

# APPLICATIONS



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# NetworkX

## Applications of Data Science - Class 8

Giora Simchoni

[gsimchoni@gmail.com](mailto:gsimchoni@gmail.com) and add #dsapps in subject

Stat. and OR Department, TAU

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# Why NetworkX?

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# Pros and Cons of NetworkX

## Pros:

- Maintained!
- Friendly: Community, Docs, Installation (as opposed to `igraph`)
- Relatively easy interface (as opposed to `igraph`)
- Speaks pandas, numpy and other important python tools
- Nodes can be anything, including python objects

## Cons:

- Slow, probably not for large networks (as opposed to `igraph`, `graph-tool`)
- Unimpressive viz (as opposed to Gephi, `ggraph`, others)
- Not the most comprehensive algorithms selection

# Creating a Graph(): Manually

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# Four types of Graph objects

Undirected:

```
import networkx as nx  
  
G = nx.Graph()
```

Directed:

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

Multiedge undirected:

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

Multiedge directed:

```
G = nx.MultiDiGraph()
```

# Add Nodes

One or more nodes:

```
G = nx.Graph()  
G.add_node('John')  
G.add_nodes_from(['Paul', 'George', 'Ringo'])
```

Watch a Graph's nodes:

```
G.nodes
```

```
## NodeView(['John', 'Paul', 'George', 'Ringo'])
```

Print nicer as a list:

```
list(G.nodes)
```

```
## ['John', 'Paul', 'George', 'Ringo']
```

# Add Edges

One or more edges:

```
G.add_edge('John', 'Paul')
G.add_edges_from([('Paul', 'George'), ('John', 'Ringo')])
```

Surprisingly, this would also work:

```
G.add_edge('John', 'Brian')
```

Watch a Graph's edges:

```
print(list(G.edges))
```

```
## [('John', 'Paul'), ('John', 'Ringo'), ('John', 'Brian'), ('Paul', 'George'), ('George', 'Brian'), ('Ringo', 'Brian')]
```

# Remove nodes or edges

```
G.remove_node('Brian')
```

Did NetworkX bother to remove the edge as well?

```
print(list(G.edges))
```

```
## [('John', 'Paul'), ('John', 'Ringo'), ('Paul', 'George')]
```

Remove an edge, remove from a list:

```
G.remove_edge('Paul', 'John') # why did it work?  
G.remove_nodes_from(['John', 'George'])
```

Break the Beatles altogether:

```
G.clear()
```

# Good to know

- Adding an edge also adds its nodes if they didn't exist before
- Adding a duplicate node/edge is ignored unless `MultiGraph()`
- Removing an edge does not remove its nodes
- Removing a node removes all edges to/from it
- Removing a non-existent node/edge raises an error unless it is part of a list in which case - ignored

# Nodes and Edges Attributes

While adding to Graph:

```
G.add_node('Ringo', alive=True)
G.add_nodes_from([('George', {'alive': False}), ('John', {'alive': False}),
# can also do: G.add_nodes_from(['George', 'John'], alive=False)
G.add_edge('John', 'Paul', year=1957)
G.add_edges_from([('Ringo', 'John'), ('Ringo', 'Paul'), ('Ringo', 'George')])
```

Watch attributes with the `nodes()` and `edges()` methods:

```
print(G.nodes(data=True))
```

```
## [ ('Ringo', {'alive': True}), ('George', {'alive': False}), ('John', {'alive': False}) ]
```

```
print(G.nodes(data='alive'))
```

```
## [ ('Ringo', True), ('George', False), ('John', False), ('Paul', None) ]
```

# Nodes and Edges Attributes

Setting an attribute of an existing node/edge through the `nodes` and `edges` dictionary attributes:

```
print(G.nodes['Paul'])
```

```
## { }
```

```
G.nodes['Paul']['alive'] = True #?
```

```
G.add_edge('John', 'George')
G.edges[('John', 'George')]['year'] = 1958
```

As a dictionary you can also delete an attribute this way:

```
del G.nodes['Paul']['alive']
del G.edges[('John', 'George')]['year']
```

