

Graph Features

October 17, 2020

1 Creating a feature matrix from a networkx graph

In this notebook we will look at a few ways to quickly create a feature matrix from a networkx graph.

```
In [1]: import networkx as nx
import pandas as pd
```

```
G = nx.read_gpickle('major_us_cities')
```

1.1 Node based features

```
In [2]: G.nodes(data=True)
```

```
Out[2]: [('El Paso, TX', {'location': (-106, 31), 'population': 674433}),
('Long Beach, CA', {'location': (-118, 33), 'population': 469428}),
('Dallas, TX', {'location': (-96, 32), 'population': 1257676}),
('Oakland, CA', {'location': (-122, 37), 'population': 406253}),
('Albuquerque, NM', {'location': (-106, 35), 'population': 556495}),
('Baltimore, MD', {'location': (-76, 39), 'population': 622104}),
('Raleigh, NC', {'location': (-78, 35), 'population': 431746}),
('Mesa, AZ', {'location': (-111, 33), 'population': 457587}),
('Arlington, TX', {'location': (-97, 32), 'population': 379577}),
('Sacramento, CA', {'location': (-121, 38), 'population': 479686}),
('Wichita, KS', {'location': (-97, 37), 'population': 386552}),
('Tucson, AZ', {'location': (-110, 32), 'population': 526116}),
('Cleveland, OH', {'location': (-81, 41), 'population': 390113}),
('Louisville/Jefferson County, KY',
{'location': (-85, 38), 'population': 609893}),
('San Jose, CA', {'location': (-121, 37), 'population': 998537}),
('Oklahoma City, OK', {'location': (-97, 35), 'population': 610613}),
('Atlanta, GA', {'location': (-84, 33), 'population': 447841}),
('New Orleans, LA', {'location': (-90, 29), 'population': 378715}),
('Miami, FL', {'location': (-80, 25), 'population': 417650}),
('Fresno, CA', {'location': (-119, 36), 'population': 509924}),
('Philadelphia, PA', {'location': (-75, 39), 'population': 1553165}),
('Houston, TX', {'location': (-95, 29), 'population': 2195914}),
```

```
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    ('San Diego, CA', {'location': (-117, 32), 'population': 1355896}),
    ('Chicago, IL', {'location': (-87, 41), 'population': 2718782}),
    ('Charlotte, NC', {'location': (-80, 35), 'population': 792862}),
    ('Washington D.C.', {'location': (-77, 38), 'population': 646449}),
    ('San Antonio, TX', {'location': (-98, 29), 'population': 1409019}),
    ('Phoenix, AZ', {'location': (-112, 33), 'population': 1513367}),
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    ('Memphis, TN', {'location': (-90, 35), 'population': 653450}),
    ('Los Angeles, CA', {'location': (-118, 34), 'population': 3884307}),
    ('New York, NY', {'location': (-74, 40), 'population': 8405837}),
    ('Denver, CO', {'location': (-104, 39), 'population': 649495}),
    ('Omaha, NE', {'location': (-95, 41), 'population': 434353}),
    ('Seattle, WA', {'location': (-122, 47), 'population': 652405}),
    ('Portland, OR', {'location': (-122, 45), 'population': 609456}),
    ('Tulsa, OK', {'location': (-95, 36), 'population': 398121}),
    ('Austin, TX', {'location': (-97, 30), 'population': 885400}),
    ('Minneapolis, MN', {'location': (-93, 44), 'population': 400070}),
    ('Colorado Springs, CO', {'location': (-104, 38), 'population': 439886}),
    ('Fort Worth, TX', {'location': (-97, 32), 'population': 792727}),
    ('Indianapolis, IN', {'location': (-86, 39), 'population': 843393}),
    ('Las Vegas, NV', {'location': (-115, 36), 'population': 603488}),
    ('Detroit, MI', {'location': (-83, 42), 'population': 688701}),
    ('Nashville-Davidson, TN', {'location': (-86, 36), 'population': 634464}),
    ('Milwaukee, WI', {'location': (-87, 43), 'population': 599164}),
    ('Columbus, OH', {'location': (-82, 39), 'population': 822553}),
    ('Virginia Beach, VA', {'location': (-75, 36), 'population': 448479}),
    ('Jacksonville, FL', {'location': (-81, 30), 'population': 842583})]

```

```
In [5]: # Initialize the dataframe, using the nodes as the index
```

```
df = pd.DataFrame(index=G.nodes())
df
```

```
Out[5]: Empty DataFrame
```

```
Columns: []
```

```
Index: [El Paso, TX, Long Beach, CA, Dallas, TX, Oakland, CA, Albuquerque, NM, Baltimore, MD, ...]
```

