) with Matplotlib.

Draw the graph as a simple representation with no node labels or edge labels and using the full Matplotlib figure area and no axis labels by default. See draw_networkx() for more full-featured drawing that allows title, axis labels etc.

Parameters

- \(G\) (graph) – A networkx graph
- \(pos\) (dictionary, optional) – A dictionary with nodes as keys and positions as values. If not specified a spring layout positioning will be computed. See networkx.drawing.layout for functions that compute node positions.
- \(ax\) (Matplotlib Axes object, optional) – Draw the graph in specified Matplotlib axes.
- \(kwds\) (optional keywords) – See networkx.draw_networkx() for a description of optional keywords.

Examples

```python
>>> G = nx.dodecahedral_graph()
>>> nx.draw(G)
>>> nx.draw(G, pos=nx.spring_layout(G))  # use spring layout
```

See also:
draw_networkx(), draw_networkx_nodes(), draw_networkx_edges(), draw_networkx_labels(), draw_networkx_edge_labels()

Notes

This function has the same name as pylab.draw and pyplot.draw so beware when using

```python
>>> from networkx import *
```
since you might overwrite the pylab.draw function.

With pyplot use

```python
>>> import matplotlib.pyplot as plt
>>> import networkx as nx
>>> G = nx.dodecahedral_graph()
>>> nx.draw(G)  # networkx draw()
>>> plt.draw()  # pyplot draw()
```

Also see the NetworkX drawing examples at https://networkx.github.io/documentation/latest/auto_examples/index.html

10.1.3 networkx.drawing.nx_pylab.draw_networkx

draw_networkx \((G, pos=None, arrows=True, with_labels=True, **kwds)\)
Draw the graph \(G\) using Matplotlib.
Draw the graph with Matplotlib with options for node positions, labeling, titles, and many other drawing features. See draw() for simple drawing without labels or axes.

**Parameters**

- **G (graph)** – A networkx graph
- **pos (dictionary, optional)** – A dictionary with nodes as keys and positions as values. If not specified a spring layout positioning will be computed. See networkx.drawing.layout for functions that compute node positions.
- **arrows (bool, optional (default=True))** – For directed graphs, if True draw arrowheads. Note: Arrows will be the same color as edges.
- **arrowstyle (str, optional (default=’-|>’))** – For directed graphs, choose the style of the arrowheads. See :py:class: matplotlib.patches.ArrowStyle for more options.
- **arrowsize (int, optional (default=10))** – For directed graphs, choose the size of the arrow head head’s length and width. See :py:class: matplotlib.patches.FancyArrowPatch for attribute mutation_scale for more info.
- **with_labels (bool, optional (default=True))** – Set to True to draw labels on the nodes.
- **ax (Matplotlib Axes object, optional)** – Draw the graph in the specified Matplotlib axes.
- **nodelist (list, optional (default G.nodes()))** – Draw only specified nodes
- **edgelist (list, optional (default=G.edges()))** – Draw only specified edges
- **node_size (scalar or array, optional (default=300))** – Size of nodes. If an array is specified it must be the same length as nodelist.
- **node_color (color string, or array of floats, (default='r'))** – Node color. Can be a single color format string, or a sequence of colors with the same length as nodelist. If numeric values are specified they will be mapped to colors using the cmap and vmin,vmax parameters. See matplotlib.scatter for more details.
- **node_shape (string, optional (default='o'))** – The shape of the node. Specification is as matplotlib.scatter marker, one of ‘so^>v<dph8’.
- **alpha (float, optional (default=1.0))** – The node and edge transparency
- **cmap (Matplotlib colormap, optional (default=None))** – Colormap for mapping intensities of nodes
- **vmin,vmax (float, optional (default=None))** – Minimum and maximum for node colormap scaling
- **linewidths ([None | scalar | sequence])** – Line width of symbol border (default =1.0)
- **width (float, optional (default=1.0))** – Line width of edges
- **edge_color (color string, or array of floats (default='r'))** – Edge color. Can be a single color format string, or a sequence of colors with the same length as edgelist. If numeric values are specified they will be mapped to colors using the edge_cmap and edge_vmin,edge_vmax parameters.
- **edge_cmap (Matplotlib colormap, optional (default=None))** – Colormap for mapping intensities of edges
- **edge_vmin,edge_vmax (floats, optional (default=None))** – Minimum and maximum for edge colormap scaling
- **style (string, optional (default='solid'))** – Edge line style (solid,dash,dotted,dashdot)
• **labels** *(dictionary, optional (default=None)) – Node labels in a dictionary keyed by node of text labels*

• **font_size** *(int, optional (default=12)) – Font size for text labels*

• **font_color** *(string, optional (default='k' black)) – Font color string*

• **font_weight** *(string, optional (default='normal')) – Font weight*

• **font_family** *(string, optional (default='sans-serif')) – Font family*

• **label** *(string, optional) – Label for graph legend*

**Notes**

For directed graphs, arrows are drawn at the head end. Arrows can be turned off with keyword arrows=False.

**Examples**

```python
>>> G = nx.dodecahedral_graph()
>>> nx.draw(G)
>>> nx.draw(G, pos=nx.spring_layout(G))  # use spring layout

>>> import matplotlib.pyplot as plt
>>> limits = plt.axis('off')  # turn off axis
```

Also see the NetworkX drawing examples at https://networkx.github.io/documentation/latest/auto_examples/index.html

**See also:**

`draw()`, `draw_networkx_nodes()`, `draw_networkx_edges()`, `draw_networkx_labels()`, `draw_networkx_edge_labels()`

### 10.1.4 networkx.drawing.nx_pylab.draw_networkx_nodes

**draw_networkx_nodes** *(G, pos, nodelist=None, node_size=300, node_color='r', node_shape='o', alpha=1.0, cmap=None, vmin=None, vmax=None, ax=None, linewidths=None, edgecolors=None, label=None, **kwds)*

Draw the nodes of the graph G.

This draws only the nodes of the graph G.

**Parameters**

• **G** *(graph) – A networkx graph*

• **pos** *(dictionary) – A dictionary with nodes as keys and positions as values. Positions should be sequences of length 2.*

• **ax** *(Matplotlib Axes object, optional) – Draw the graph in the specified Matplotlib axes.*

• **nodelist** *(list, optional) – Draw only specified nodes (default G.nodes())*

• **node_size** *(scalar or array) – Size of nodes (default=300). If an array is specified it must be the same length as nodelist.*
• **node_color** *(color string, or array of floats)* – Node color. Can be a single color format string (default='r'), or a sequence of colors with the same length as nodelist. If numeric values are specified they will be mapped to colors using the cmap and vmin,vmax parameters. See matplotlib.scatter for more details.

• **node_shape** *(string)* – The shape of the node. Specification is as matplotlib.scatter marker, one of 'so>v<dph8' (default='o').

• **alpha** *(float or array of floats)* – The node transparency. This can be a single alpha value (default=1.0), in which case it will be applied to all the nodes of color. Otherwise, if it is an array, the elements of alpha will be applied to the colors in order (cycling through alpha multiple times if necessary).

• **cmap** *(Matplotlib colormap)* – Colormap for mapping intensities of nodes (default=None)

• **vmin,vmax** *(floats)* – Minimum and maximum for node colormap scaling (default=None)

• **linewidths** *(sequence)* – Line width of symbol border (default =1.0)

• **edgecolors** *(sequence)* – Colors of node borders (default = node_color)

• **label** *(string)* – Label for legend

**Returns** PathCollection of the nodes.

**Return type** matplotlib.collections.PathCollection

### Examples

```python
>>> G = nx.dodecahedral_graph()
>>> nodes = nx.draw_networkx_nodes(G, pos=nx.spring_layout(G))
```

Also see the NetworkX drawing examples at https://networkx.github.io/documentation/latest/auto_examples/index.html

See also:

draw(), draw_networkx(), draw_networkx_edges(), draw_networkx_labels(), draw_networkx_edge_labels()

### 10.1.5 networkx.drawing.nx_pylab.draw_networkx_edges

draw_networkx_edges *(G, pos, edgelist=None, width=1.0, edge_color='k', style='solid', alpha=1.0, arrowstyle='->', arrowsize=10, edge_cmap=None, edge_vmin=None, edge_vmax=None, ax=None, arrows=True, label=None, node_size=300, nodelist=None, node_shape='o', **kwds)*

Draw the edges of the graph G.

This draws only the edges of the graph G.

**Parameters**

• **G** *(graph)* – A networkx graph

• **pos** *(dictionary)* – A dictionary with nodes as keys and positions as values. Positions should be sequences of length 2.