# Nodes and Edges Attributes

Finally you can set an attribute from a simple dictionary:

```
year_met = {  
    ('John', 'Paul'): 1957,  
    ('Paul', 'Ringo'): 1960,  
    ('Paul', 'George'): 1958,  
    ('John', 'George'): 1958  
}  
nx.set_edge_attributes(G, year_met, 'year')
```

Or multiple attributes with a nested dictionary:

```
nodeAttrs = {  
    'John': {'alive': False, 'born': 1940},  
    'Paul': {'alive': True, 'born': 1942},  
    'George': {'alive': False, 'born': 1943},  
    'Ringo': {'alive': True, 'born': 1940}  
}  
nx.set_node_attributes(G, nodeAttrs)
```

# Good to have

The edge attribute `weight` is so important it got its own method:

```
G = nx.Graph()  
G.add_weighted_edges_from([(0, 1, 3.0), (1, 2, 7.5)])
```

Quick methods to know:

```
print(G.number_of_nodes())
```

```
## 3
```

```
print(G.number_of_edges())
```

```
## 2
```

```
print(G.is_directed())
```

```
## False
```

# Good to have

```
print(G.has_node(3))  
  
## False  
  
print(G.has_edge(0, 1))  
  
## True  
  
print(G.subgraph([0, 1]).number_of_edges())  
  
## 1  
  
print(list(G.neighbors(1)))  
  
## [0, 2]
```

# What about DiGraph ()?

Convert an undirected graph to a directed graph:

```
D = nx.DiGraph(G)
```

Edges direction matters:

```
D.add_edge(2, 3, weight=10.0)  
print(D.has_edge(2, 3))
```

```
## True
```

```
print(D.has_edge(3, 2))
```

```
## False
```

Other than that...

# Visualize a Graph(): matplotlib

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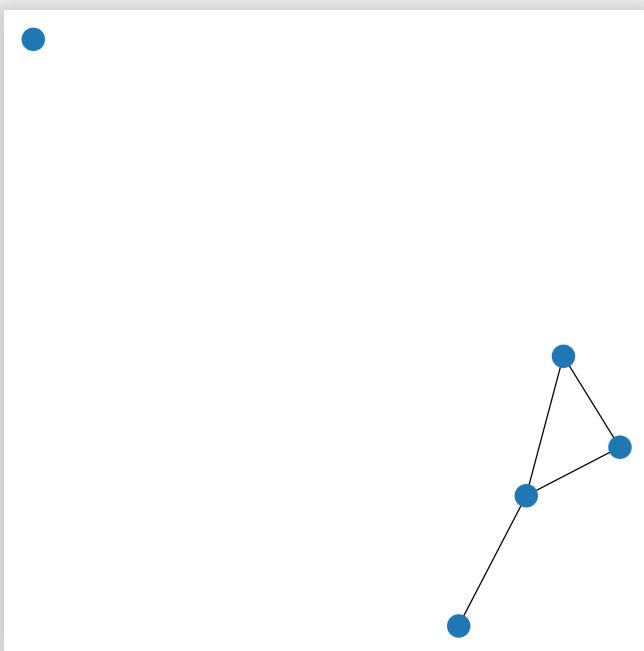
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# `draw()`: The very basic

```
import matplotlib.pyplot as plt

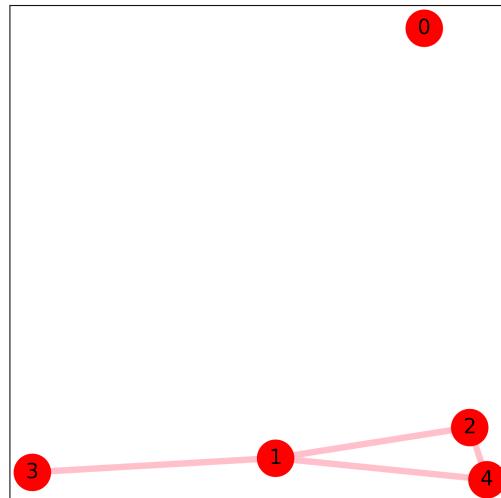
G = nx.erdos_renyi_graph(n=5, p=0.6) # a.k.a binomial_graph()

nx.draw(G)
plt.show()
```



