Chapter 13: Graph construction and management in Python

NetworkX is a Python package for the creation, manipulation, and study of the structure, dynamics, and functions of complex networks. It is usually imported with the *nx* abbreviation.

How to install networkx?

We need to install the networkx package.
Note: if you have installed geopandas, you most likely also installed networkx already, as one of its dependency.

Anaconda - Platform independent

If you have Anaconda installed, open the *Anaconda Prompt* and type in:

```
conda install -c conda-forge networkx
```

Python Package Installer (pip) - Linux

If you have standalone Python3 and Jupyter Notebook install on Linux, open a command prompt / terminal and type in:

```
pip3 install networkx
```

How to use networkx?

The netwrokx package is a module which you can simply import. It is usually aliased with the `nx` abbreviation:

```python
import networkx as nx
```

Graph creation

NetworkX supports 4 type of graphs:

- undirected, simple graphs: `Graph`
- directed simple graphs: `DiGraph`
- undirected graph with parallel edges: `MultiGraph`
- directed graph with parallel edges: `MultiDiGraph`

Creation of a new, empty graph is straightforward:

In [1]:

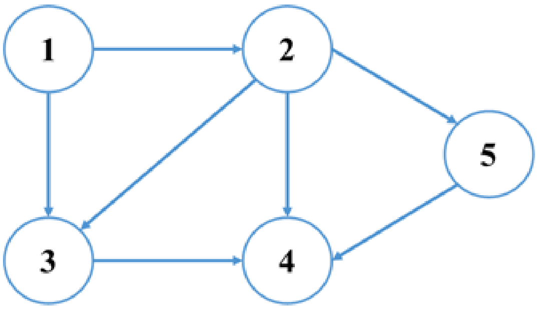
```
import networkx as nx
graph = nx.Graph() # undirected, simple graph
```

Representation

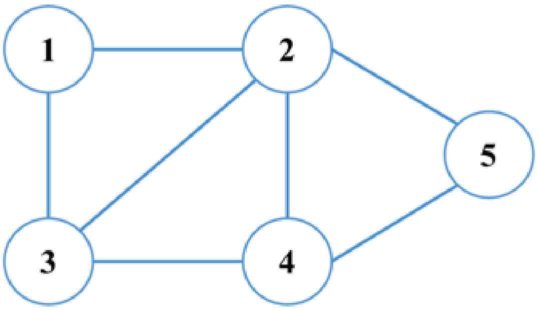
To represent the graphs, two data structures as very common practices are well-known. One has a purely arithmetic representation (*adjacency matrix*), and the other has a mixed arithmetic and chain representation (*edge list* or *neighborhood list*).

Adjacency matrix representation

In graph theory and computer science, an adjacency matrix is a square matrix. Its elements indicate whether pairs of vertices are adjacent in the graph or not.



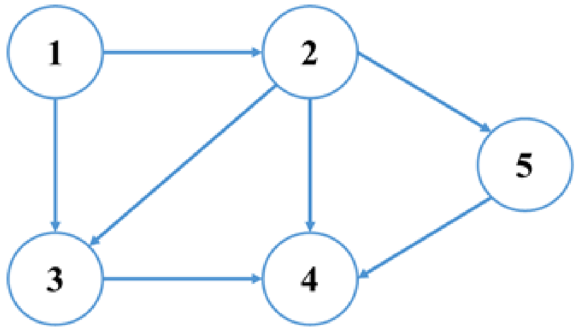
$$\begin{pmatrix} 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{pmatrix}$$