• **edgelist** *(collection of edge tuples)* – Draw only specified edges(default=G.edges())

• **width** *(float, or array of floats)* – Line width of edges (default=1.0)
• **edge_color** *(color string, or array of floats)* – Edge color. Can be a single color format string (default='r'), or a sequence of colors with the same length as edgelist. If numeric values are specified they will be mapped to colors using the `edge_cmap` and `edge_vmin,edge_vmax` parameters.

• **style** *(string)* – Edge line style (default='solid') *(solid|dashed|dotted,dashdot)*

• **alpha** *(float)* – The edge transparency (default=1.0)

• **edge_cmap** *(Matplotlib colormap)* – Colormap for mapping intensities of edges (default=None)

• **edge_vmin,edge_vmax** *(floats)* – Minimum and maximum for edge colormap scaling (default=None)

• **ax** *(Matplotlib Axes object, optional)* – Draw the graph in the specified Matplotlib axes.

• **arrows** *(bool, optional (default=True))* – For directed graphs, if True draw arrowheads. Note: Arrows will be the same color as edges.

• **arrowstyle** *(str, optional (default='-|>'))* – For directed graphs, choose the style of the arrow heads. See :py:class:`matplotlib.patches.ArrowStyle` for more options.

• **arrowsize** *(int, optional (default=10))* – For directed graphs, choose the size of the arrow head head’s length and width. See :py:class:`matplotlib.patches.FancyArrowPatch` for attribute `mutation_scale` for more info.

• **label** *(None|string)* – Label for legend

Returns

• **matplotlib.collection.LineCollection** – LineCollection of the edges

• **list of matplotlib.patches.FancyArrowPatch** – FancyArrowPatch instances of the directed edges

• Depending whether the drawing includes arrows or not.

Notes

For directed graphs, arrows are drawn at the head end. Arrows can be turned off with keyword `arrows=False`. Be sure to include `‘node_size’` as a keyword argument; arrows are drawn considering the size of nodes.

Examples

```python
>>> G = nx.dodecahedral_graph()
>>> edges = nx.draw_networkx_edges(G, pos=nx.spring_layout(G))
```

```python
>>> G = nx.DiGraph()
>>> G.add_edges_from([(1, 2), (1, 3), (2, 3)])
>>> arcs = nx.draw_networkx_edges(G, pos=nx.spring_layout(G))
>>> alphas = [0.3, 0.4, 0.5]
>>> for i, arc in enumerate(arcs):
...    # change alpha values of arcs
...    arc.set_alpha(alphas[i])
```

Also see the NetworkX drawing examples at https://networkx.github.io/documentation/latest/auto_examples/index.html

See also:
draw(), draw_networkx(), draw_networkx_nodes(), draw_networkx_labels(),
draw_networkx_edge_labels()

10.1.6 networkx.drawing.nx_pylab.draw_networkx_labels
draw_networkx_labels(G, pos, labels=None, font_size=12, font_color='k',
font_family='sans-serif', font_weight='normal', alpha=1.0, bbox=None, ax=None, **kwds)
Draw node labels on the graph G.

Parameters
- G (graph) – A networkx graph
- pos (dictionary) – A dictionary with nodes as keys and positions as values. Positions should be sequences of length 2.
- labels (dictionary, optional (default=None)) – Node labels in a dictionary keyed by node of text labels
- font_size (int) – Font size for text labels (default=12)
- font_color (string) – Font color string (default='k' black)
- font_family (string) – Font family (default='sans-serif')
- font_weight (string) – Font weight (default='normal')
- alpha (float) – The text transparency (default=1.0)
- ax (Matplotlib Axes object, optional) – Draw the graph in the specified Matplotlib axes.

Returns dict of labels keyed on the nodes
Return type dict

Examples

```python
>>> G = nx.dodecahedral_graph()
>>> labels = nx.draw_networkx_labels(G, pos=nx.spring_layout(G))
```

Also see the NetworkX drawing examples at https://networkx.github.io/documentation/latest/auto_examples/index.html

See also:
- draw(), draw_networkx(), draw_networkx_nodes(), draw_networkx_edges(), draw_networkx_edge_labels()
- pos (dictionary) – A dictionary with nodes as keys and positions as values. Positions should be sequences of length 2.
- ax (Matplotlib Axes object, optional) – Draw the graph in the specified Matplotlib axes.
- alpha (float) – The text transparency (default=1.0)
- edge_labels (dictionary) – Edge labels in a dictionary keyed by edge two-tuple of text labels (default=None). Only labels for the keys in the dictionary are drawn.
- label_pos (float) – Position of edge label along edge (0=head, 0.5=中心, 1=tail)
- font_size (int) – Font size for text labels (default=12)
- font_color (string) – Font color string (default='k' black)
- font_weight (string) – Font weight (default='normal')
- font_family (string) – Font family (default='sans-serif')
- bbox (Matplotlib bbox) – Specify text box shape and colors.
- clip_on (bool) – Turn on clipping at axis boundaries (default=True)

Returns dict of labels keyed on the edges
Return type dict

Examples

```python
>>> G = nx.dodecahedral_graph()
>>> edge_labels = nx.draw_networkx_edge_labels(G, pos=nx.spring_layout(G))
```

Also see the NetworkX drawing examples at https://networkx.github.io/documentation/latest/auto_examples/index.html

See also:
```
draw(), draw_networkx(), draw_networkx_nodes(), draw_networkx_edges(), draw_networkx_labels()
```

10.1.8 networkx.drawing.nx_pylab.draw_circular
draw_circular(G, **kwargs)

Draw the graph G with a circular layout.

Parameters

- G (graph) – A networkx graph
- kwargs (optional keywords) – See networkx.draw_networkx() for a description of optional keywords, with the exception of the pos parameter which is not used by this function.

10.1.9 networkx.drawing.nx_pylab.draw_kamada_kawai
draw_kamada_kawai(G, **kwargs)

Draw the graph G with a Kamada-Kawai force-directed layout.

Parameters

- G (graph) – A networkx graph
• **kwargs (optional keywords) – See networkx.draw_networkx() for a description of optional keywords, with the exception of the pos parameter which is not used by this function.

### 10.1.10 networkx.drawing.nx_pylab.draw_random

**draw_random** *(G, **kwargs)*

Draw the graph G with a random layout.

**Parameters**

• G (graph) – A networkx graph

• **kwargs (optional keywords) – See networkx.draw_networkx() for a description of optional keywords, with the exception of the pos parameter which is not used by this function.

### 10.1.11 networkx.drawing.nx_pylab.draw_spectral

**draw_spectral** *(G, **kwargs)*

Draw the graph G with a spectral layout.

**Parameters**

• G (graph) – A networkx graph

• **kwargs (optional keywords) – See networkx.draw_networkx() for a description of optional keywords, with the exception of the pos parameter which is not used by this function.

### 10.1.12 networkx.drawing.nx_pylab.draw_spring

**draw_spring** *(G, **kwargs)*

Draw the graph G with a spring layout.

**Parameters**

• G (graph) – A networkx graph

• **kwargs (optional keywords) – See networkx.draw_networkx() for a description of optional keywords, with the exception of the pos parameter which is not used by this function.

### 10.1.13 networkx.drawing.nx_pylab.draw_shell

**draw_shell** *(G, **kwargs)*

Draw networkx graph with shell layout.

**Parameters**

• G (graph) – A networkx graph

• **kwargs (optional keywords) – See networkx.draw_networkx() for a description of optional keywords, with the exception of the pos parameter which is not used by this function.
10.2 Graphviz AGraph (dot)

10.2.1 Graphviz AGraph

Interface to pygraphviz AGraph class.

Examples

```python
>>> G = nx.complete_graph(5)
>>> A = nx.nx_agraph.to_agraph(G)
>>> H = nx.nx_agraph.from_agraph(A)
```

See also:

Pygraphviz  http://pygraphviz.github.io/

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<td>Return a NetworkX Graph or DiGraph from a PyGraphviz graph.</td>
</tr>
<tr>
<td><code>to_agraph</code> (N)</td>
<td>Return a pygraphviz graph from a NetworkX graph N.</td>
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<td><code>write_dot</code> (G, path)</td>
<td>Write NetworkX graph G to Graphviz dot format on path.</td>
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<tr>
<td><code>pygraphviz_layout</code> (G[, prog, root, args])</td>
<td>Create node positions for G using Graphviz.</td>
</tr>
</tbody>
</table>

10.2.2 networkx.drawing.nx_agraph.from_agraph

`from_agraph` (A, create_using=None)

Return a NetworkX Graph or DiGraph from a PyGraphviz graph.