1.1.1 Extracting attributes

Using `nx.get_node_attributes` it's easy to extract the node attributes in the graph into DataFrame columns.

```
In [6]: df['location'] = pd.Series(nx.get_node_attributes(G, 'location'))
df['population'] = pd.Series(nx.get_node_attributes(G, 'population'))

df.head()
```

```
Out[6]:
```

	location	population
El Paso, TX	(-106, 31)	674433

Long Beach, CA	(-118, 33)	469428
Dallas, TX	(-96, 32)	1257676
Oakland, CA	(-122, 37)	406253
Albuquerque, NM	(-106, 35)	556495

1.1.2 Creating node based features

Most of the networkx functions related to nodes return a dictionary, which can also easily be added to our dataframe.

```
In [7]: df['clustering'] = pd.Series(nx.clustering(G))
        df['degree'] = pd.Series(G.degree())
```

df

```
Out[7]:
```

	location	population	clustering	degree
El Paso, TX	(-106, 31)	674433	0.700000	5
Long Beach, CA	(-118, 33)	469428	0.745455	11
Dallas, TX	(-96, 32)	1257676	0.763636	11
Oakland, CA	(-122, 37)	406253	1.000000	8
Albuquerque, NM	(-106, 35)	556495	0.523810	7
Baltimore, MD	(-76, 39)	622104	0.800000	10
Raleigh, NC	(-78, 35)	431746	0.615385	13
Mesa, AZ	(-111, 33)	457587	0.750000	8
Arlington, TX	(-97, 32)	379577	0.763636	11
Sacramento, CA	(-121, 38)	479686	0.777778	9
Wichita, KS	(-97, 37)	386552	0.622222	10
Tucson, AZ	(-110, 32)	526116	0.750000	8
Cleveland, OH	(-81, 41)	390113	0.659341	14
Louisville/Jefferson County, KY	(-85, 38)	609893	0.641026	13
San Jose, CA	(-121, 37)	998537	1.000000	8
Oklahoma City, OK	(-97, 35)	610613	0.636364	12
Atlanta, GA	(-84, 33)	447841	0.611111	9
New Orleans, LA	(-90, 29)	378715	0.607143	8
Miami, FL	(-80, 25)	417650	0.000000	1
Fresno, CA	(-119, 36)	509924	0.888889	9
Philadelphia, PA	(-75, 39)	1553165	0.800000	10
Houston, TX	(-95, 29)	2195914	0.861111	9
Boston, MA	(-71, 42)	645966	1.000000	5
Kansas City, MO	(-94, 39)	467007	0.472527	14
San Diego, CA	(-117, 32)	1355896	0.745455	11
Chicago, IL	(-87, 41)	2718782	0.618182	11
Charlotte, NC	(-80, 35)	792862	0.636364	12
Washington D.C.	(-77, 38)	646449	0.712121	12
San Antonio, TX	(-98, 29)	1409019	1.000000	7
Phoenix, AZ	(-112, 33)	1513367	0.694444	9
San Francisco, CA	(-122, 37)	837442	1.000000	8
Memphis, TN	(-90, 35)	653450	0.494505	14

Los Angeles, CA	(-118, 34)	3884307	0.745455	11
New York, NY	(-74, 40)	8405837	0.833333	9
Denver, CO	(-104, 39)	649495	0.666667	4
Omaha, NE	(-95, 41)	434353	0.444444	9
Seattle, WA	(-122, 47)	652405	0.000000	1
Portland, OR	(-122, 45)	609456	0.000000	2
Tulsa, OK	(-95, 36)	398121	0.727273	11
Austin, TX	(-97, 30)	885400	0.892857	8
Minneapolis, MN	(-93, 44)	400070	1.000000	4
Colorado Springs, CO	(-104, 38)	439886	0.466667	6
Fort Worth, TX	(-97, 32)	792727	0.763636	11
Indianapolis, IN	(-86, 39)	843393	0.641026	13
Las Vegas, NV	(-115, 36)	603488	0.666667	12
Detroit, MI	(-83, 42)	688701	0.672727	11
Nashville-Davidson, TN	(-86, 36)	634464	0.589744	13
Milwaukee, WI	(-87, 43)	599164	0.666667	10
Columbus, OH	(-82, 39)	822553	0.619048	15
Virginia Beach, VA	(-75, 36)	448479	0.861111	9
Jacksonville, FL	(-81, 30)	842583	0.500000	4