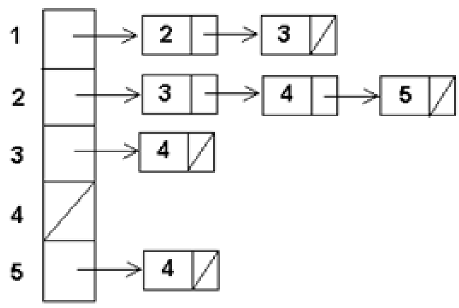


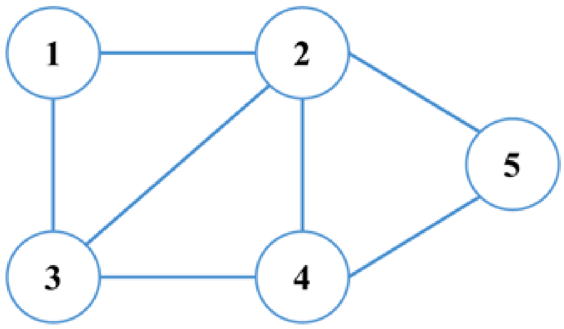
$$\begin{pmatrix} 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 \end{pmatrix}$$

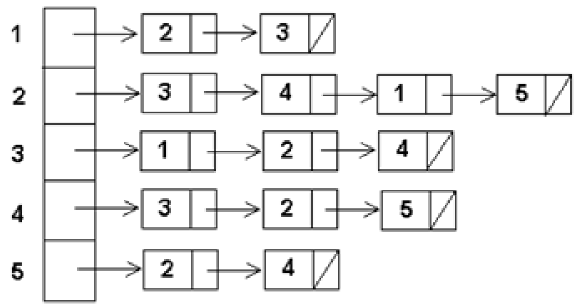
Edge list representation

The edge list is a data structure used to represent a graph as a list of its edges for each vertices. The internal data structures of *NetworkX* is based on the *adjacency list* representation and implemented using Python dictionary data structures.









Building a graph from scratch

We can add nodes and edges to a graph:

In [2]:

```
graph.add_node(1)
graph.add_node(2)
graph.add_node(3)
graph.add_node(4)
graph.add_node(5)
graph.add_node(6)
graph.add_node(7)
graph.add_node(8)
```

In [3]:

```
graph.add_edge(1, 2)
graph.add_edge(1, 3)
graph.add_edge(1, 4)
graph.add_edge(2, 3)
graph.add_edge(2, 5)
graph.add_edge(2, 6)
graph.add_edge(3, 6)
graph.add_edge(4, 5)
graph.add_edge(4, 7)
```

Adding an edge to a non-existing node will also create that particular node:

In [4]:

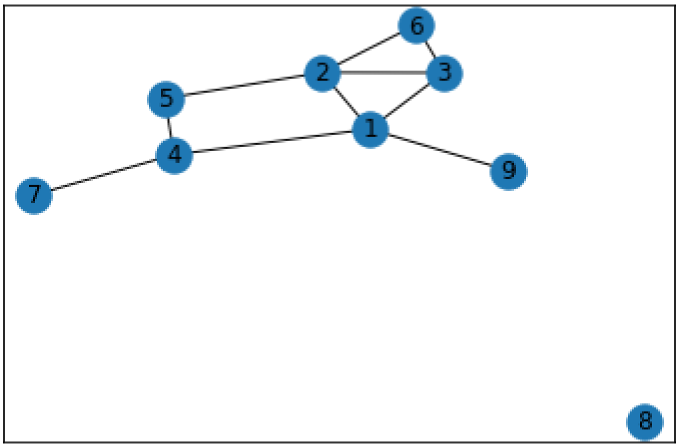
```
graph.add_edge(1, 9)
```

Graph visualization with Matplotlib

NetworkX has **tight integration** with *matplotlib*, therefore visualization of a graph can be done easily.

In [5]:

```
import matplotlib.pyplot as plt

# Special Jupyter Notebook command, so the plots by matplotlib will be displayed
 inside the Jupyter Notebook
%matplotlib inline

nx.draw_networkx(graph)
plt.show()
```



Building a graph from a *pandas* DataFrame

Let's use the following basic dataset of airroutes flight data:

1. From city
2. To city
3. Distance

The dataset is given in the `flights.csv` file in the `data` folder. The used delimiter is the semicolon (`;`) character.