Parameters

- A (PyGraphviz AGraph) – A graph created with PyGraphviz
- create_using (NetworkX graph class instance) – The output is created using the given graph class instance

Examples

```python
>>> K5 = nx.complete_graph(5)
>>> A = nx.nx_agraph.to_agraph(K5)
>>> G = nx.nx_agraph.from_agraph(A)
>>> G = nx.nx_agraph.from_agraph(A)
```

Notes

The Graph G will have a dictionary G.graph_attr containing the default graphviz attributes for graphs, nodes and edges.

Default node attributes will be in the dictionary G.node_attr which is keyed by node.
Edge attributes will be returned as edge data in G. With edge_attr=False the edge data will be the Graphviz edge weight attribute or the value 1 if no edge weight attribute is found.

### 10.2.3 networkx.drawing.nx_agraph.to_agraph

to_agraph \((N)\)

Return a pygraphviz graph from a NetworkX graph N.

**Parameters**

- **N** *(NetworkX graph)* – A graph created with NetworkX

**Examples**

```python
>>> K5 = nx.complete_graph(5)
>>> A = nx.nx_agraph.to_agraph(K5)
```

**Notes**

If N has an dict N.graph_attr an attempt will be made first to copy properties attached to the graph (see from_agraph) and then updated with the calling arguments if any.

### 10.2.4 networkx.drawing.nx_agraph.write_dot

write_dot \((G, path)\)

Write NetworkX graph G to Graphviz dot format on path.

**Parameters**

- **G** *(graph)* – A networkx graph
- **path** *(filename)* – Filename or file handle to write

### 10.2.5 networkx.drawing.nx_agraph.read_dot

read_dot \((path)\)

Return a NetworkX graph from a dot file on path.

**Parameters**

- **path** *(file or string)* – File name or file handle to read.

### 10.2.6 networkx.drawing.nx_agraph.graphviz_layout

graphviz_layout \((G, prog='neato', root=None, args=\"\")\)

Create node positions for G using Graphviz.

**Parameters**

- **G** *(NetworkX graph)* – A graph created with NetworkX
- **prog** *(string)* – Name of Graphviz layout program
- **root** *(string, optional)* – Root node for twopi layout
- **args** *(string, optional)* – Extra arguments to Graphviz layout program

**Returns** *(dictionary)* – Dictionary of x, y, positions keyed by node.
Examples

```python
>>> G = nx.petersen_graph()
>>> pos = nx.nx_agraph.graphviz_layout(G)
>>> pos = nx.nx_agraph.graphviz_layout(G, prog='dot')
```

Notes

This is a wrapper for pygraphviz_layout.

10.2.7 networkx.drawing.nx_agraph.pygraphviz_layout

**pygraphviz_layout** *(G, prog='neato', root=None, args='')*

Create node positions for G using Graphviz.

**Parameters**

- **G** *(NetworkX graph)* – A graph created with NetworkX
- **prog** *(string)* – Name of Graphviz layout program
- **root** *(string, optional)* – Root node for twopi layout
- **args** *(string, optional)* – Extra arguments to Graphviz layout program
- **Returns** *(dictionary)* – Dictionary of x, y, positions keyed by node.

Examples

```python
>>> G = nx.petersen_graph()
>>> pos = nx.nx_agraph.graphviz_layout(G)
>>> pos = nx.nx_agraph.graphviz_layout(G, prog='dot')
```

10.3 Graphviz with pydot

10.3.1 Pydot

Import and export NetworkX graphs in Graphviz dot format using pydot.

Either this module or nx_agraph can be used to interface with graphviz.

See also:

- **pydot**  [https://github.com/erocarrera/pydot](https://github.com/erocarrera/pydot)
- **DOT**

```
from_pydot(P)  # Return a NetworkX graph from a Pydot graph.
to_pydot(N)  # Return a pydot graph from a NetworkX graph N.
write_dot(G, path)  # Write NetworkX graph G to Graphviz dot format on path.
```

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<td><code>read_dot(path)</code></td>
<td>Return a NetworkX MultiGraph or MultiDiGraph from the dot file with the passed path.</td>
</tr>
<tr>
<td><code>graphviz_layout(G[, prog, root])</code></td>
<td>Create node positions using Pydot and Graphviz.</td>
</tr>
<tr>
<td><code>pydot_layout(G[, prog, root])</code></td>
<td>Create node positions using pydot and Graphviz.</td>
</tr>
</tbody>
</table>

### 10.3.2 `networkx.drawing.nx_pydot.from_pydot`  

`from_pydot(P)`  
Return a NetworkX graph from a Pydot graph.

- **Parameters**  
  - `P` (*Pydot graph*) – A graph created with Pydot  
- **Returns**  
  - `G` – A MultiGraph or MultiDiGraph.  
- **Return type**  
  - NetworkX multigraph

**Examples**

```python
>>> K5 = nx.complete_graph(5)
>>> A = nx.nx_pydot.to_pydot(K5)
>>> G = nx.nx_pydot.from_pydot(A)  # return MultiGraph

# make a Graph instead of MultiGraph >>> G = nx.Graph(nx.nx_pydot.from_pydot(A))
```

### 10.3.3 `networkx.drawing.nx_pydot.to_pydot`  

`to_pydot(N)`  
Return a pydot graph from a NetworkX graph N.

- **Parameters**  
  - `N` (*NetworkX graph*) – A graph created with NetworkX

**Examples**

```python
>>> K5 = nx.complete_graph(5)
>>> P = nx.nx_pydot.to_pydot(K5)
```

**Notes**

### 10.3.4 `networkx.drawing.nx_pydot.write_dot`  

`write_dot(G, path)`  
Write NetworkX graph G to Graphviz dot format on path.  
Path can be a string or a file handle.
10.3.5 networkx.drawing.nx_pydot.read_dot

```
read_dot(path)
```

Return a NetworkX MultiGraph or MultiDiGraph from the dot file with the passed path.

If this file contains multiple graphs, only the first such graph is returned. All graphs _except_ the first are silently ignored.

Parameters path (str or file) – Filename or file handle.

Returns G – A MultiGraph or MultiDiGraph.

Return type MultiGraph or MultiDiGraph

Notes

Use `G = nx.Graph(read_dot(path))` to return a Graph instead of a MultiGraph.

10.3.6 networkx.drawing.nx_pydot.graphviz_layout

```
graphviz_layout(G, prog='neato', root=None, **kwds)
```

Create node positions using Pydot and Graphviz.

Returns a dictionary of positions keyed by node.

Examples

```python
>>> G = nx.complete_graph(4)
>>> pos = nx.nx_pydot.graphviz_layout(G)
>>> pos = nx.nx_pydot.graphviz_layout(G, prog='dot')
```

Notes

This is a wrapper for pydot_layout.

10.3.7 networkx.drawing.nx_pydot.pydot_layout

```
pydot_layout(G, prog='neato', root=None, **kwds)
```

Create node positions using pydot and Graphviz.

Parameters

- G (Graph) – NetworkX graph to be laid out.
- prog (optional[str]) – Basename of the GraphViz command with which to layout this graph.
  
  Defaults to `neato`, the default GraphViz command for undirected graphs.

Returns Dictionary of positions keyed by node.

Return type dict
Examples

>>> G = nx.complete_graph(4)
>>> pos = nx.nx_pydot.pydot_layout(G)
>>> pos = nx.nx_pydot.pydot_layout(G, prog='dot')

10.4 Graph Layout

10.4.1 Layout

Node positioning algorithms for graph drawing.

For random_layout() the possible resulting shape is a square of side $[0, \text{scale}]$ (default: $[0, 1]$). Changing center shifts the layout by that amount.

For the other layout routines, the extent is $[\text{center} - \text{scale}, \text{center} + \text{scale}]$ (default: $[-1, 1]$).

Warning: Most layout routines have only been tested in 2-dimensions.

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<td>circular_layout(G[, scale, center, dim])</td>
<td>Position nodes on a circle.</td>
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<tr>
<td>kamada_kawai_layout(G[, dist, pos, weight, ...])</td>
<td>Position nodes using Kamada-Kawai path-length cost-function.</td>
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<tr>
<td>random_layout(G[, center, dim, random_state])</td>
<td>Position nodes uniformly at random in the unit square.</td>
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<td>rescale_layout(pos[, scale])</td>
<td>Return scaled position array to (-scale, scale) in all axes.</td>
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<tr>
<td>shell_layout(G[, nlist, scale, center, dim])</td>
<td>Position nodes in concentric circles.</td>
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<tr>
<td>spring_layout(G[, k, pos, fixed, ...])</td>
<td>Position nodes using Fruchterman-Reingold force-directed algorithm.</td>
</tr>
<tr>
<td>spectral_layout(G[, weight, scale, center, dim])</td>
<td>Position nodes using the eigenvectors of the graph Laplacian.</td>
</tr>
</tbody>
</table>

10.4.2 networkx.drawing.layout.circular_layout

circular_layout(G, scale=1, center=None, dim=2)

Position nodes on a circle.