2 Edge based features

In [8]: `G.edges(data=True)`

```
Out[8]: [('El Paso, TX', 'Albuquerque, NM', {'weight': 367.88584356108345}),
('El Paso, TX', 'Mesa, AZ', {'weight': 536.256659972679}),
('El Paso, TX', 'Tucson, AZ', {'weight': 425.41386739988224}),
('El Paso, TX', 'Phoenix, AZ', {'weight': 558.7835703774161}),
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('Long Beach, CA', 'Sacramento, CA', {'weight': 611.0649790490104}),
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('Long Beach, CA', 'San Jose, CA', {'weight': 518.2330606219175}),
('Long Beach, CA', 'Fresno, CA', {'weight': 360.4704577972272}),
('Long Beach, CA', 'San Diego, CA', {'weight': 151.45008247402757}),
('Long Beach, CA', 'Phoenix, AZ', {'weight': 567.4125390872786}),
('Long Beach, CA', 'San Francisco, CA', {'weight': 585.6985397766858}),
('Long Beach, CA', 'Los Angeles, CA', {'weight': 31.69419563651866}),
('Long Beach, CA', 'Las Vegas, NV', {'weight': 385.2597725411484}),
('Dallas, TX', 'Arlington, TX', {'weight': 29.425931317908415}),
('Dallas, TX', 'Wichita, KS', {'weight': 548.0572491959326}),
('Dallas, TX', 'Oklahoma City, OK', {'weight': 306.2597807397289}),
('Dallas, TX', 'New Orleans, LA', {'weight': 711.0141469371868}),
('Dallas, TX', 'Houston, TX', {'weight': 361.54185907832755}),
('Dallas, TX', 'Kansas City, MO', {'weight': 730.377587942699}),
('Dallas, TX', 'San Antonio, TX', {'weight': 406.0065656782324}),
```

('Dallas, TX', 'Memphis, TN', {'weight': 675.3316242841653}),
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 ('Dallas, TX', 'Austin, TX', {'weight': 292.91146634693376}),
 ('Dallas, TX', 'Fort Worth, TX', {'weight': 49.93359898977102}),
 ('Oakland, CA', 'Sacramento, CA', {'weight': 109.82159793013636}),
 ('Oakland, CA', 'San Jose, CA', {'weight': 61.90292319070633}),
 ('Oakland, CA', 'Fresno, CA', {'weight': 250.2309725980516}),
 ('Oakland, CA', 'San Diego, CA', {'weight': 730.9953136286227}),
 ('Oakland, CA', 'San Francisco, CA', {'weight': 13.428080525235567}),
 ('Oakland, CA', 'Los Angeles, CA', {'weight': 552.3121684216721}),
 ('Oakland, CA', 'Las Vegas, NV', {'weight': 658.3408716278288}),
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 ('Albuquerque, NM', 'Tucson, AZ', {'weight': 510.7965704802782}),
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 'Washington D.C.',
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 ('Louisville/Jefferson County, KY',
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 'Columbus, OH',
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 ('Chicago, IL', 'Minneapolis, MN', {'weight': 570.2677332774025}),
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(
    ('Charlotte, NC', 'Nashville-Davidson, TN', {'weight': 545.8353443886101}),
    ('Charlotte, NC', 'Columbus, OH', {'weight': 559.2175271096321}),
    ('Charlotte, NC', 'Virginia Beach, VA', {'weight': 472.95036855569816}),
    ('Charlotte, NC', 'Jacksonville, FL', {'weight': 549.2112199489682}),
    ('Washington D.C.', 'New York, NY', {'weight': 327.37847523720734}),