## `draw_networkx()`: Some more options

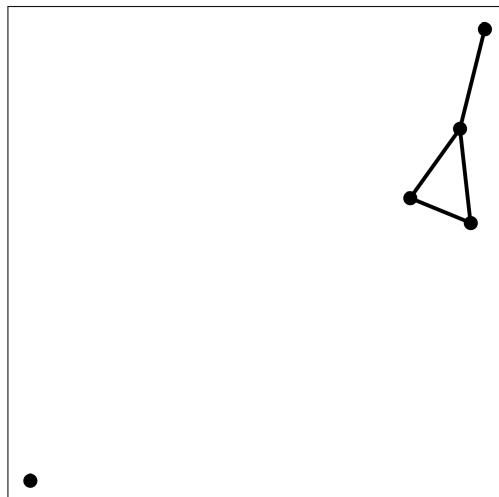
```
nx.draw_networkx(G, node_size=800, node_color='red', edge_color='pink',
                  width=5, font_size=16)
plt.show()
```



You may like the unpacking a dictionary option better:

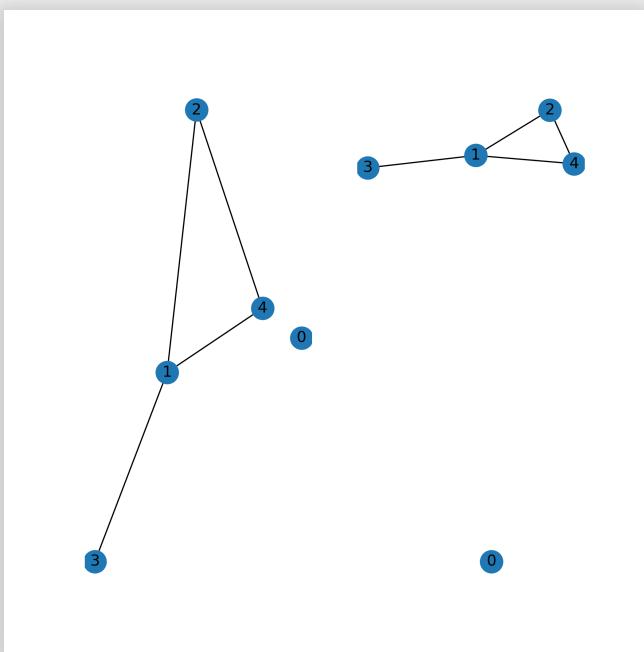
```
options = {
    'node_color': 'black',
    'node_size': 100,
    'width': 3,
}

nx.draw_networkx(G, **options)
plt.show()
```



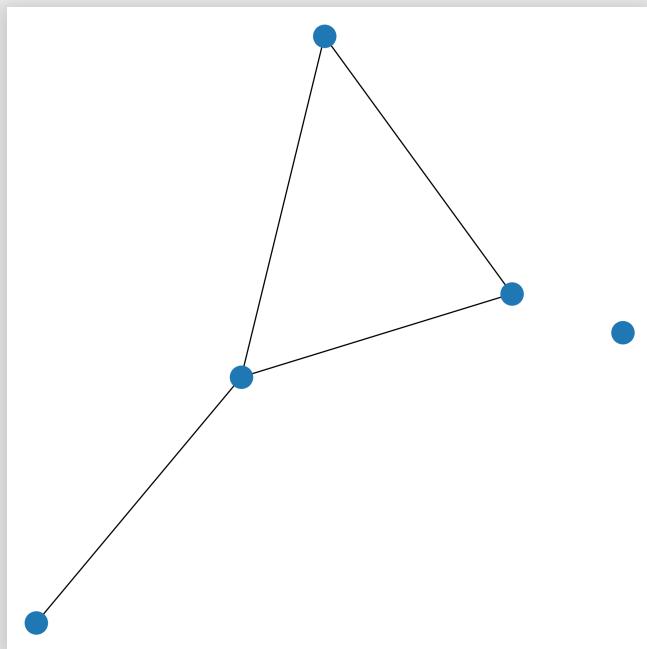
# Layouts Galore

```
plt.subplot(121)
limits = plt.axis('off')
nx.draw_networkx(G, pos=nx.kamada_kawai_layout(G) )
plt.subplot(122)
limits = plt.axis('off')
nx.draw_networkx(G, pos=nx.fruchterman_reingold_layout(G) )
plt.show()
```



