CSCI 6444 : INTRODUCTION TO BIG DATA & ANALYTICS

Class Project 1 – Graph Analytics

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Dataset

The given dataset [soc-Epinions1_adj.tsv] is a graph of links of opinions from the SOC-E website. There are total of 811480 entries in the dataset and approximately 10 million nodes. Format of each row is <node-1>, <node-2>, # Edges.

Project 1.R | opinions

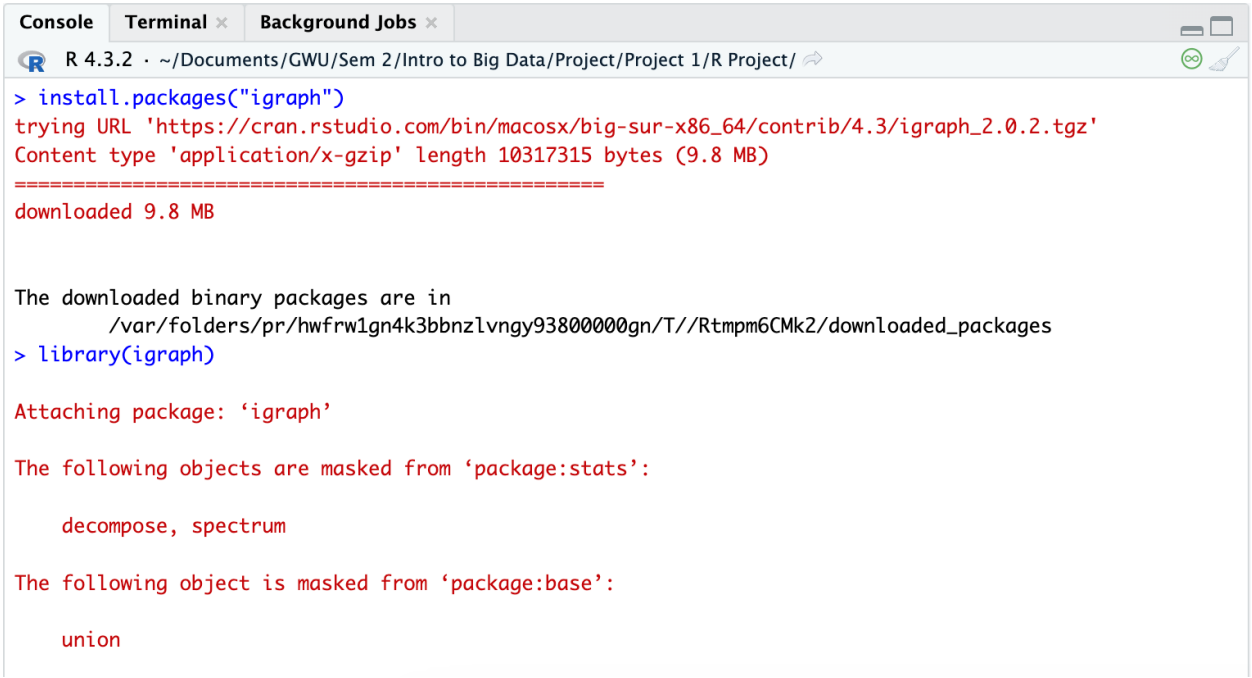
Filter

	V1	V2	V3
1	3	1	1
2	4	1	1
3	115	1	1
4	150	1	1
5	182	1	1
6	226	1	1
7	282	1	1
8	337	1	1
9	371	1	1
10	448	1	1
11	559	1	1
12	670	1	1
13	780	1	1
14	826	1	1
15	875	1	1
16	891	1	1
17	897	1	1
18	925	1	1

Showing 1 to 18 of 811,480 entries, 3 total columns

Installing igraph package from one of CRAN mirrors.

The igraph package is used to generate graphs, compute centrality measures and path length based properties as well as graph components and graph motifs. We use the install.package command to install igraph package from CRAN servers.



It is important that once we download and install the package, we import the package into our program. To do this we have used the library command.

Importing the specified dataset

In this step we import the dataset into our program. Only then will we be able to perform the necessary operations. To achieve this goal we use certain functions.