Parse the CSV file into a *pandas* DataFrame:

In [6]:

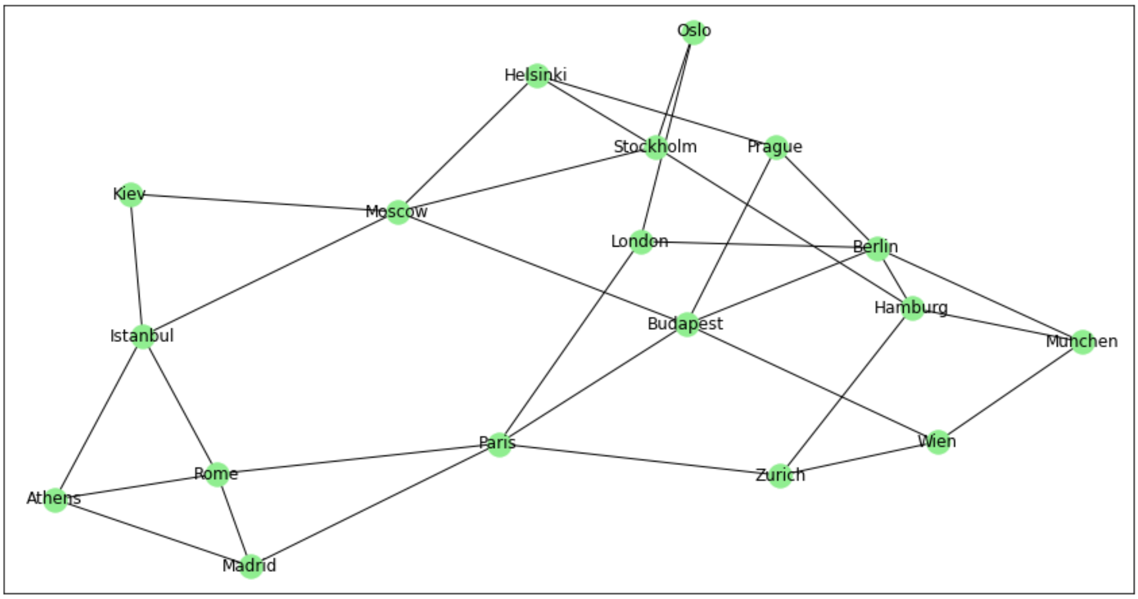
```
import pandas as pd

flight_table = pd.read_csv('../data/flights.csv', delimiter = ';')
display(flight_table)
```

	From city	To city	Distance
0	London	Paris	342
1	London	Berlin	932
2	London	Oslo	1153
3	Paris	Zurich	488
4	Paris	Budapest	1244
...	...	...	...
27	Athens	Istanbul	562
28	Kiev	Istanbul	1056
29	Istanbul	Moscow	1755
30	Rome	Athens	1051
31	Kiev	Moscow	755

NetworkX has a **from** and **to** conversion for *pandas* DataFrames. Assuming all airroutes are bi-directional, build an undirected graph:

In [7]:

```
flight_graph = nx.from_pandas_edgelist(flight_table, 'From city', 'To city')
plt.figure(figsize=[15,8])
nx.draw_networkx(flight_graph, node_color = 'lightgreen')
plt.show()
```



You can define the type of the graph with the optional `create_using` parameter. Its default value is `Graph`.

```
nx.from_pandas_edgelist(flight_table, 'From city', 'To city', create_usin
g = nx.DiGraph)
```