    ('Washington D.C.', 'Indianapolis, IN', {'weight': 789.4034447188161}),
    ('Washington D.C.', 'Detroit, MI', {'weight': 633.5169854294026}),
    ('Washington D.C.', 'Columbus, OH', {'weight': 524.8211194461829}),
    ('Washington D.C.', 'Virginia Beach, VA', {'weight': 246.445149222362}),
    ('San Antonio, TX', 'Tulsa, OK', {'weight': 783.407957742418}),
    ('San Antonio, TX', 'Austin, TX', {'weight': 118.36314806535839}),
    ('San Antonio, TX', 'Fort Worth, TX', {'weight': 386.37486866810514}),
    ('Phoenix, AZ', 'Los Angeles, CA', {'weight': 573.9011736942347}),
    ('Phoenix, AZ', 'Las Vegas, NV', {'weight': 411.9094912462262}),
    ('San Francisco, CA', 'Los Angeles, CA', {'weight': 558.7708978607576}),
    ('San Francisco, CA', 'Las Vegas, NV', {'weight': 670.2380164875032}),
    ('Memphis, TN', 'Tulsa, OK', {'weight': 548.09611297848}),
    ('Memphis, TN', 'Fort Worth, TX', {'weight': 721.7845495553929}),
    ('Memphis, TN', 'Indianapolis, IN', {'weight': 617.295220276267}),
    ('Memphis, TN', 'Nashville-Davidson, TN', {'weight': 315.75011030810685}),
    ('Los Angeles, CA', 'Las Vegas, NV', {'weight': 367.37280090555305}),
    ('New York, NY', 'Detroit, MI', {'weight': 772.9011410671837}),
    ('New York, NY', 'Columbus, OH', {'weight': 765.9634514216572}),
    ('New York, NY', 'Virginia Beach, VA', {'weight': 461.65690712679395}),
    ('Denver, CO', 'Omaha, NE', {'weight': 777.8863249384502}),
    ('Denver, CO', 'Colorado Springs, CO', {'weight': 101.65075926223551}),
    ('Omaha, NE', 'Tulsa, OK', {'weight': 566.5584360997123}),
    ('Omaha, NE', 'Minneapolis, MN', {'weight': 469.53764600116483}),
    ('Omaha, NE', 'Colorado Springs, CO', {'weight': 796.8394903997096}),
    ('Omaha, NE', 'Milwaukee, WI', {'weight': 695.28556620892}),
    ('Seattle, WA', 'Portland, OR', {'weight': 232.98003496425403}),
    ('Tulsa, OK', 'Austin, TX', {'weight': 674.071176589555}),
    ('Tulsa, OK', 'Fort Worth, TX', {'weight': 397.0462555225492}),
    ('Austin, TX', 'Fort Worth, TX', {'weight': 279.2607716124542}),
    ('Minneapolis, MN', 'Milwaukee, WI', {'weight': 479.28775968088723}),
    ('Indianapolis, IN', 'Detroit, MI', {'weight': 386.1408406535182}),
    ('Indianapolis, IN', 'Nashville-Davidson, TN', {'weight': 404.3913216129687}),
    ('Indianapolis, IN', 'Milwaukee, WI', {'weight': 391.5388446310555}),
    ('Indianapolis, IN', 'Columbus, OH', {'weight': 270.3063479826381}),
    ('Detroit, MI', 'Milwaukee, WI', {'weight': 404.7034896583142}),
    ('Detroit, MI', 'Nashville-Davidson, TN', {'weight': 756.943864661379}),
    ('Detroit, MI', 'Columbus, OH', {'weight': 263.423764720247}),
    ('Nashville-Davidson, TN', 'Milwaukee, WI', {'weight': 770.1467064269982}),
    ('Nashville-Davidson, TN', 'Columbus, OH', {'weight': 536.2745483969072}),
    ('Milwaukee, WI', 'Columbus, OH', {'weight': 532.5684227398444}),
    ('Columbus, OH', 'Virginia Beach, VA', {'weight': 701.8766661783677})]

```

In [9]: # Initialize the dataframe, using the edges as the index