# Use a Layout directly

```
nx.draw_kamada_kawai(G)  
plt.show()
```



# For nicer graphs go to...

- [Grave](#)?
- [nxviz](#)?
- [Plotly](#) (interactive graphs for Python or R)
- [Gephi](#) (a Desktop app, neither R nor Python but both export to Gephi format)
- [d3](#) (JS delight)
- [ggraph](#) (R)?

# Create a Graph(): In Real Life

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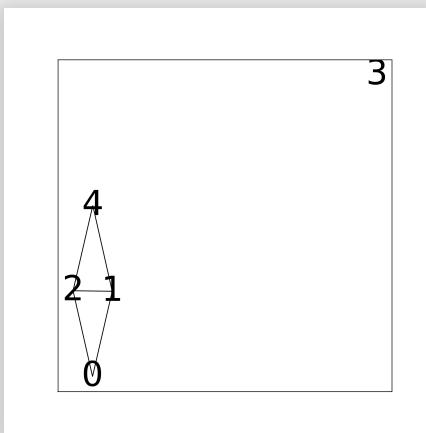
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# Numpy

```
import numpy as np

A = np.array([
[0, 1, 1, 0, 0],
[1, 0, 1, 0, 1],
[1, 1, 0, 0, 1],
[0, 0, 0, 0, 0],
[0, 1, 1, 0, 0]])

G = nx.from_numpy_matrix(A)
nx.draw_networkx(G, node_size=0, font_size=40)
plt.show()
```

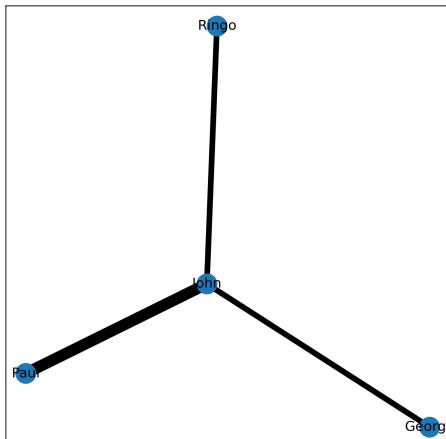


# Edgelist - a list of edges

```
beatles_edgelist = [('John', 'Paul', {'weight': 1.0}), ('John', 'Ringo', {'weight': 0.5})]

G = nx.from_edgelist(beatles_edgelist)

weights = [10 * attrs['weight'] for u, v, attrs in G.edges(data=True)]
nx.draw_networkx(G, width=weights)
plt.show()
```



# Edgelist - a file

This is how the `beatles.edgelist` file looks like:

```
John Paul 1  
John George 0.5  
John Ringo 0.5
```

Read it with `read_edgelist()` or  
`read_weighted_edgelist()`:

```
with open('../data/beatles.edgelist', 'rb') as edgelist_file:  
    G = nx.read_edgelist(edgelist_file, data=((('weight', float),))  
    print(G.edges(data=True))
```

```
## [ ('John', 'Paul', {'weight': 1.0}), ('John', 'George', {'weight': 0.5}),
```

```
with open('../data/beatles.edgelist', 'rb') as edgelist_file:  
    G = nx.read_weighted_edgelist(edgelist_file)  
    print(G.edges(data=True))
```

```
## [ ('John', 'Paul', {'weight': 1.0}), ('John', 'George', {'weight': 0.5}),
```

# CSV

This is how the `beatles.csv` file looks like:

```
John,Paul,1957,1.0
John,George,1958,0.5
John,Ringo,1960,0.5
```

You can still use `read_edgelist()` to read it:

```
with open('../data/beatles.csv', 'rb') as edgelist_file:
    G = nx.read_edgelist(edgelist_file, delimiter=',', data=((('year'
print(G.edges(data=True))

## [ ('John', 'Paul', {'year': 1957, 'weight': 1.0}), ('John', 'George', {'y
```

Or, you can just use Pandas `read_csv()` and...