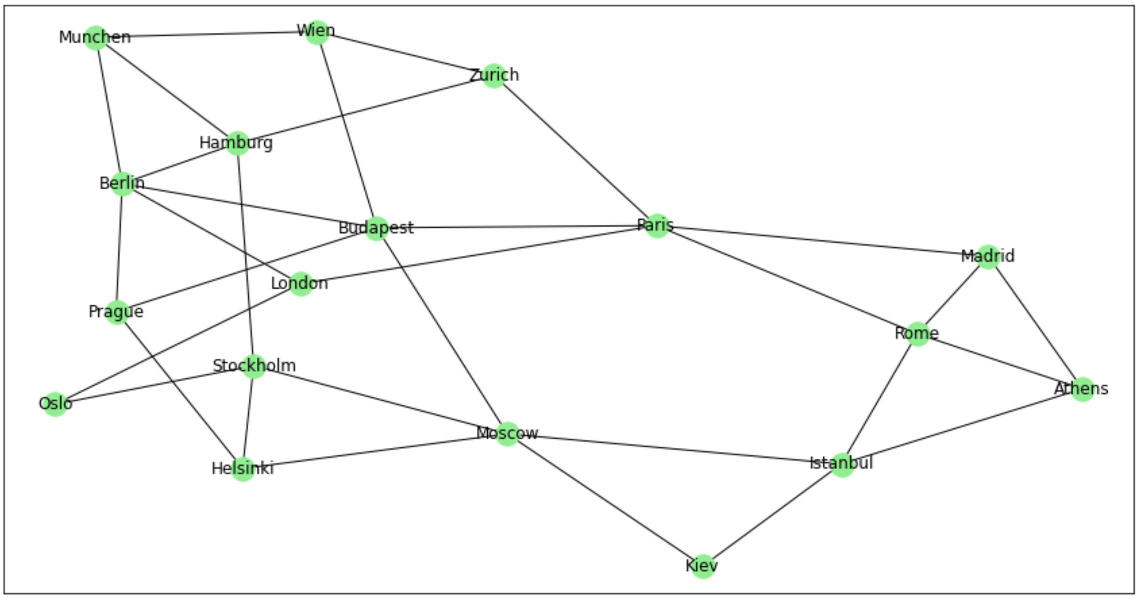
Building a graph from a CSV file *(optional)*

As an alternative solution a CSV file can be processed line-by-line with the built-in **csv** Python package:

In [8]:

```
import csv

flight_graph = nx.Graph()

csv_file = open('../data/flights.csv')
csv_reader = csv.reader(csv_file, delimiter=';')
next(csv_reader, None) # skip header line
for row in csv_reader:
    print('Reading flight {0} <=> {1}, distance: {2}km'.format(row[0], row[1], r
ow[2]))
    flight_graph.add_edge(row[0], row[1])
csv_file.close()

plt.figure(figsize=[15,8])
nx.draw_networkx(flight_graph, node_color = 'lightgreen')
plt.show()
```

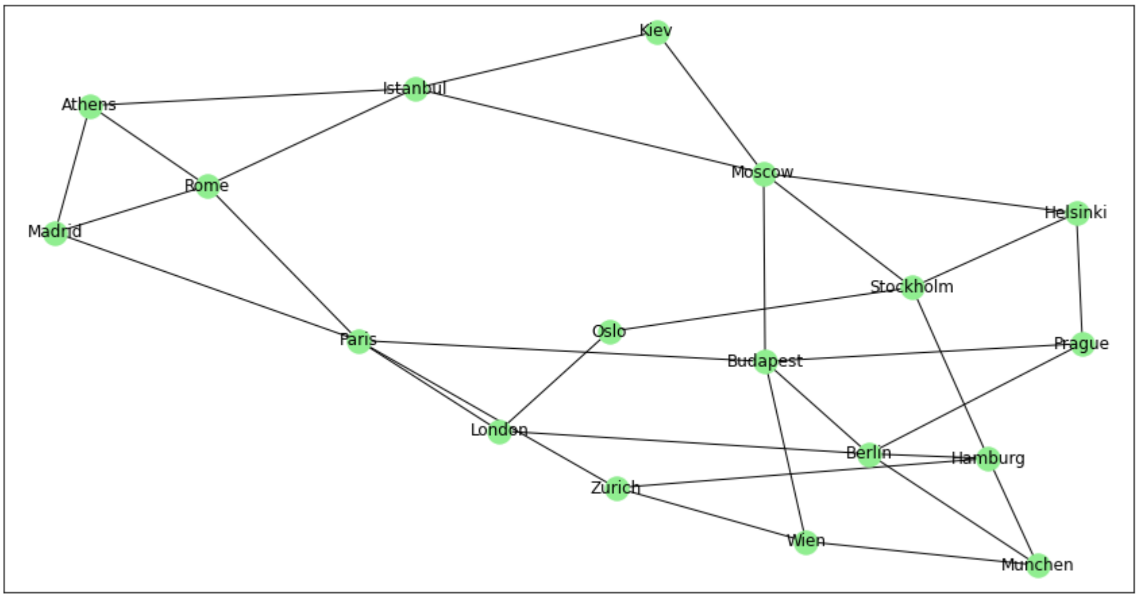
```
Reading flight London <=> Paris, distance: 342km
Reading flight London <=> Berlin, distance: 932km
Reading flight London <=> Oslo, distance: 1153km
Reading flight Paris <=> Zurich, distance: 488km
Reading flight Paris <=> Budapest, distance: 1244km
...
Reading flight Athens <=> Istanbul, distance: 562km
Reading flight Kiev <=> Istanbul, distance: 1056km
Reading flight Istanbul <=> Moscow, distance: 1755km
Reading flight Rome <=> Athens, distance: 1051km
Reading flight Kiev <=> Moscow, distance: 755km
```