Parameters

- **G** (*NetworkX graph or list of nodes*) – A position will be assigned to every node in G.
- **scale** (*number* (default: 1)) – Scale factor for positions.
- **center** (*array-like* or *None*) – Coordinate pair around which to center the layout.
- **dim** (*int*) – Dimension of layout. If dim>2, the remaining dimensions are set to zero in the returned positions.

Returns **pos** – A dictionary of positions keyed by node

Return type **dict**

10.4. Graph Layout 609
Examples

```python
>>> G = nx.path_graph(4)
>>> pos = nx.circular_layout(G)
```

Notes

This algorithm currently only works in two dimensions and does not try to minimize edge crossings.

10.4.3 `networkx.drawing.layout.kamada_kawai_layout`

`kamada_kawai_layout(G, dist=None, pos=None, weight='weight', scale=1, center=None, dim=2)`

Position nodes using Kamada-Kawai path-length cost-function.

Parameters:

- `G` (*NetworkX graph or list of nodes*) – A position will be assigned to every node in `G`.
- `dist` (*float (default=None]*) – A two-level dictionary of optimal distances between nodes, indexed by source and destination node. If `None`, the distance is computed using `shortest_path_length()`.
- `pos` (*dict or None optional (default=None]*) – Initial positions for nodes as a dictionary with node as keys and values as a coordinate list or tuple. If `None`, then use `circular_layout()`.
- `weight` (*string or None optional (default='weight')*) – The edge attribute that holds the numerical value used for the edge weight. If `None`, then all edge weights are `1`.
- `scale` (*number (default: 1]*) – Scale factor for positions.
- `center` (*array-like or None*) – Coordinate pair around which to center the layout.
- `dim` (*int*) – Dimension of layout.

Returns `pos` – A dictionary of positions keyed by node

Return type `dict`

Examples

```python
>>> G = nx.path_graph(4)
>>> pos = nx.kamada_kawai_layout(G)
```

10.4.4 `networkx.drawing.layout.random_layout`

`random_layout(G, center=None, dim=2, random_state=None)`

Position nodes uniformly at random in the unit square.

For every node, a position is generated by choosing each of `dim` coordinates uniformly at random on the interval `[0.0, 1.0)`.

NumPy (`http://scipy.org`) is required for this function.

Parameters:

- `G` (*NetworkX graph or list of nodes*) – A position will be assigned to every node in `G`. 
• **center** (*array-like or None*) – Coordinate pair around which to center the layout.
• **dim** (*int*) – Dimension of layout.
• **random_state** (*int, RandomState instance or None optional (default=None]*) – Set the random state for deterministic node layouts. If int, `random_state` is the seed used by the random number generator, if numpy.random.RandomState instance, `random_state` is the random number generator, if None, the random number generator is the RandomState instance used by numpy.random.

**Returns** pos – A dictionary of positions keyed by node

**Return type** dict

### Examples

```python
>>> G = nx.lollipop_graph(4, 3)
>>> pos = nx.random_layout(G)
```

10.4.5 `networkx.drawing.layout.rescale_layout`

**rescale_layout** (*pos, scale=1*)

Return scaled position array to (-scale, scale) in all axes.

The function acts on NumPy arrays which hold position information. Each position is one row of the array. The dimension of the space equals the number of columns. Each coordinate in one column.

To rescale, the mean (center) is subtracted from each axis separately. Then all values are scaled so that the largest magnitude value from all axes equals `scale` (thus, the aspect ratio is preserved). The resulting NumPy Array is returned (order of rows unchanged).

**Parameters**

• **pos** (*numpy array*) – positions to be scaled. Each row is a position.
• **scale** (*number (default: 1]*) – The size of the resulting extent in all directions.

**Returns** pos – scaled positions. Each row is a position.

**Return type** numpy array

10.4.6 `networkx.drawing.layout.shell_layout`

**shell_layout** (*G, nlist=None, scale=1, center=None, dim=2*)

Position nodes in concentric circles.

**Parameters**

• **G** (*NetworkX graph or list of nodes*) – A position will be assigned to every node in G.
• **nlist** (*list of lists*) – List of node lists for each shell.
• **scale** (*number (default: 1]*) – Scale factor for positions.
• **center** (*array-like or None*) – Coordinate pair around which to center the layout.
• **dim** (*int*) – Dimension of layout, currently only dim=2 is supported.

**Returns** pos – A dictionary of positions keyed by node
Return type: `dict`

Examples

```python
>>> G = nx.path_graph(4)
>>> shells = [[0], [1, 2, 3]]
>>> pos = nx.shell_layout(G, shells)
```

Notes

This algorithm currently only works in two dimensions and does not try to minimize edge crossings.

10.4.7 networkx.drawing.layout.spring_layout

`spring_layout(G, k=None, pos=None, fixed=None, iterations=50, threshold=0.0001, weight='weight', scale=1, center=None, dim=2, random_state=None)`

Position nodes using Fruchterman-Reingold force-directed algorithm.

Parameters

- `G (NetworkX graph or list of nodes)` – A position will be assigned to every node in G.
- `k (float (default=None))` – Optimal distance between nodes. If None the distance is set to 1/sqrt(n) where n is the number of nodes. Increase this value to move nodes farther apart.
- `pos (dict or None optional (default=None))` – Initial positions for nodes as a dictionary with node as keys and values as a coordinate list or tuple. If None, then use random initial positions.
- `fixed (list or None optional (default=None))` – Nodes to keep fixed at initial position.
- `iterations (int optional (default=50))` – Maximum number of iterations taken
- `threshold (float optional (default = 1e-4))` – Threshold for relative error in node position changes. The iteration stops if the error is below this threshold.
- `weight (string or None optional (default='weight'))` – The edge attribute that holds the numerical value used for the edge weight. If None, then all edge weights are 1.
- `scale (number (default: 1))` – Scale factor for positions. Not used unless fixed is None.
- `center (array-like or None)` – Coordinate pair around which to center the layout. Not used unless fixed is None.
- `dim (int)` – Dimension of layout.
- `random_state (int, RandomState instance or None optional (default=None))` – Set the random state for deterministic node layouts. If int, random_state is the seed used by the random number generator, if numpy.random.RandomState instance, random_state is the random number generator, if None, the random number generator is the RandomState instance used by numpy.random.

Returns `pos` – A dictionary of positions keyed by node

Return type: `dict`
Examples

```python
>>> G = nx.path_graph(4)
>>> pos = nx.spring_layout(G)
```

# The same using longer but equivalent function name >>> pos = nx.fruchterman_reingold_layout(G)

10.4.8 networkx.drawing.layout.spectral_layout

```
spectral_layout(G, weight='weight', scale=1, center=None, dim=2)
```
Position nodes using the eigenvectors of the graph Laplacian.

Parameters

- **G** (*NetworkX graph or list of nodes*) – A position will be assigned to every node in G.
- **weight** (*string or None optional (default='weight')*) – The edge attribute that holds the numerical value used for the edge weight. If None, then all edge weights are 1.
- **scale** (*number (default: 1)*) – Scale factor for positions.
- **center** (*array-like or None*) – Coordinate pair around which to center the layout.
- **dim** (*int*) – Dimension of layout.

Returns **pos** – A dictionary of positions keyed by node

Return type **dict**

Examples

```python
>>> G = nx.path_graph(4)
>>> pos = nx.spectral_layout(G)
```

Notes

Directed graphs will be considered as undirected graphs when positioning the nodes.