```
df = pd.DataFrame(index=G.edges())
```

2.0.1 Extracting attributes

Using `nx.get_edge_attributes`, it's easy to extract the edge attributes in the graph into DataFrame columns.

```
In [10]: df['weight'] = pd.Series(nx.get_edge_attributes(G, 'weight'))
```

```
df
```

```
Out[10]:
```

	weight
(El Paso, TX, Albuquerque, NM)	367.885844
(El Paso, TX, Mesa, AZ)	536.256660
(El Paso, TX, Tucson, AZ)	425.413867
(El Paso, TX, Phoenix, AZ)	558.783570
(El Paso, TX, Colorado Springs, CO)	797.751712
(Long Beach, CA, Oakland, CA)	579.582999
(Long Beach, CA, Mesa, AZ)	590.156204
(Long Beach, CA, Sacramento, CA)	611.064979
(Long Beach, CA, Tucson, AZ)	698.656667
(Long Beach, CA, San Jose, CA)	518.233061
(Long Beach, CA, Fresno, CA)	360.470458
(Long Beach, CA, San Diego, CA)	151.450082
(Long Beach, CA, Phoenix, AZ)	567.412539
(Long Beach, CA, San Francisco, CA)	585.698540
(Long Beach, CA, Los Angeles, CA)	31.694196
(Long Beach, CA, Las Vegas, NV)	385.259773
(Dallas, TX, Arlington, TX)	29.425931
(Dallas, TX, Wichita, KS)	548.057249
(Dallas, TX, Oklahoma City, OK)	306.259781
(Dallas, TX, New Orleans, LA)	711.014147
(Dallas, TX, Houston, TX)	361.541859
(Dallas, TX, Kansas City, MO)	730.377588
(Dallas, TX, San Antonio, TX)	406.006566
(Dallas, TX, Memphis, TN)	675.331624
(Dallas, TX, Tulsa, OK)	382.464108
(Dallas, TX, Austin, TX)	292.911466
(Dallas, TX, Fort Worth, TX)	49.933599
(Oakland, CA, Sacramento, CA)	109.821598
(Oakland, CA, San Jose, CA)	61.902923
(Oakland, CA, Fresno, CA)	250.230973
...	...
(Memphis, TN, Tulsa, OK)	548.096113
(Memphis, TN, Fort Worth, TX)	721.784550
(Memphis, TN, Indianapolis, IN)	617.295220
(Memphis, TN, Nashville-Davidson, TN)	315.750110
(Los Angeles, CA, Las Vegas, NV)	367.372801

(New York, NY, Detroit, MI)	772.901141
(New York, NY, Columbus, OH)	765.963451
(New York, NY, Virginia Beach, VA)	461.656907
(Denver, CO, Omaha, NE)	777.886325
(Denver, CO, Colorado Springs, CO)	101.650759
(Omaha, NE, Tulsa, OK)	566.558436
(Omaha, NE, Minneapolis, MN)	469.537646
(Omaha, NE, Colorado Springs, CO)	796.839490
(Omaha, NE, Milwaukee, WI)	695.285566
(Seattle, WA, Portland, OR)	232.980035
(Tulsa, OK, Austin, TX)	674.071177
(Tulsa, OK, Fort Worth, TX)	397.046256
(Austin, TX, Fort Worth, TX)	279.260772
(Minneapolis, MN, Milwaukee, WI)	479.287760
(Indianapolis, IN, Detroit, MI)	386.140841
(Indianapolis, IN, Nashville-Davidson, TN)	404.391322
(Indianapolis, IN, Milwaukee, WI)	391.538845
(Indianapolis, IN, Columbus, OH)	270.306348
(Detroit, MI, Milwaukee, WI)	404.703490
(Detroit, MI, Nashville-Davidson, TN)	756.943865
(Detroit, MI, Columbus, OH)	263.423765
(Nashville-Davidson, TN, Milwaukee, WI)	770.146706
(Nashville-Davidson, TN, Columbus, OH)	536.274548
(Milwaukee, WI, Columbus, OH)	532.568423
(Columbus, OH, Virginia Beach, VA)	701.876666

[235 rows x 1 columns]

2.0.2 Creating edge based features

Many of the networkx functions related to edges return a nested data structures. We can extract the relevant data using list comprehension.