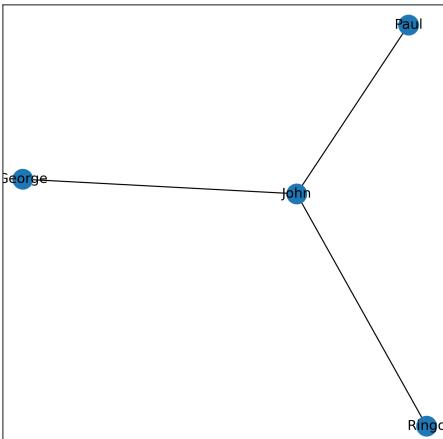
# Pandas

```
import pandas as pd

beatles_df = pd.read_csv('../data/beatles.csv', header=None)
beatles_df.columns = ['source', 'target', 'year', 'weight']

G = nx.from_pandas_edgelist(beatles_df, 'source', 'target', ['year', 'weight'])

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



# What about writing?

All methods we've seen have a `write_` or `to_` complementary function:

```
print(nx.to_edgelist(G))
```

```
## [ ('John', 'Paul', {'year': 1957, 'weight': 1.0}), ('John', 'George', {'y
```

# What about `DiGraph()`?

All methods we've seen have a `create_using` parameter:

```
D = nx.from_pandas_edgelist(beatles_df, 'source', 'target',
['year', 'weight'], create_using=nx.DiGraph)
```

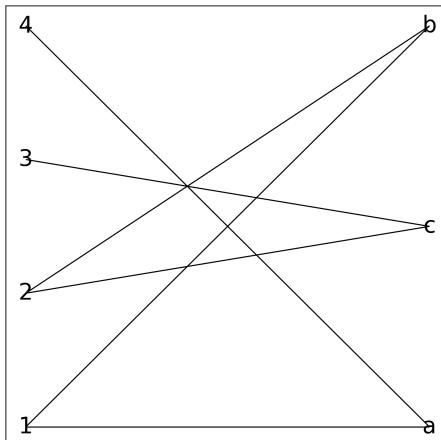
⚠ When creating `DiGraph()` NetworkX assumes  $A_{ij}$  corresponds to the edge from  $i$  to  $j$ , contrary to our convention. Therefore, you should use `A.transpose()`

# Bipartite

For creating a bipartite network, use the `bipartite` node attribute:

```
G = nx.Graph()
G.add_nodes_from([1, 2, 3, 4], bipartite=0)
G.add_nodes_from(['a', 'b', 'c'], bipartite=1)
G.add_edges_from([(1, 'a'), (1, 'b'), (2, 'b'), (2, 'c'), (3, 'c')])

nx.draw_networkx(G, pos=nx.bipartite_layout(G, [1, 2, 3, 4])), nodes
plt.show()
```



"In real life" you would probably have something like the Marvel incidence matrix in a CSV, what NetworkX calls a *biadjacency\_matrix*, or a list of edges you could make a Scipy *sparse matrix* with, from which you can create a bipartite graph:

```
from scipy import sparse

marvel = pd.read_csv("../data/marvel_incidence_matrix.csv")
B = marvel.iloc[:, 1: ].values

sB = sparse.csr_matrix(B)

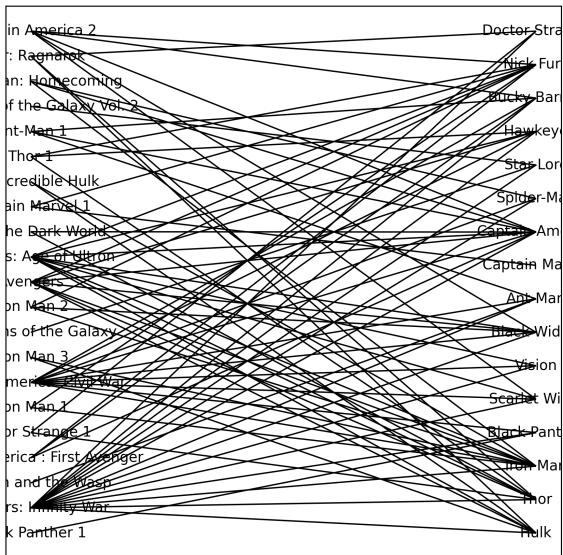
G = nx.bipartite.from_bipartite_matrix(sB)
print(G.nodes(data=True))