For larger graphs (>500 nodes) this will use the SciPy sparse eigenvalue solver (ARPACK).
11.1 Exceptions

Base exceptions and errors for NetworkX.

```python
class NetworkXException
    Base class for exceptions in NetworkX.

class NetworkXError
    Exception for a serious error in NetworkX

class NetworkXPointlessConcept
    Raised when a null graph is provided as input to an algorithm that cannot use it.
    The null graph is sometimes considered a pointless concept\(^1\), thus the name of the exception.

References

```python
class NetworkXAlgorithmError
    Exception for unexpected termination of algorithms.

class NetworkXUnfeasible
    Exception raised by algorithms trying to solve a problem instance that has no feasible solution.

class NetworkXNoPath
    Exception for algorithms that should return a path when running on graphs where such a path does not exist.

class NetworkXNoCycle
    Exception for algorithms that should return a cycle when running on graphs where such a cycle does not exist.

class NodeNotFound
    Exception raised if requested node is not present in the graph

class HasACycle
    Raised if a graph has a cycle when an algorithm expects that it will have no cycles.

class NetworkXUnbounded
    Exception raised by algorithms trying to solve a maximization or a minimization problem instance that is unbounded.

class NetworkXNotImplemented
    Exception raised by algorithms not implemented for a type of graph.
```

class AmbiguousSolution
   Raised if more than one valid solution exists for an intermediary step of an algorithm.

   In the face of ambiguity, refuse the temptation to guess. This may occur, for example, when trying to determine
   the bipartite node sets in a disconnected bipartite graph when computing bipartite matchings.

class ExceededMaxIterations
   Raised if a loop iterates too many times without breaking.

   This may occur, for example, in an algorithm that computes progressively better approximations to a value but
   exceeds an iteration bound specified by the user.

class PowerIterationFailedConvergence (num_iterations, *args, **kw)
   Raised when the power iteration method fails to converge within a specified iteration limit.

   num_iterations is the number of iterations that have been completed when this exception was raised.
12.1 Helper Functions

Miscellaneous Helpers for NetworkX.

These are not imported into the base networkx namespace but can be accessed, for example, as

```python
>>> import networkx

>>> networkx.utils.is_string_like('spam')
True
```

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<tr>
<th>Function</th>
<th>Description</th>
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<td><code>is_string_like(obj)</code></td>
<td>Check if obj is string.</td>
</tr>
<tr>
<td><code>flatten(obj[, result])</code></td>
<td>Return flattened version of (possibly nested) iterable object.</td>
</tr>
<tr>
<td><code>iterable(obj)</code></td>
<td>Return True if obj is iterable with a well-defined len().</td>
</tr>
<tr>
<td><code>is_list_of_ints(intlist)</code></td>
<td>Return True if list is a list of ints.</td>
</tr>
<tr>
<td><code>make_str(x)</code></td>
<td>Return the string representation of x.</td>
</tr>
<tr>
<td><code>generate_unique_node()</code></td>
<td>Generate a unique node label.</td>
</tr>
<tr>
<td><code>default_opener(filename)</code></td>
<td>Opens <code>filename</code> using system’s default program.</td>
</tr>
<tr>
<td><code>pairwise(iterable[, cyclic])</code></td>
<td>s -&gt; (s0, s1), (s1, s2), (s2, s3), ..</td>
</tr>
<tr>
<td><code>groups(many_to_one)</code></td>
<td>Converts a many-to-one mapping into a one-to-many mapping.</td>
</tr>
<tr>
<td><code>create_random_state([random_state])</code></td>
<td>Returns a numpy.</td>
</tr>
</tbody>
</table>

### 12.1.1 `networkx.utils.misc.is_string_like`

`is_string_like(obj)`

Check if obj is string.

### 12.1.2 `networkx.utils.misc.flatten`

```python
flatten(obj[, result])
```

Return flattened version of (possibly nested) iterable object.

### 12.1.3 `networkx.utils.misc.iterable`

```python
iterable(obj)
```

Return True if obj is iterable with a well-defined len().
12.1.4 networkx.utils.misc.is_list_of_ints

is_list_of_ints(intlist)
Return True if list is a list of ints.

12.1.5 networkx.utils.misc.make_str

make_str(x)
Return the string representation of t.

12.1.6 networkx.utils.misc.generate_unique_node

generate_unique_node()
Generate a unique node label.

12.1.7 networkx.utils.misc.default_opener

default_opener(filename)
Opens filename using system’s default program.
Parameters filename (str) – The path of the file to be opened.

12.1.8 networkx.utils.misc.pairwise

pairwise(iterable, cyclic=False)
s -> (s0, s1), (s1, s2), (s2, s3), …

12.1.9 networkx.utils.misc.groups

groups(many_to_one)
Converts a many-to-one mapping into a one-to-many mapping.
many_to_one must be a dictionary whose keys and values are all hashable.
The return value is a dictionary mapping values from many_to_one to sets of keys from many_to_one that have that value.
For example:

```python
>>> from networkx.utils import groups
>>> many_to_one = {"a": 1, "b": 1, "c": 2, "d": 3, "e": 3}
>>> groups(many_to_one)
{1: {'a', 'b'}, 2: {'c'}, 3: {'d', 'e'}}
```

12.1.10 networkx.utils.misc.create_random_state

create_random_state(random_state=None)
Returns a numpy.random.RandomState instance depending on input.
Parameters `random_state` *(int or RandomState instance or None optional (default=None))*
- If int, `random_state` is the seed used by the random number generator, if `numpy.random.RandomState` instance, `random_state` is the random number generator, if None, the random number generator is the RandomState instance used by `numpy.random`.

### 12.2 Data Structures and Algorithms

Union-find data structure.

```python
UnionFind.union(*objects)  # Find the sets containing the objects and merge them all.
```

#### 12.2.1 `networkx.utils.union_find.UnionFind.union`

### 12.3 Random Sequence Generators

Utilities for generating random numbers, random sequences, and random selections.

```python
powerlaw_sequence(n[, exponent])  # Return sample sequence of length n from a power law distribution.
```

#### 12.3.1 `networkx.utils.random_sequence.powerlaw_sequence`

`powerlaw_sequence(n, exponent=2.0)`
- Return sample sequence of length n from a power law distribution.

```python
cumulative_distribution(distribution)  # Return normalized cumulative distribution from discrete distribution.
```

#### 12.3.2 `networkx.utils.random_sequence.cumulative_distribution`

`cumulative_distribution(distribution)`
- Return normalized cumulative distribution from discrete distribution.

```python
discrete_sequence(n[, distribution, ...])  # Return sample sequence of length n from a given discrete distribution or discrete cumulative distribution.
```

#### 12.3.3 `networkx.utils.random_sequence.discrete_sequence`

`discrete_sequence(n, distribution=None, cdistribution=None)`
- Return sample sequence of length n from a given discrete distribution or discrete cumulative distribution.

```python
zipf_rv(alpha[, xmin, seed])  # Return a random value chosen from the Zipf distribution.
```

#### 12.3.4 `networkx.utils.random_sequence.zipf_rv`

`zipf_rv(alpha[, xmin, seed])`
- Return a random value chosen from the Zipf distribution.

```python
random_weighted_sample(mapping, k)  # Return k items without replacement from a weighted sample.
```

#### 12.3.5 `networkx.utils.random_sequence.random_weighted_sample`

`random_weighted_sample(mapping, k)`
- Return k items without replacement from a weighted sample.

```python
weighted_choice(mapping)  # Return a single element from a weighted sample.
```

#### 12.3.6 `networkx.utils.random_sequence.weighted_choice`

`weighted_choice(mapping)`
- Return a single element from a weighted sample.
One of the following must be specified.
distribution = histogram of values, will be normalized
cdistribution = normalized discrete cumulative distribution

12.3.4 networkx.utils.random_sequence.zipf_rv

zipf_rv(alpha, xmin=1, seed=None)
Return a random value chosen from the Zipf distribution.
The return value is an integer drawn from the probability distribution

\[ p(x) = \frac{x^{-\alpha}}{\zeta(\alpha, x_{\text{min}})} \]

where \( \zeta(\alpha, x_{\text{min}}) \) is the Hurwitz zeta function.

Parameters
- **alpha** (float) – Exponent value of the distribution
- **xmin** (int) – Minimum value
- **seed** (int) – Seed value for random number generator

Returns x – Random value from Zipf distribution

Return type int

Raises ValueError – If xmin < 1 or If alpha <= 1

Notes
The rejection algorithm generates random values for the power-law distribution in uniformly bounded expected
time dependent on parameters. See\(^1\) for details on its operation.

Examples