```
In [11]: df['preferential_attachment'] = [i[2] for i in nx.preferential_attachment(G, df.index)]
```

df

```
Out[11]:
```

	weight \
(El Paso, TX, Albuquerque, NM)	367.885844
(El Paso, TX, Mesa, AZ)	536.256660
(El Paso, TX, Tucson, AZ)	425.413867
(El Paso, TX, Phoenix, AZ)	558.783570
(El Paso, TX, Colorado Springs, CO)	797.751712
(Long Beach, CA, Oakland, CA)	579.582999
(Long Beach, CA, Mesa, AZ)	590.156204
(Long Beach, CA, Sacramento, CA)	611.064979
(Long Beach, CA, Tucson, AZ)	698.656667
(Long Beach, CA, San Jose, CA)	518.233061

(Long Beach, CA, Fresno, CA)	360.470458
(Long Beach, CA, San Diego, CA)	151.450082
(Long Beach, CA, Phoenix, AZ)	567.412539
(Long Beach, CA, San Francisco, CA)	585.698540
(Long Beach, CA, Los Angeles, CA)	31.694196
(Long Beach, CA, Las Vegas, NV)	385.259773
(Dallas, TX, Arlington, TX)	29.425931
(Dallas, TX, Wichita, KS)	548.057249
(Dallas, TX, Oklahoma City, OK)	306.259781
(Dallas, TX, New Orleans, LA)	711.014147
(Dallas, TX, Houston, TX)	361.541859
(Dallas, TX, Kansas City, MO)	730.377588
(Dallas, TX, San Antonio, TX)	406.006566
(Dallas, TX, Memphis, TN)	675.331624
(Dallas, TX, Tulsa, OK)	382.464108
(Dallas, TX, Austin, TX)	292.911466
(Dallas, TX, Fort Worth, TX)	49.933599
(Oakland, CA, Sacramento, CA)	109.821598
(Oakland, CA, San Jose, CA)	61.902923
(Oakland, CA, Fresno, CA)	250.230973
...	...
(Memphis, TN, Tulsa, OK)	548.096113
(Memphis, TN, Fort Worth, TX)	721.784550
(Memphis, TN, Indianapolis, IN)	617.295220
(Memphis, TN, Nashville-Davidson, TN)	315.750110
(Los Angeles, CA, Las Vegas, NV)	367.372801
(New York, NY, Detroit, MI)	772.901141
(New York, NY, Columbus, OH)	765.963451
(New York, NY, Virginia Beach, VA)	461.656907
(Denver, CO, Omaha, NE)	777.886325
(Denver, CO, Colorado Springs, CO)	101.650759
(Omaha, NE, Tulsa, OK)	566.558436
(Omaha, NE, Minneapolis, MN)	469.537646
(Omaha, NE, Colorado Springs, CO)	796.839490
(Omaha, NE, Milwaukee, WI)	695.285566
(Seattle, WA, Portland, OR)	232.980035
(Tulsa, OK, Austin, TX)	674.071177
(Tulsa, OK, Fort Worth, TX)	397.046256
(Austin, TX, Fort Worth, TX)	279.260772
(Minneapolis, MN, Milwaukee, WI)	479.287760
(Indianapolis, IN, Detroit, MI)	386.140841
(Indianapolis, IN, Nashville-Davidson, TN)	404.391322
(Indianapolis, IN, Milwaukee, WI)	391.538845
(Indianapolis, IN, Columbus, OH)	270.306348
(Detroit, MI, Milwaukee, WI)	404.703490
(Detroit, MI, Nashville-Davidson, TN)	756.943865
(Detroit, MI, Columbus, OH)	263.423765
(Nashville-Davidson, TN, Milwaukee, WI)	770.146706

(Nashville-Davidson, TN, Columbus, OH)	536.274548
(Milwaukee, WI, Columbus, OH)	532.568423
(Columbus, OH, Virginia Beach, VA)	701.876666

	preferential attachment
(El Paso, TX, Albuquerque, NM)	35
(El Paso, TX, Mesa, AZ)	40
(El Paso, TX, Tucson, AZ)	40
(El Paso, TX, Phoenix, AZ)	45
(El Paso, TX, Colorado Springs, CO)	30
(Long Beach, CA, Oakland, CA)	88
(Long Beach, CA, Mesa, AZ)	88
(Long Beach, CA, Sacramento, CA)	99
(Long Beach, CA, Tucson, AZ)	88
(Long Beach, CA, San Jose, CA)	88
(Long Beach, CA, Fresno, CA)	99
(Long Beach, CA, San Diego, CA)	121
(Long Beach, CA, Phoenix, AZ)	99
(Long Beach, CA, San Francisco, CA)	88
(Long Beach, CA, Los Angeles, CA)	121
(Long Beach, CA, Las Vegas, NV)	132
(Dallas, TX, Arlington, TX)	121
(Dallas, TX, Wichita, KS)	110
(Dallas, TX, Oklahoma City, OK)	132
(Dallas, TX, New Orleans, LA)	88
(Dallas, TX, Houston, TX)	99
(Dallas, TX, Kansas City, MO)	154
(Dallas, TX, San Antonio, TX)	77
(Dallas, TX, Memphis, TN)	154
(Dallas, TX, Tulsa, OK)	121
(Dallas, TX, Austin, TX)	88
(Dallas, TX, Fort Worth, TX)	121
(Oakland, CA, Sacramento, CA)	72
(Oakland, CA, San Jose, CA)	64
(Oakland, CA, Fresno, CA)	72
...	...
(Memphis, TN, Tulsa, OK)	154
(Memphis, TN, Fort Worth, TX)	154
(Memphis, TN, Indianapolis, IN)	182
(Memphis, TN, Nashville-Davidson, TN)	182
(Los Angeles, CA, Las Vegas, NV)	132
(New York, NY, Detroit, MI)	99
(New York, NY, Columbus, OH)	135
(New York, NY, Virginia Beach, VA)	81
(Denver, CO, Omaha, NE)	36
(Denver, CO, Colorado Springs, CO)	24
(Omaha, NE, Tulsa, OK)	99
(Omaha, NE, Minneapolis, MN)	36

(Omaha, NE, Colorado Springs, CO)	54
(Omaha, NE, Milwaukee, WI)	90
(Seattle, WA, Portland, OR)	2
(Tulsa, OK, Austin, TX)	88
(Tulsa, OK, Fort Worth, TX)	121
(Austin, TX, Fort Worth, TX)	88
(Minneapolis, MN, Milwaukee, WI)	40
(Indianapolis, IN, Detroit, MI)	143
(Indianapolis, IN, Nashville-Davidson, TN)	169
(Indianapolis, IN, Milwaukee, WI)	130
(Indianapolis, IN, Columbus, OH)	195
(Detroit, MI, Milwaukee, WI)	110
(Detroit, MI, Nashville-Davidson, TN)	143
(Detroit, MI, Columbus, OH)	165
(Nashville-Davidson, TN, Milwaukee, WI)	130
(Nashville-Davidson, TN, Columbus, OH)	195
(Milwaukee, WI, Columbus, OH)	150
(Columbus, OH, Virginia Beach, VA)	135

[235 rows x 2 columns]

In the case where the function expects two nodes to be passed in, we can map the index to a lambda function.

```
In [12]: df['Common Neighbors'] = df.index.map(lambda city: len(list(nx.common_neighbors(G, city
```

df