Closing an opened file is easy to forget and a common programmer mistake. Use the `with` statement, which will automatically close the file (if it was successfully opened):

In [9]:

```
flight_graph = nx.Graph()

with open('../data/flights.csv') as csv_file:
    csv_reader = csv.reader(csv_file, delimiter=';')
    next(csv_reader, None) # skip header line
    for row in csv_reader:
        #print('Reading flight {0} <=> {1}, distance: {2}km'.format(row[0], row
[1], row[2]))
        flight_graph.add_edge(row[0], row[1])

plt.figure(figsize=[15,8])
nx.draw_networkx(flight_graph, node_color = 'lightgreen')
plt.show()
```



Analyzing the graph

Querying the size and degree information

In [10]:

```
print('Number of nodes: {0}'.format(flight_graph.order()))
print('Number of edges:{0}'.format(flight_graph.size()))
print('Degrees of the nodes: {0}'.format(flight_graph.degree()))
```

```
Number of nodes: 18
Number of edges:32
Degrees of the nodes: [('London', 3), ('Paris', 5), ('Berlin', 5),
('Oslo', 2), ('Zurich', 3), ('Budapest', 5), ('Rome', 4), ('Madrid',
3), ('Athens', 3), ('Stockholm', 4), ('Helsinki', 3), ('Moscow', 5),
('Prague', 3), ('Hamburg', 4), ('Munchen', 3), ('Wien', 3), ('Istanb
ul', 4), ('Kiev', 2)]
```

For *directed graphs*, there is also `in_degree` and `out_degree` defined.

Iterate through the nodes

In [11]:

```
for node in flight_graph.nodes:
    print(node)
```

```
London
Paris
Berlin
Oslo
Zurich
Budapest
Rome
Madrid
Athens
Stockholm
Helsinki
Moscow
Prague
Hamburg
Munchen
Wien
Istanbul
Kiev
```

Note: iterating through the graph itself (`flight_graph` *) is the same.*

Iterate through the edges

In [12]:

```
for from_node, to_node in flight_graph.edges:
    print("{0} <=> {1}".format(from_node, to_node))
```

```
London <=> Paris
London <=> Berlin
London <=> Oslo
Paris <=> Zurich
Paris <=> Budapest
...
Moscow <=> Istanbul
Moscow <=> Kiev
Hamburg <=> Munchen
Munchen <=> Wien
Istanbul <=> Kiev
```

Query the neighbors of a node

In [13]:

```
for neighbor in flight_graph.neighbors('Budapest'):
    print(neighbor)
```

```
Paris
Berlin
Wien
Prague
Moscow
```

Pay attention that it is written as `neighbors` (American English) and *NOT* `neighbours` (British English).