```python
>>> nx.zipf_rv(alpha=2, xmin=3, seed=42)
```

References

12.3.5 networkx.utils.random_sequence.random_weighted_sample

random_weighted_sample(mapping, k)
Return k items without replacement from a weighted sample.
The input is a dictionary of items with weights as values.

---

\(^1\) Luc Devroye, Non-Uniform Random Variate Generation, Springer-Verlag, New York, 1986.
12.3.6 networkx.utils.random_sequence.weighted_choice

**weighted_choice**(mapping)

Return a single element from a weighted sample.

The input is a dictionary of items with weights as values.

12.4 Decorators

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<th>Decorator Function</th>
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<td>open_file(path_arg, mode)</td>
<td>Decorator to ensure clean opening and closing of files.</td>
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<tr>
<td>not_implemented_for(*graph_types)</td>
<td>Decorator to mark algorithms as not implemented</td>
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<tr>
<td>nodes_or_number(which_args)</td>
<td>Decorator to allow number of nodes or container of nodes.</td>
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<tr>
<td>preserve_random_state(func)</td>
<td>Decorator to preserve the numpy.</td>
</tr>
<tr>
<td>random_state(random_state_index)</td>
<td>Decorator to generate a numpy.</td>
</tr>
</tbody>
</table>

12.4.1 networkx.utils.decorators.open_file

**open_file**(path_arg, mode='r')

Decorator to ensure clean opening and closing of files.

**Parameters**

- **path_arg**(int) – Location of the path argument in args. Even if the argument is a named positional argument (with a default value), you must specify its index as a positional argument.

- **mode**(str) – String for opening mode.

**Returns** _open_file_ – Function which cleanly executes the io.

**Return type** function

**Examples**

Decorate functions like this:

```python
@open_file(0,'r')
def read_function(pathname):
    pass

@open_file(1,'w')
def write_function(G,pathname):
    pass

@open_file(1,'w')
def write_function(G, pathname='graph.dot')
    pass

@open_file('path', 'w+')
def another_function(arg, **kwargs):
    path = kwargs['path']
    pass
```

12.4. Decorators
12.4.2 networkx.utils.decorators.not_implemented_for

**not_implemented_for(** *graph_types*)

Decorator to mark algorithms as not implemented

**Parameters**

- **graph_types** (*container of strings*) – Entries must be one of ‘directed’, ‘undirected’, ‘multigraph’, ‘graph’.

**Returns**

- **_require** – The decorated function.

**Return type**

**function**

**Raises**

- NetworkXNotImplemented
- If any of the packages cannot be imported

**Notes**

Multiple types are joined logically with “and”. For “or” use multiple @not_implemented_for() lines.

**Examples**

Decorate functions like this:

```python
@not_implemented_for('directed')
def sp_function(G):
    pass

@not_implemented_for('directed','multigraph')
def sp_np_function(G):
    pass
```

12.4.3 networkx.utils.decorators.nodes_or_number

**nodes_or_number** (*which_args*)

Decorator to allow number of nodes or container of nodes.

**Parameters**

- **which_args** (*int or sequence of ints*) – Location of the node arguments in args. Even if the argument is a named positional argument (with a default value), you must specify its index as a positional argument. If more than one node argument is allowed, can be a list of locations.

**Returns**

- **_nodes_or_numbers** – Function which replaces int args with ranges.

**Return type**

**function**

**Examples**

Decorate functions like this:

```python
@nodes_or_number(0)
def empty_graph(nodes):
    pass
```

(continues on next page)
@nodes_or_number([[0,1]])
def grid_2d_graph(m1, m2, periodic=False):
    pass

@nodes_or_number(1)
def full_rary_tree(r, n):
    # r is a number. n can be a number of a list of nodes
    pass

12.4.4 networkx.utils.decorators.preserve_random_state

preserve_random_state(func)
Decorator to preserve the numpy.random state during a function.

Parameters func (function) – function around which to preserve the random state.

Returns wrapper – Function which wraps the input function by saving the state before calling the
function and restoring the function afterward.

Return type function

Examples

Decorate functions like this:

@preserve_random_state
def do_random_stuff(x, y):
    return x + y * numpy.random.random()

Notes

If numpy.random is not importable, the state is not saved or restored.

12.4.5 networkx.utils.decorators.random_state

random_state(random_state_index)
Decorator to generate a numpy.random.RandomState instance.

Argument position random_state_index is processed by create_random_state.

Parameters random_state_index (int) – Location of the random_state argument in args that is to
be used to generate the numpy.random.RandomState instance. Even if the argument is a named
positional argument (with a default value), you must specify its index as a positional argument.

Returns _random_state – Function whose random_state keyword argument is a RandomState in-
stance.

Return type function
12.5 Cuthill-McKee Ordering

Cuthill-McKee ordering of graph nodes to produce sparse matrices

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>cuthill_mckee_ordering(G[, heuristic])</td>
<td>Generate an ordering (permutation) of the graph nodes to make a sparse matrix.</td>
</tr>
<tr>
<td>reverse_cuthill_mckee_ordering(G[, heuristic])</td>
<td>Generate an ordering (permutation) of the graph nodes to make a sparse matrix.</td>
</tr>
</tbody>
</table>

12.5.1 networkx.utils.rcm.cuthill_mckee_ordering

Generate an ordering (permutation) of the graph nodes to make a sparse matrix.

Parameters

- `G (graph)` – A NetworkX graph
- `heuristic (function, optional)` – Function to choose starting node for RCM algorithm. If None a node from a pseudo-peripheral pair is used. A user-defined function can be supplied that takes a graph object and returns a single node.

Returns

- `nodes` – Generator of nodes in Cuthill-McKee ordering.
- `Return type` generator

Examples

```python
>>> from networkx.utils import cuthill_mckee_ordering
>>> G = nx.path_graph(4)
>>> rcm = list(cuthill_mckee_ordering(G))
>>> A = nx.adjacency_matrix(G, nodelist=rcm)
```

Smallest degree node as heuristic function:

---

```python
>>> def smallest_degree(G):
...    return min(G, key=G.degree)
>>> rcm = list(cuthill_mckee_ordering(G, heuristic=smallest_degree))
```

See also:

`reverse_cuthill_mckee_ordering()`

Notes

The optimal solution to the bandwidth reduction is NP-complete\(^2\).

References

12.5.2 `networkx.utils.rcm.reverse_cuthill_mckee_ordering`

`reverse_cuthill_mckee_ordering(G, heuristic=None)`
Generate an ordering (permutation) of the graph nodes to make a sparse matrix.

Uses the reverse Cuthill-McKee heuristic (based on breadth-first search)\(^1\).

Parameters

- **G** *(graph)* – A NetworkX graph
- **heuristic** *(function, optional)* – Function to choose starting node for RCM algorithm. If None a node from a pseudo-peripheral pair is used. A user-defined function can be supplied that takes a graph object and returns a single node.

Returns **nodes** – Generator of nodes in reverse Cuthill-McKee ordering.

Return type **generator**

Examples

```python
>>> from networkx.utils import reverse_cuthill_mckee_ordering
>>> G = nx.path_graph(4)
>>> rcm = list(reverse_cuthill_mckee_ordering(G))
>>> A = nx.adjacency_matrix(G, nodelist=rcm)
```

Smallest degree node as heuristic function:

```python
>>> def smallest_degree(G):
...    return min(G, key=G.degree)
>>> rcm = list(reverse_cuthill_mckee_ordering(G, heuristic=smallest_degree))
```

See also:

`cuthill_mckee_ordering()`


http://doi.acm.org/10.1145/800195.805928
Notes

The optimal solution the the bandwidth reduction is NP-complete\(^2\).

References

12.6 Context Managers

\texttt{reversed(*args, **kwds)}

A context manager for temporarily reversing a directed graph in place.

12.6.1 networkx.utils.contextmanagers.reversed

\texttt{reversed(*args, **kwds)}

A context manager for temporarily reversing a directed graph in place.

This is a no-op for undirected graphs.

Parameters

- G (\textit{graph}) – A NetworkX graph.

**Glossary**

**dictionary**  A Python dictionary maps keys to values. Also known as “hashes”, or “associative arrays” in other programming languages. See [https://docs.python.org/2/tutorial/datastructures.html#dictionaries](https://docs.python.org/2/tutorial/datastructures.html#dictionaries)

**edge**  Edges are either two-tuples of nodes \((u, v)\) or three tuples of nodes with an edge attribute dictionary \((u, v, \text{dict})\).

**ebunch**  An iterable container of edge tuples like a list, iterator, or file.

**edge attribute**  Edges can have arbitrary Python objects assigned as attributes by using keyword/value pairs when adding an edge assigning to the \(G\text{.edges}[u][v]\) attribute dictionary for the specified edge \(u-v\).

**hashable**  An object is hashable if it has a hash value which never changes during its lifetime (it needs a \(_\text{hash}()\) method), and can be compared to other objects (it needs an \(_\text{eq}()\) or \(_\text{cmp}()\) method). Hashable objects which compare equal must have the same hash value.

Hashability makes an object usable as a dictionary key and a set member, because these data structures use the hash value internally.

All of Python’s immutable built-in objects are hashable, while no mutable containers (such as lists or dictionaries) are. Objects which are instances of user-defined classes are hashable by default; they all compare unequal, and their hash value is their \(\text{id}()\).

Definition from [https://docs.python.org/2/glossary.html](https://docs.python.org/2/glossary.html)

**nbunch**  An nbunch is a single node, container of nodes or None (representing all nodes). It can be a list, set, graph, etc.. To filter an nbunch so that only nodes actually in \(G\) appear, use \(G\text{.nbunch\_iter(nbunch)}\).

**node**  A node can be any hashable Python object except None.

**node attribute**  Nodes can have arbitrary Python objects assigned as attributes by using keyword/value pairs when adding a node or assigning to the \(G\text{.nodes}[n]\) attribute dictionary for the specified node \(n\).
This guide can help you start working with NetworkX.

### A.1 Creating a graph

Create an empty graph with no nodes and no edges.