```
Out[12]:
```

	weight \
(El Paso, TX, Albuquerque, NM)	367.885844
(El Paso, TX, Mesa, AZ)	536.256660
(El Paso, TX, Tucson, AZ)	425.413867
(El Paso, TX, Phoenix, AZ)	558.783570
(El Paso, TX, Colorado Springs, CO)	797.751712
(Long Beach, CA, Oakland, CA)	579.582999
(Long Beach, CA, Mesa, AZ)	590.156204
(Long Beach, CA, Sacramento, CA)	611.064979
(Long Beach, CA, Tucson, AZ)	698.656667
(Long Beach, CA, San Jose, CA)	518.233061
(Long Beach, CA, Fresno, CA)	360.470458
(Long Beach, CA, San Diego, CA)	151.450082
(Long Beach, CA, Phoenix, AZ)	567.412539
(Long Beach, CA, San Francisco, CA)	585.698540
(Long Beach, CA, Los Angeles, CA)	31.694196
(Long Beach, CA, Las Vegas, NV)	385.259773
(Dallas, TX, Arlington, TX)	29.425931
(Dallas, TX, Wichita, KS)	548.057249
(Dallas, TX, Oklahoma City, OK)	306.259781

(Dallas, TX, New Orleans, LA)	711.014147
(Dallas, TX, Houston, TX)	361.541859
(Dallas, TX, Kansas City, MO)	730.377588
(Dallas, TX, San Antonio, TX)	406.006566
(Dallas, TX, Memphis, TN)	675.331624
(Dallas, TX, Tulsa, OK)	382.464108
(Dallas, TX, Austin, TX)	292.911466
(Dallas, TX, Fort Worth, TX)	49.933599
(Oakland, CA, Sacramento, CA)	109.821598
(Oakland, CA, San Jose, CA)	61.902923
(Oakland, CA, Fresno, CA)	250.230973
...	...
(Memphis, TN, Tulsa, OK)	548.096113
(Memphis, TN, Fort Worth, TX)	721.784550
(Memphis, TN, Indianapolis, IN)	617.295220
(Memphis, TN, Nashville-Davidson, TN)	315.750110
(Los Angeles, CA, Las Vegas, NV)	367.372801
(New York, NY, Detroit, MI)	772.901141
(New York, NY, Columbus, OH)	765.963451
(New York, NY, Virginia Beach, VA)	461.656907
(Denver, CO, Omaha, NE)	777.886325
(Denver, CO, Colorado Springs, CO)	101.650759
(Omaha, NE, Tulsa, OK)	566.558436
(Omaha, NE, Minneapolis, MN)	469.537646
(Omaha, NE, Colorado Springs, CO)	796.839490
(Omaha, NE, Milwaukee, WI)	695.285566
(Seattle, WA, Portland, OR)	232.980035
(Tulsa, OK, Austin, TX)	674.071177
(Tulsa, OK, Fort Worth, TX)	397.046256
(Austin, TX, Fort Worth, TX)	279.260772
(Minneapolis, MN, Milwaukee, WI)	479.287760
(Indianapolis, IN, Detroit, MI)	386.140841
(Indianapolis, IN, Nashville-Davidson, TN)	404.391322
(Indianapolis, IN, Milwaukee, WI)	391.538845
(Indianapolis, IN, Columbus, OH)	270.306348
(Detroit, MI, Milwaukee, WI)	404.703490
(Detroit, MI, Nashville-Davidson, TN)	756.943865
(Detroit, MI, Columbus, OH)	263.423765
(Nashville-Davidson, TN, Milwaukee, WI)	770.146706
(Nashville-Davidson, TN, Columbus, OH)	536.274548
(Milwaukee, WI, Columbus, OH)	532.568423
(Columbus, OH, Virginia Beach, VA)	701.876666

	preferential attachment \
(El Paso, TX, Albuquerque, NM)	35
(El Paso, TX, Mesa, AZ)	40
(El Paso, TX, Tucson, AZ)	40
(El Paso, TX, Phoenix, AZ)	45

(El Paso, TX, Colorado Springs, CO)	30
(Long Beach, CA, Oakland, CA)	88
(Long Beach, CA, Mesa, AZ)	88
(Long Beach, CA, Sacramento, CA)	99
(Long Beach, CA, Tucson, AZ)	88
(Long Beach, CA, San Jose, CA)	88
(Long Beach, CA, Fresno, CA)	99
(Long Beach, CA, San Diego, CA)	121
(Long Beach, CA, Phoenix, AZ)	99
(Long Beach, CA, San Francisco, CA)	88
(Long Beach, CA, Los Angeles, CA)	121
(Long Beach, CA, Las Vegas, NV)	132
(Dallas, TX, Arlington, TX)	121
(Dallas, TX, Wichita, KS)	110
(Dallas, TX, Oklahoma City, OK)	132
(Dallas, TX, New Orleans, LA)	88
(Dallas, TX, Houston, TX)	99
(Dallas, TX, Kansas City, MO)	154