Check node and edge existence

In [14]:

```
if flight_graph.has_node('Budapest'):
    print('The Budapest node exists.')
if flight_graph.has_edge('Budapest', 'Paris'):
    print('The Budapest <=> Paris edge exists.')
```

```
The Budapest node exists.
The Budapest <=> Paris edge exists.
```

Weighted graphs

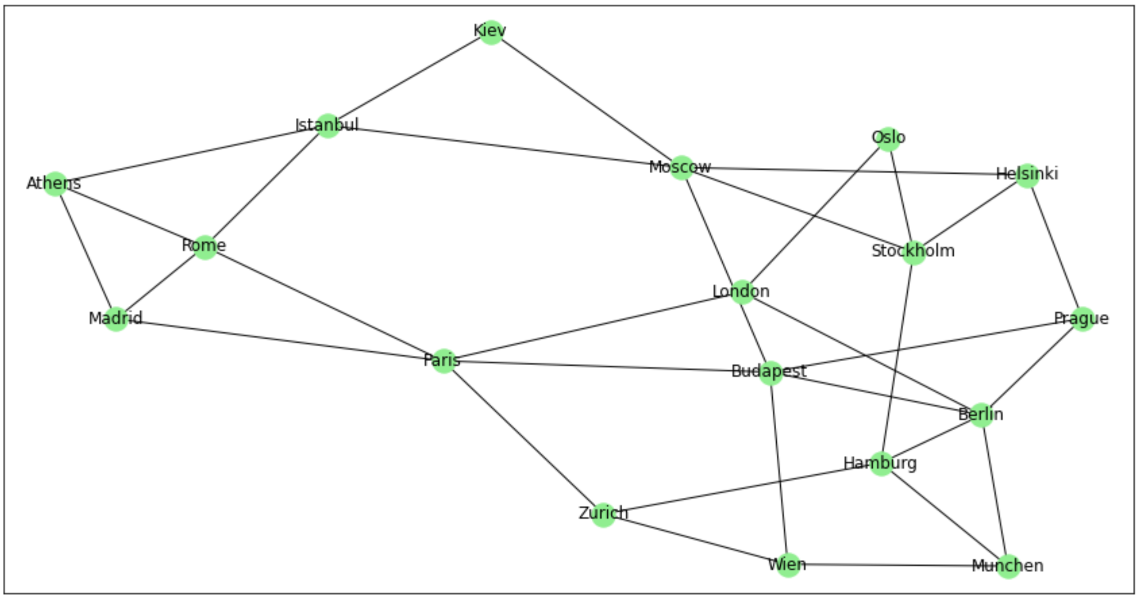
Attributes (metadata) can be assigned to the nodes and edges of a graph.

Building weighted graphs

When creating the graph from a *pandas* DataFrame, the 4th parameter of the `from_pandas_edgelist` function defines which *Series* (columns) of the *DataFrame* shall be added to the edges as attributes. If `True` , all the remaining columns will be added. If `None` , no edge attributes are added to the graph. Its default value is `None` .

In [15]:

```
flight_graph = nx.from_pandas_edgelist(flight_table, 'From city', 'To city', ['D
istance'])
plt.figure(figsize=[15,8])
nx.draw_networkx(flight_graph, node_color = 'lightgreen')
plt.show()
```



Optional: when building a graph "manually", the node and edge attributes can be passed to the `add_node` an `add_edge` methods.

In [16]:

```
flight_graph = nx.Graph()

with open('../data/flights.csv') as csv_file:
    csv_reader = csv.reader(csv_file, delimiter=';')
    next(csv_reader, None) # skip header line
    for row in csv_reader:
        print('Reading flight {0} <=> {1}, distance: {2}km'.format(row[0], row[1
], row[2]))
        flight_graph.add_edge(row[0], row[1], dist = row[2])
```

```
Reading flight London <=> Paris, distance: 342km
Reading flight London <=> Berlin, distance: 932km
Reading flight London <=> Oslo, distance: 1153km
Reading flight Paris <=> Zurich, distance: 488km
Reading flight Paris <=> Budapest, distance: 1244km
...
Reading flight Athens <=> Istanbul, distance: 562km
Reading flight Kiev <=> Istanbul, distance: 1056km
Reading flight Istanbul <=> Moscow, distance: 1755km
Reading flight Rome <=> Athens, distance: 1051km
Reading flight Kiev <=> Moscow, distance: 755km
```