```python
>>> import networkx as nx
>>> G = nx.Graph()
```

By definition, a *Graph* is a collection of nodes (vertices) along with identified pairs of nodes (called edges, links, etc). In NetworkX, nodes can be any hashable object e.g., a text string, an image, an XML object, another Graph, a customized node object, etc.

**Note:** Python’s `None` object should not be used as a node as it determines whether optional function arguments have been assigned in many functions.

### A.2 Nodes

The graph $G$ can be grown in several ways. NetworkX includes many graph generator functions and facilities to read and write graphs in many formats. To get started though we’ll look at simple manipulations. You can add one node at a time,

```python
>>> G.add_node(1)
```

add a list of nodes,

```python
>>> G.add_nodes_from([2, 3])
```

or add any iterable container of nodes. You can also add nodes along with node attributes if your container yields 2-tuples (node, node_attribute_dict). Node attributes are discussed further below.

```python
>>> H = nx.path_graph(10)
>>> G.add_nodes_from(H)
```

Note that $G$ now contains the nodes of $H$ as nodes of $G$. In contrast, you could use the graph $H$ as a node in $G$.

```python
>>> G.add_node(H)
```
The graph $G$ now contains $H$ as a node. This flexibility is very powerful as it allows graphs of graphs, graphs of files, graphs of functions and much more. It is worth thinking about how to structure your application so that the nodes are useful entities. Of course you can always use a unique identifier in $G$ and have a separate dictionary keyed by identifier to the node information if you prefer.

**Note:** You should not change the node object if the hash depends on its contents.

### A.3 Edges

$G$ can also be grown by adding one edge at a time,

```python
>>> G.add_edge(1, 2)
>>> e = (2, 3)
>>> G.add_edge(*e)  # unpack edge tuple*
```

by adding a list of edges,

```python
>>> G.add_edges_from([(1, 2), (1, 3)])
```

or by adding any *ebunch* of edges. An *ebunch* is any iterable container of edge-tuples. An edge-tuple can be a 2-tuple of nodes or a 3-tuple with 2 nodes followed by an edge attribute dictionary, e.g., $(2, 3, \{'\text{weight}': 3.1415\})$. Edge attributes are discussed further below

```python
>>> G.add_edges_from(H.edges)
```

There are no complaints when adding existing nodes or edges. For example, after removing all nodes and edges,

```python
>>> G.clear()
```

we add new nodes/edges and NetworkX quietly ignores any that are already present.

```python
>>> G.add_edges_from([(1, 2), (1, 3)])
>>> G.add_node(1)
>>> G.add_edge(1, 2)
>>> G.add_node("spam")  # adds node "spam"
>>> G.add_nodes_from("spam")  # adds 4 nodes: 's', 'p', 'a', 'm'
>>> G.add_edge(3, 'm')
```

At this stage the graph $G$ consists of 8 nodes and 3 edges, as can be seen by:

```python
>>> G.number_of_nodes()
8
>>> G.number_of_edges()
3
```

We can examine the nodes and edges. Four basic graph properties facilitate reporting: $G$.$\text{nodes}$, $G$.$\text{edges}$, $G$.$\text{adj}$ and $G$.$\text{degree}$. These are set-like views of the nodes, edges, neighbors (adjacencies), and degrees of nodes in a graph. They offer a continually updated read-only view into the graph structure. They are also dict-like in that you can look up node and edge data attributes via the views and iterate with data attributes using methods .items(), .data('span'). If you want a specific container type instead of a view, you can specify one. Here we use lists, though sets, dicts, tuples and other containers may be better in other contexts.
>>> list(G.nodes)
['a', 1, 2, 3, 'spam', 'm', 'p', 's']

>>> list(G.edges)
[(1, 2), (1, 3), (3, 'm')]

>>> list(G.adj[1])  # or list(G.neighbors(1))
[2, 3]

>>> G.degree[1]  # the number of edges incident to 1
2

One can specify to report the edges and degree from a subset of all nodes using an nbunch. An nbunch is any of: None (meaning all nodes), a node, or an iterable container of nodes that is not itself a node in the graph.

>>> G.edges([2, 'm'])
EdgeDataView([(2, 1), ('m', 3)])

>>> G.degree([2, 3])
DegreeView({2: 1, 3: 2})

One can remove nodes and edges from the graph in a similar fashion to adding. Use methods Graph.remove_node(), Graph.remove_nodes_from(), Graph.remove_edge() and Graph.remove_edges_from(), e.g.

>>> G.remove_node(2)

>>> G.remove_nodes_from("spam")

>>> list(G.nodes)
[1, 3, 'spam']

>>> G.remove_edge(1, 3)

When creating a graph structure by instantiating one of the graph classes you can specify data in several formats.

>>> G.add_edge(1, 2)

>>> H = nx.DiGraph(G)  # create a DiGraph using the connections from G

>>> list(H.edges())
[(1, 2), (2, 1)]

>>> edgelist = [(0, 1), (1, 2), (2, 3)]

>>> H = nx.Graph(edgelist)

A.4 What to use as nodes and edges

You might notice that nodes and edges are not specified as NetworkX objects. This leaves you free to use meaningful items as nodes and edges. The most common choices are numbers or strings, but a node can be any hashable object (except None), and an edge can be associated with any object x using G.add_edge(n1, n2, object=x).

As an example, n1 and n2 could be protein objects from the RCSB Protein Data Bank, and x could refer to an XML record of publications detailing experimental observations of their interaction.

We have found this power quite useful, but its abuse can lead to unexpected surprises unless one is familiar with Python. If in doubt, consider using convert_node_labels_to_integers() to obtain a more traditional graph with integer labels.

A.5 Accessing edges and neighbors

In addition to the views Graph.edges(), and Graph.adj(), access to edges and neighbors is possible using subscript notation.
You can get/set the attributes of an edge using subscript notation if the edge already exists.

```python
>>> G[1][3]['color'] = "blue"
>>> G.edges[1, 2]['color'] = "red"
```

Fast examination of all (node, adjacency) pairs is achieved using `G.adjacency()`, or `G.adj.items()`. Note that for undirected graphs, adjacency iteration sees each edge twice.

```python
>>> FG = nx.Graph()
>>> FG.add_weighted_edges_from([(1, 2, 0.125), (1, 3, 0.75), (2, 4, 1.2), (3, 4, 0.375)])
>>> for n, nbrs in FG.adj.items():
... for nbr, eattr in nbrs.items():
... if eattr['weight'] < 0.5: print('(%d, %d, %.3f)' % (n, nbr, eattr['weight']))
(1, 2, 0.125)
(2, 1, 0.125)
(3, 4, 0.375)
(4, 3, 0.375)
```

Convenient access to all edges is achieved with the edges property.

```python
>>> for u, v, wt in FG.edges.data('weight'):
... if wt < 0.5: print('(%d, %d, %.3f)' % (u, v, wt))
(1, 2, 0.125)
(3, 4, 0.375)
```

## A.6 Adding attributes to graphs, nodes, and edges

Attributes such as weights, labels, colors, or whatever Python object you like, can be attached to graphs, nodes, or edges.

Each graph, node, and edge can hold key/value attribute pairs in an associated attribute dictionary (the keys must be hashable). By default these are empty, but attributes can be added or changed using `add_edge`, `add_node` or direct manipulation of the attribute dictionaries named `G.graph`, `G.nodes`, and `G.edges` for a graph `G`.

### A.6.1 Graph attributes

Assign graph attributes when creating a new graph

```python
>>> G = nx.Graph(day="Friday")
>>> G.graph
{'day': 'Friday'}
```

Or you can modify attributes later
A.6.2 Node attributes

Add node attributes using `add_node()`, `add_nodes_from()`, or `G.nodes`

```python
>>> G.add_node(1, time='5pm')
>>> G.add_nodes_from([3], time='2pm')
>>> G.nodes[1]
{'time': '5pm'}
>>> G.nodes[1]['room'] = 714
>>> G.nodes.data()  # NodeDataView({1: {'room': 714, 'time': '5pm'}, 3: {'time': '2pm'}})
```

Note that adding a node to `G.nodes` does not add it to the graph, use `G.add_node()` to add new nodes. Similarly for edges.

A.6.3 Edge Attributes

Add/change edge attributes using `add_edge()`, `add_edges_from()`, or subscript notation.

