# Graph-Features

July 7, 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.

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

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

### 1.1 Node based features

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

```
[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}),
('San Francisco, CA', {'location': (-122, 37), 'population': 837442}),
('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})]
```

```python
[3]: # Initialize the dataframe, using the nodes as the index
     df = pd.DataFrame(index=G.nodes())
```

### 1.1.1 Extracting attributes

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

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

     df.head()
```

```
[4]:                    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.

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

     df
```

[5]:

| | 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

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

```
[6]: [('El Paso, TX', 'Albuquerque, NM', {'weight': 367.88584356108345}),
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```

```
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```

```
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```

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('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})]
```

```
[7]:  # 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.

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

      df
```

[8]:
|  | 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.

```
[9]: df['preferential attachment'] = [i[2] for i in nx.preferential_attachment(G, df.
     ↪index)]


     df
```

[9]:
```
                                                      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 lamda function.

```
[10]: df['Common Neighbors'] = df.index.map(lambda city: len(list(nx.
      ↪common_neighbors(G, city[0], city[1]))))

      df
```

```
[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
```

|  | 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]
```