Query the edge metadata

The metadata, called the *weight* of an edge can be queried then:

In [17]:

```
print('Metadata for the Budapest <=> Paris edge: {0}'.format(flight_graph['Budap
est']['Paris']))
print('Metadata for all edges from Budapest: {0}'.format(flight_graph['Budapest'
]))
```

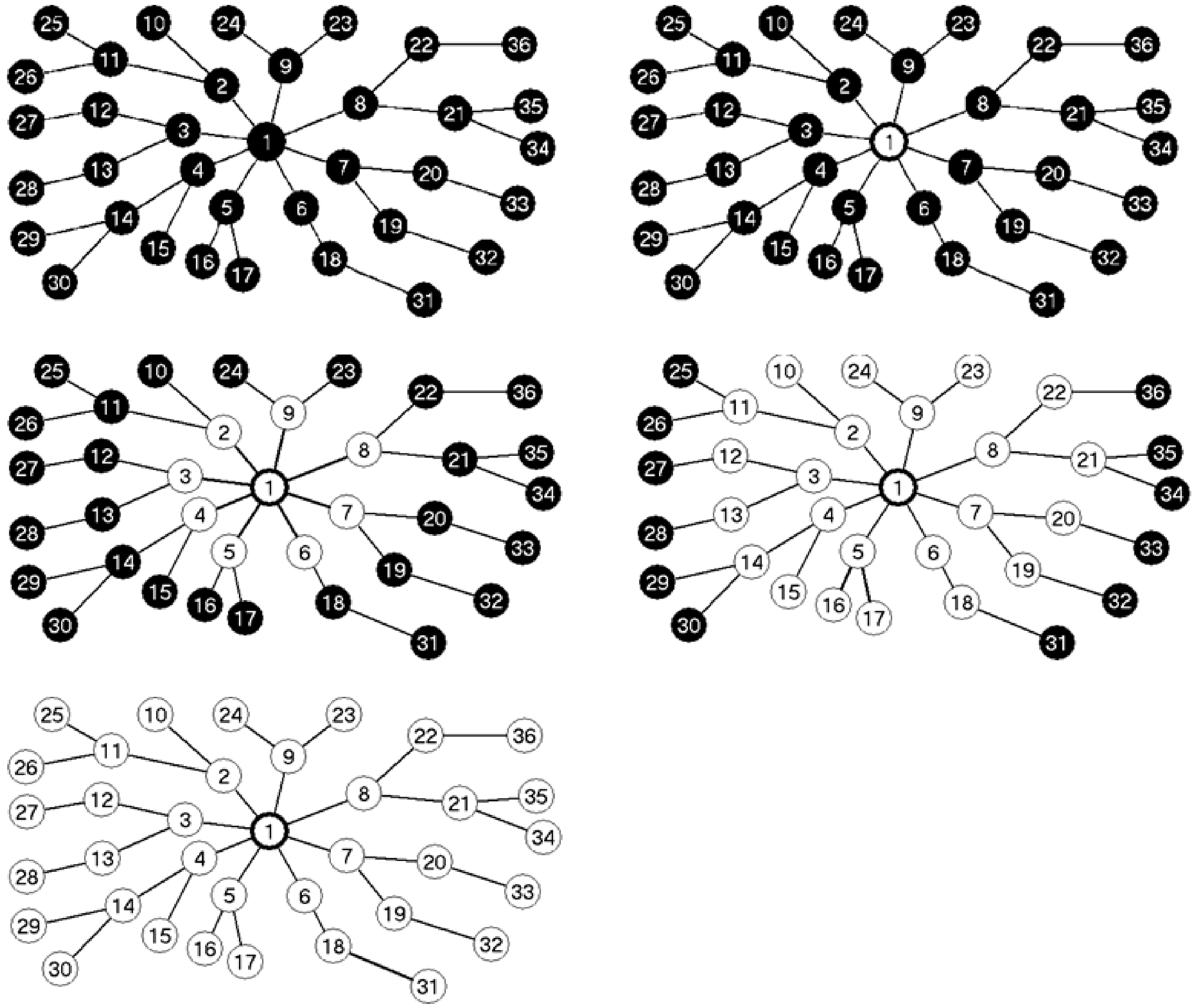
```
Metadata for the Budapest <=> Paris edge: {'dist': '1244'}
Metadata for all edges from Budapest: {'Paris': {'dist': '1244'}, 'B
erlin': {'dist': '688'}, 'Wien': {'dist': '214'}, 'Prague': {'dist':
'444'}, 'Moscow': {'dist': '1569'}}
```