(Dallas, TX, San Antonio, TX)	77
(Dallas, TX, Memphis, TN)	154
(Dallas, TX, Tulsa, OK)	121
(Dallas, TX, Austin, TX)	88
(Dallas, TX, Fort Worth, TX)	121
(Oakland, CA, Sacramento, CA)	72
(Oakland, CA, San Jose, CA)	64
(Oakland, CA, Fresno, CA)	72
...	...
(Memphis, TN, Tulsa, OK)	154
(Memphis, TN, Fort Worth, TX)	154
(Memphis, TN, Indianapolis, IN)	182
(Memphis, TN, Nashville-Davidson, TN)	182
(Los Angeles, CA, Las Vegas, NV)	132
(New York, NY, Detroit, MI)	99
(New York, NY, Columbus, OH)	135
(New York, NY, Virginia Beach, VA)	81
(Denver, CO, Omaha, NE)	36
(Denver, CO, Colorado Springs, CO)	24
(Omaha, NE, Tulsa, OK)	99
(Omaha, NE, Minneapolis, MN)	36
(Omaha, NE, Colorado Springs, CO)	54
(Omaha, NE, Milwaukee, WI)	90
(Seattle, WA, Portland, OR)	2
(Tulsa, OK, Austin, TX)	88
(Tulsa, OK, Fort Worth, TX)	121
(Austin, TX, Fort Worth, TX)	88
(Minneapolis, MN, Milwaukee, WI)	40
(Indianapolis, IN, Detroit, MI)	143
(Indianapolis, IN, Nashville-Davidson, TN)	169

(Indianapolis, IN, Milwaukee, WI)	130
(Indianapolis, IN, Columbus, OH)	195
(Detroit, MI, Milwaukee, WI)	110
(Detroit, MI, Nashville-Davidson, TN)	143
(Detroit, MI, Columbus, OH)	165
(Nashville-Davidson, TN, Milwaukee, WI)	130
(Nashville-Davidson, TN, Columbus, OH)	195
(Milwaukee, WI, Columbus, OH)	150
(Columbus, OH, Virginia Beach, VA)	135

Common Neighbors

(El Paso, TX, Albuquerque, NM)	4
(El Paso, TX, Mesa, AZ)	3
(El Paso, TX, Tucson, AZ)	3
(El Paso, TX, Phoenix, AZ)	3
(El Paso, TX, Colorado Springs, CO)	1
(Long Beach, CA, Oakland, CA)	7
(Long Beach, CA, Mesa, AZ)	5
(Long Beach, CA, Sacramento, CA)	7
(Long Beach, CA, Tucson, AZ)	5
(Long Beach, CA, San Jose, CA)	7
(Long Beach, CA, Fresno, CA)	8
(Long Beach, CA, San Diego, CA)	10
(Long Beach, CA, Phoenix, AZ)	6
(Long Beach, CA, San Francisco, CA)	7
(Long Beach, CA, Los Angeles, CA)	10
(Long Beach, CA, Las Vegas, NV)	10
(Dallas, TX, Arlington, TX)	10
(Dallas, TX, Wichita, KS)	6
(Dallas, TX, Oklahoma City, OK)	9
(Dallas, TX, New Orleans, LA)	5
(Dallas, TX, Houston, TX)	8
(Dallas, TX, Kansas City, MO)	6
(Dallas, TX, San Antonio, TX)	6
(Dallas, TX, Memphis, TN)	8
(Dallas, TX, Tulsa, OK)	9
(Dallas, TX, Austin, TX)	7
(Dallas, TX, Fort Worth, TX)	10
(Oakland, CA, Sacramento, CA)	7
(Oakland, CA, San Jose, CA)	7
(Oakland, CA, Fresno, CA)	7
...	...
(Memphis, TN, Tulsa, OK)	7
(Memphis, TN, Fort Worth, TX)	8
(Memphis, TN, Indianapolis, IN)	5
(Memphis, TN, Nashville-Davidson, TN)	6
(Los Angeles, CA, Las Vegas, NV)	10
(New York, NY, Detroit, MI)	5

(New York, NY, Columbus, OH)	7
(New York, NY, Virginia Beach, VA)	7
(Denver, CO, Omaha, NE)	2
(Denver, CO, Colorado Springs, CO)	3
(Omaha, NE, Tulsa, OK)	3
(Omaha, NE, Minneapolis, MN)	3
(Omaha, NE, Colorado Springs, CO)	3
(Omaha, NE, Milwaukee, WI)	3
(Seattle, WA, Portland, OR)	0
(Tulsa, OK, Austin, TX)	6
(Tulsa, OK, Fort Worth, TX)	9
(Austin, TX, Fort Worth, TX)	7
(Minneapolis, MN, Milwaukee, WI)	3
(Indianapolis, IN, Detroit, MI)	7
(Indianapolis, IN, Nashville-Davidson, TN)	11
(Indianapolis, IN, Milwaukee, WI)	7
(Indianapolis, IN, Columbus, OH)	10
(Detroit, MI, Milwaukee, WI)	6
(Detroit, MI, Nashville-Davidson, TN)	6
(Detroit, MI, Columbus, OH)	10
(Nashville-Davidson, TN, Milwaukee, WI)	7
(Nashville-Davidson, TN, Columbus, OH)	9
(Milwaukee, WI, Columbus, OH)	6
(Columbus, OH, Virginia Beach, VA)	7

[235 rows x 3 columns]