## [(0, {'bipartite': 0}), (1, {'bipartite': 0}), (2, {'bipartite': 0}), (3,
```

```
films = marvel['Film'].to_list()
characters = marvel.columns[1:].to_list()

id_to_label = {id: char for id, char in enumerate(films + characters)}
G = nx.relabel_nodes(G, id_to_label)

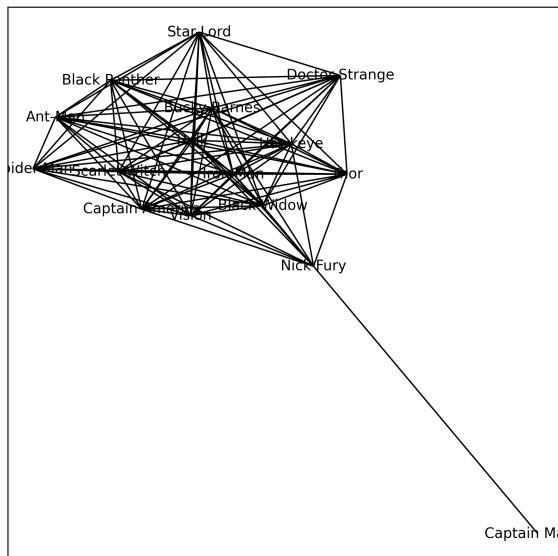
nx.draw_networkx(G, pos=nx.bipartite_layout(G, films), node_size=1000)
plt.show()
```



You've seen how to project an incidence matrix with numpy:

```
P = B.transpose() @ B
np.fill_diagonal(P, 0)
Gc = nx.from_numpy_matrix(P)

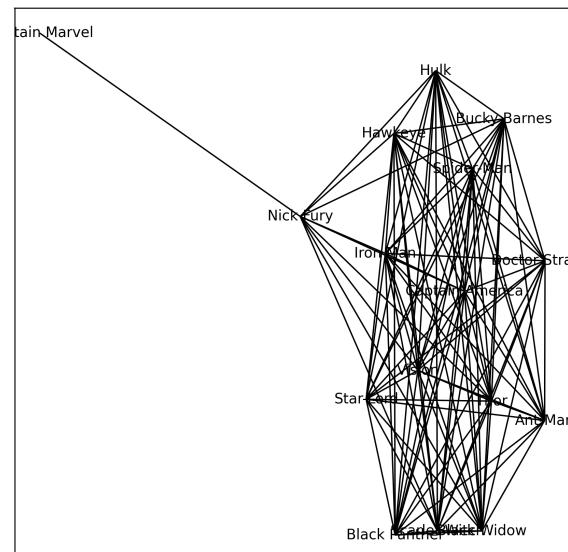
id_to_char = {id: char for id, char in enumerate(characters)}
Gc = nx.relabel_nodes(Gc, id_to_char)
nx.draw_networkx(Gc, node_size=0, font_size=10)
plt.show()
```



# But NetworkX can do all that for you:

```
Gc = nx.bipartite.projected_graph(G, characters)

nx.draw_networkx(Gc, node_size=0, font_size=10)
plt.show()
```



# Similarity

Let's recreate the sci-fi similarity network. We'll do some filtering:

- The original CSV includes 156 books, we'll take only those marked as "popular"
- Take only books with at least 2 features marked > 0
- Won't be looking at the author's name, gender, or date of release

```
scifi = pd.read_csv('../data/sci_fi_books.csv', index_col='book')
scifi['n_features'] = (scifi.iloc[:, 6:17] > 0).sum(axis=1)
scifi = scifi[scifi['popular'] == 1]

scifi_fil = scifi[scifi['n_features'] >= 2]
cols_to_drop = ['date', 'author', 'frequency', 'author_gender',
                 'quarter_century', 'century', 'popular', 'n_features']
scifi_fil = scifi_fil.drop(cols_to_drop, axis=1)