Further readings

- Check out the official NetworkX tutorial (https://networkx.github.io/documentation/stable/tutorial.html).
- Browse the official NetworkX reference (https://networkx.github.io/documentation/stable/reference/index.html).

Breadth-first search

Breadth-first search (*BFS*) is an algorithm for traversing or searching a graph. It starts at some arbitrary node of a graph, and explores all the neighbour nodes at the present depth prior to moving on to the nodes at the next depth level.



The breadth-first search traversal can be implemented with a *queue* data structure (see [Chapter 7 (07_collections.pdf#Queues)](07_collections.pdf#Queues)).
As a showcase, let's request a starting city from the user and a number of maximum flights. Calculate which cities can be reached! Handle the case of a not existing starting city.

In [18]:

```python
from collections import deque

start_city = input('Start city: ')
flight_count = int(input('Max number of flights: '))

# Check existence of start city
if flight_graph.has_node(start_city):
    ready_list = []
    process_queue = deque([(start_city, 0)])

    # Process until queue is empty
    while len(process_queue) > 0:
        # Move first item of process queue to ready list
        process_item = process_queue.popleft()
        process_city, process_dist = process_item
        ready_list.append(process_item)

        # NOTE: if process_dist > flight_count, we can halt the algorithm here,
        # all reachable cities are in the ready list
        #if process_dist > flight_count:
        #    break

        # "Expand" the processed node: add its neighbors to the process queue
        for neighbor_city in flight_graph.neighbors(process_city):
            # Only add neighbors which are not already in the ready list or the
 process_queue
            found = (neighbor_city in [city for city, dist in process_queue] or
                     neighbor_city in [city for city, dist in ready_list])

            if not found:
                process_queue.append((neighbor_city, process_dist + 1))

    # Display results
    for city, dist in ready_list:
        if dist <= flight_count:
            print(city)
else:
    print('{0} city is unknown' % start_city)
```

```
Budapest
Paris
Berlin
Wien
Prague
...
Stockholm
Istanbul
Kiev
Oslo
Athens
```

NetworkX contains several [traversal algorithms (https://networkx.github.io/documentation/stable/reference/algorithms/traversal.html)](https://networkx.github.io/documentation/stable/reference/algorithms/traversal.html) out of the box, so we don't need to reimplement them.

In [19]:

```
start_city = input('Start city: ')
flight_count = int(input('Max number of flights: '))

# Check existence of start city
if flight_graph.has_node(start_city):
    reachable_cities = [ start_city ]

    # Do breadth first search
    successors = nx.bfs_successors(flight_graph, start_city, flight_count - 1)
    for item in successors:
        print('{0} -> {1}'.format(item[0], item[1]))
        reachable_cities += item[1]

    print('Reachable cities: {0}'.format(reachable_cities))
else:
    print('{0} city is unknown'.format(start_city))
```

```
Budapest -> ['Paris', 'Berlin', 'Wien', 'Prague', 'Moscow']
Paris -> ['London', 'Zurich', 'Rome', 'Madrid']
Berlin -> ['Hamburg', 'Munchen']
Prague -> ['Helsinki']
Moscow -> ['Stockholm', 'Istanbul', 'Kiev']
Reachable cities: ['Budapest', 'Paris', 'Berlin', 'Wien', 'Prague',
'Moscow', 'London', 'Zurich', 'Rome', 'Madrid', 'Hamburg', 'Munche
n', 'Helsinki', 'Stockholm', 'Istanbul', 'Kiev']
```