```python
>>> G.add_edge(1, 2, weight=4.7)
>>> G.add_edges_from([(3, 4), (4, 5)], color='red')
>>> G.add_edges_from([(1, 2, {'color': 'blue'}), (2, 3, {'weight': 8})])
>>> G[1][2]['weight'] = 4.7
>>> G.edges[3, 4]['weight'] = 4.2
```

The special attribute `weight` should be numeric as it is used by algorithms requiring weighted edges.

A.7 Directed graphs

The `DiGraph` class provides additional properties specific to directed edges, e.g., `DiGraph.out_edges()`, `DiGraph.in_degree()`, `DiGraph.predecessors()`, `DiGraph.successors()` etc. To allow algorithms to work with both classes easily, the directed versions of `neighbors()` is equivalent to `successors()` while `degree` reports the sum of `in_degree` and `out_degree` even though that may feel inconsistent at times.

```python
>>> DG = nx.DiGraph()
>>> DG.add_weighted_edges_from([(1, 2, 0.5), (3, 1, 0.75)])
>>> DG.out_degree(1, weight='weight')  # 0.5
>>> DG.degree(1, weight='weight')  # 1.25
>>> list(DG.successors(1))  # [2]
>>> list(DG.neighbors(1))  # [2]
```

Some algorithms work only for directed graphs and others are not well defined for directed graphs. Indeed the tendency to lump directed and undirected graphs together is dangerous. If you want to treat a directed graph as undirected for some measurement you should probably convert it using `Graph.to_undirected()` or with

A.7. Directed graphs
A.8 Multigraphs

NetworkX provides classes for graphs which allow multiple edges between any pair of nodes. The \texttt{MultiGraph} and \texttt{MultiDiGraph} classes allow you to add the same edge twice, possibly with different edge data. This can be powerful for some applications, but many algorithms are not well defined on such graphs. Where results are well defined, e.g., \texttt{MultiGraph.degree()} we provide the function. Otherwise you should convert to a standard graph in a way that makes the measurement well defined.

```python
>>> MG = nx.MultiGraph()
>>> MG.add_weighted_edges_from([(1, 2, 0.5), (1, 2, 0.75), (2, 3, 0.5)])
>>> dict(MG.degree(weight='weight'))
{1: 1.25, 2: 1.75, 3: 0.5}
>>> GG = nx.Graph()
>>> for n, nbrs in MG.adjacency():
...     for nbr, edict in nbrs.items():
...         minvalue = min([d['weight'] for d in edict.values()])
...         GG.add_edge(n, nbr, weight = minvalue)
... >>> nx.shortest_path(GG, 1, 3)
[1, 2, 3]
```

A.9 Graph generators and graph operations

In addition to constructing graphs node-by-node or edge-by-edge, they can also be generated by

1. Applying classic graph operations, such as:

   - \texttt{subgraph(G, nbunch)} - induced subgraph view of \texttt{G} on nodes in \texttt{nbunch}
   - \texttt{union(G1,G2)} - graph union
   - \texttt{disjoint_union(G1,G2)} - graph union assuming all nodes are different
   - \texttt{cartesian_product(G1,G2)} - Cartesin product graph
   - \texttt{compose(G1,G2)} - combine graphs identifying nodes common to both
   - \texttt{complement(G)} - graph complement
   - \texttt{create_empty_copy(G)} - return an empty copy of the same graph \texttt{class}
   - \texttt{convert_to_undirected(G)} - return an undirected representation of \texttt{G}
   - \texttt{convert_to_directed(G)} - return a directed representation of \texttt{G}

2. Using a call to one of the classic small graphs, e.g.,

   ```python
   >>> petersen = nx.petersen_graph()
   >>> tutte = nx.tutte_graph()
   >>> maze = nx.sedgewick_maze_graph()
   >>> tet = nx.tetrahedral_graph()
   ```

3. Using a (constructive) generator for a classic graph, e.g.,

   ```python
   >>> K_5 = nx.complete_graph(5)
   >>> K_3_5 = nx.complete_bipartite_graph(3, 5)
   >>> barbell = nx.barbell_graph(10, 10)
   >>> lollipop = nx.lollipop_graph(10, 20)
   ```
4. Using a stochastic graph generator, e.g.,

```python
>>> er = nx.erdos_renyi_graph(100, 0.15)
>>> ws = nx.watts_strogatz_graph(30, 3, 0.1)
>>> ba = nx.barabasi_albert_graph(100, 5)
>>> red = nx.random_lobster(100, 0.9, 0.9)
```

5. Reading a graph stored in a file using common graph formats, such as edge lists, adjacency lists, GML, GraphML, pickle, LEDA and others.

```python
>>> nx.write_gml(red, "path.to.file")
>>> mygraph = nx.read_gml("path.to.file")
```

For details on graph formats see Reading and writing graphs and for graph generator functions see Graph generators

### A.10 Analyzing graphs

The structure of $G$ can be analyzed using various graph-theoretic functions such as:

```python
>>> G = nx.Graph()
>>> G.add_edges_from([(1, 2), (1, 3)])
>>> G.add_node("spam")  # adds node "spam"
>>> list(nx.connected_components(G))
[set([1, 2, 3]), set(['spam'])]
>>> sorted(d for n, d in G.degree())
[0, 1, 1, 2]
>>> nx.clustering(G)
{1: 0, 2: 0, 3: 0, 'spam': 0}
```

Some functions with large output iterate over (node, value) 2-tuples. These are easily stored in a `dict` structure if you desire.

```python
>>> sp = dict(nx.all_pairs_shortest_path(G))
>>> sp[3]
{1: [3, 1], 2: [3, 1, 2], 3: [3]}
```

See Algorithms for details on graph algorithms supported.

### A.11 Drawing graphs

NetworkX is not primarily a graph drawing package but basic drawing with Matplotlib as well as an interface to use the open source Graphviz software package are included. These are part of the networkx.drawing module and will be imported if possible.

First import Matplotlib’s plot interface (pylab works too)

```python
>>> import matplotlib.pyplot as plt
```

You may find it useful to interactively test code using `ipython -pylab`, which combines the power of ipython and matplotlib and provides a convenient interactive mode.

To test if the import of networkx.drawing was successful draw $G$ using one of
>>> G = nx.petersen_graph()
>>> plt.subplot(121)
<matplotlib.axes._subplots.AxesSubplot object at ...>
>>> nx.draw(G, with_labels=True, font_weight='bold')
>>> plt.subplot(122)
<matplotlib.axes._subplots.AxesSubplot object at ...>
>>> nx.draw_shell(G, nlist=[range(5, 10), range(5)], with_labels=True, font_weight='bold')

when drawing to an interactive display. Note that you may need to issue a Matplotlib

>>> plt.show()

command if you are not using matplotlib in interactive mode (see Matplotlib FAQ).

>>> options = {
...    'node_color': 'black',
...    'node_size': 100,
...    'width': 3,
...}
>>> plt.subplot(221)
<matplotlib.axes._subplots.AxesSubplot object at ...>
>>> nx.draw_random(G, **options)
>>> plt.subplot(222)
<matplotlib.axes._subplots.AxesSubplot object at ...>

(continues on next page)
You can find additional options via `draw_networkx()` and layouts via `layout`. You can use multiple shells with `draw_shell()`.

```python
>>> G = nx.dodecahedral_graph()
>>> shells = [[2, 3, 4, 5, 6], [8, 1, 0, 19, 18, 17, 16, 15, 14, 7], [9, 10, 11, 12, 13]]
>>> nx.draw_shell(G, nlist=shells, **options)
```
To save drawings to a file, use, for example

```python
>>> nx.draw(G)
>>> plt.savefig("path.png")
```

writes to the file `path.png` in the local directory. If Graphviz and PyGraphviz or pydot, are available on your system, you can also use `nx_agraph.graphviz_layout(G)` or `nx_pydot.graphviz_layout(G)` to get the node positions, or write the graph in dot format for further processing.

```python
>>> from networkx.drawing.nx_pydot import write_dot
>>> pos = nx.nx_agraph.graphviz_layout(G)
>>> nx.draw(G, pos=pos)
>>> write_dot(G, 'file.dot')
```

See *Drawing* for additional details.

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