# to use Pandas corr function need to transpose data frame
scifi_corr = scifi_fil.T.corr(method='spearman')
```

We reached a 25x25 symmetric correlation matrix for 25 books:

```
scifi_corr.values[:5, :5]
```

```
## array([[ 1.          ,  0.62769528,  0.2975283 ,  0.69310571, -0.2111842 ],
##        [ 0.62769528,  1.          ,  0.68760573,  0.3303204 ,  0.23530427],
##        [ 0.2975283 ,  0.68760573,  1.          ,  0.0037037 ,  0.48989795],
##        [ 0.69310571,  0.3303204 ,  0.0037037 ,  1.          , -0.04082483],
##        [-0.2111842 ,  0.23530427,  0.48989795, -0.04082483,  1. ]])
```

Turn all upper triangle to Nan, so we'll get only  $25 * 24 / 2$  correlations:

```
scifi_corr.values[np.triu_indices_from(scifi_corr.values)] = np.nan
scifi_corr.values[:5, :5]
```

```
## array([[ nan,         nan,         nan,         nan,         nan],
##        [ 0.62769528,  nan,         nan,         nan,         nan],
##        [ 0.2975283 ,  0.68760573,  nan,         nan,         nan],
##        [ 0.69310571,  0.3303204 ,  0.0037037 ,  nan,         nan],
##        [-0.2111842 ,  0.23530427,  0.48989795, -0.04082483,  nan]])
```

Convert this to a long edgelist, filter out the Nan:

```
scifi_edgelist = scifi_corr.reset_index().melt(id_vars='book',
    value_vars=scifi_fil.index, var_name='book2', value_name='corr')

scifi_edgelist = scifi_edgelist[~pd.isna(scifi_edgelist['corr'])]
print(scifi_edgelist.shape)

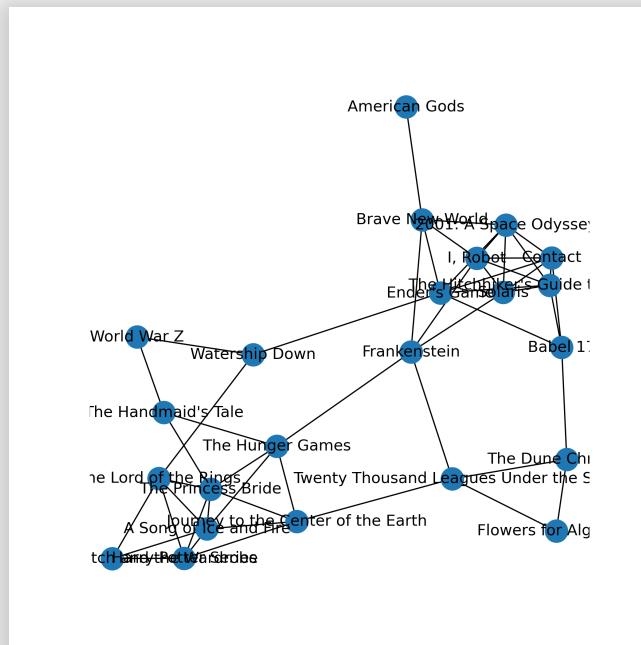
## (300, 3)
```

```
scifi_edgelist.head(5)
```

		book	book2	corr
## 1	Twenty Thousand Leagues Under the Sea	Frankenstein	Frankenstein	0.627695
## 2	Journey to the Center of the Earth	Frankenstein	Frankenstein	0.297528
## 3	Brave New World	Frankenstein	Frankenstein	0.693106
## 4	The Lion, the Witch and the Wardrobe	Frankenstein	Frankenstein	-0.211184
## 5	I, Robot	Frankenstein	Frankenstein	0.700617

Filter all correlations above 0.5 and convert to a Graph ():

```
G = nx.from_pandas_edgelist(scifi_edgelist[scifi_edgelist['corr'] >= 0.5][['book', 'book2', 'corr'])  
  
nx.draw_networkx(G)  
limits = plt.axis('off')  
plt.show()
```



# Let NetworkX work

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# Adjacency Matrix

You can get a Numpy matrix with `to_numpy_matrix()`:

```
A = nx.to_numpy_matrix(G)  
print(A.shape)
```

```
## (23, 23)
```

```
A[:4, :4]
```

```
## matrix([[0., 1., 0., 0.],  
##          [1., 0., 1., 1.],  
##          [0., 1., 0., 1.],  
##          [0., 1., 1., 0.]])
```

 Say, didn't we have 25 books?

But a realistic network would be large and sparse so the `adjacency_matrix()` method returns a SciPy sparse matrix:

```
A = nx.adjacency_matrix(G)
```

```
print(A.shape)
```

```
## (23, 23)
```

```
print(A[:4, :4])
```

```
## (0, 1) 1
## (1, 0) 1
## (1, 2) 1
## (1, 3) 1
## (2, 1) 1
## (2, 3) 1
## (3, 1) 1
## (3, 2) 1
```

💡 Do you know what a sparse matrix is?

# Easy to check if...

```
print(nx.is_directed(G))
```

```
## False
```

```
print(nx.is_directed_acyclic_graph(G))
```

```
## False
```

```
print(nx.is_bipartite(G))
```

```
## False
```

```
print(nx.is_connected(G))
```

```
## True
```

# Degree and Density

Degree is a big deal, there's an attribute *and* a method for that:

```
G.degree
```

```
## DegreeView({'Twenty Thousand Leagues Under the Sea': 4, 'Frankenstein':
```

```
list(G.degree)
```

```
## [('Twenty Thousand Leagues Under the Sea', 4), ('Frankenstein', 5), ('Br
```

Average degree:

```
np.mean(list(dict(G.degree).values()))
```

```
## 4.434782608695652
```

Get the degree of a specific node:

```
G.degree['Contact']
```

```
## 6
```

Get the density of a network:

```
nx.density(G)
```

```
## 0.2015810276679842
```

For directed graphs, use `in_degree` and `out_degree`:

```
D = nx.DiGraph(G)

D.in_degree()
D.out_degree()
```

# Paths and Diameter

Is there a path between two nodes?

```
nx.has_path(G, 'Frankenstein', 'Contact')
```

```
## True
```

What is the shortest path distance between two nodes:

```
nx.shortest_path_length(G, 'Frankenstein', 'Contact')
```

```
## 2
```

Give me (one, there could be more) shortest path:

```
nx.shortest_path(G, 'Frankenstein', 'Contact')
```

```
## ['Frankenstein', 'I, Robot', 'Contact']
```

Give me all shortest paths between two nodes:

```
all_sps = nx.all_shortest_paths(G, 'Frankenstein', 'Contact') # get  
list(all_sps)  
  
## [[['Frankenstein', 'I, Robot', 'Contact'], ['Frankenstein', 'Solaris', 'C
```

Get the diameter of a network:

```
nx.diameter(G)  
  
## 5
```

# Components

How many connected components?

```
nx.number_connected_components(G)
```

```
## 1
```

All connected components, each is a set of nodes:

```
cc = nx.connected_components(G) # generator!
list(cc)
```

```
## [{ 'American Gods', 'A Song of Ice and Fire', 'The Princess Bride', 'The
```

Get component of a specific node:

```
nx.node_connected_component(G, 'Contact')
```

```
## { 'American Gods', 'A Song of Ice and Fire', 'The Princess Bride', 'The
```

## Get largest component (a.k.a Giant Connected Component)

```
gcc = max(nx.connected_components(G), key=len)  
len(gcc)
```

```
## 23
```

For directed graphs use `strongly_`/`weakly_` prefixes with previous functions:

```
D = nx.DiGraph(G)  
  
nx.number_strongly_connected_components(D)  
nx.strongly_connected_components(D)
```

# Laplacian

```
L = nx.laplacian_matrix(G)  
L.todense() [:5, :5]  
  
## matrix([[ 4, -1,  0,  0,  0],  
##           [-1,  5, -1, -1, -1],  
##           [ 0, -1,  5, -1,  0],  
##           [ 0, -1, -1,  6, -1],  
##           [ 0, -1,  0, -1,  5]], dtype=int32)
```