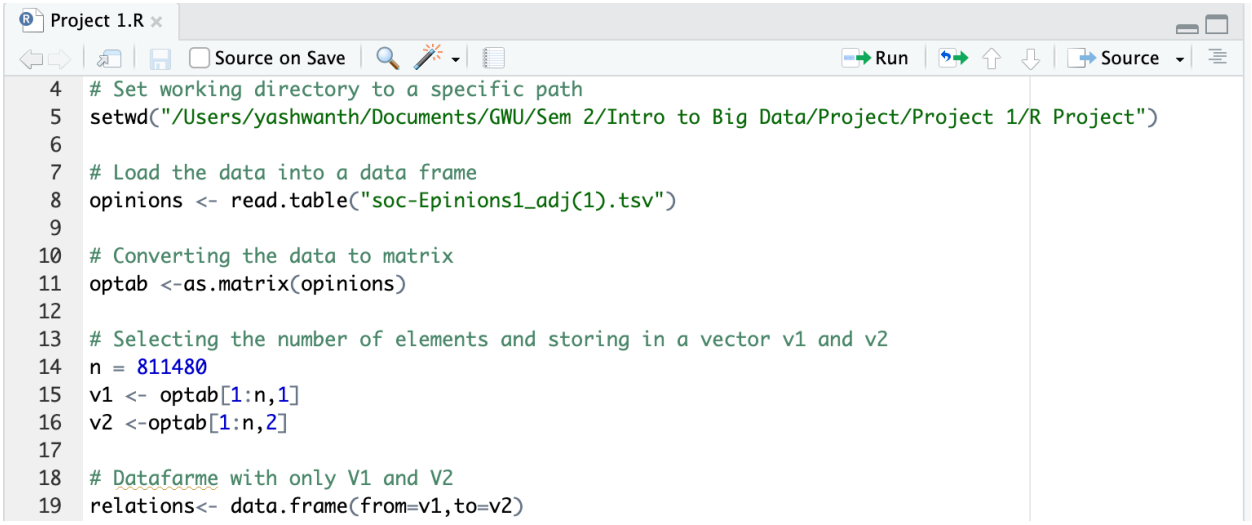
setwds - This function specifies the present working directory from which all files are to be taken. Inside this specified directory is where the dataset is stored.

read.table – This function reads the data from the file and stores it in a variable called opinions. The read.table function is used to read tabular data from text files.

as.matrix – This function converts the data in opinions to a matrix and stores it in a variable called optab. Matrices are a fundamental data structure in R that can be used to store and manipulate numerical data.

data.frame – This function is is used to create a dataframe, which is a fundamental data structure for organizing and manipulating data. Dataframes are rectangular data structures where

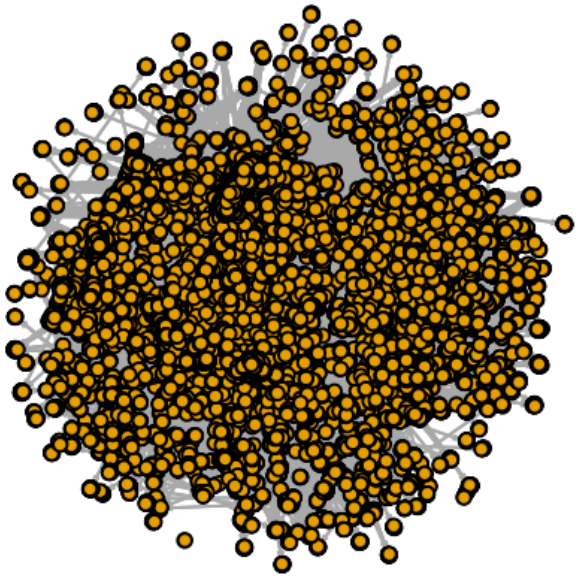
each column can be of a different data type and each row represents a separate observation or record.



Creating and Plotting Graph

After using these functions, the relations dataframe is created using the vectors v1 and v2. Each row in the relations dataframe represents a relationship between two entities. The relations dataframe organizes the relationship data in a structured format, which can be useful for further analysis, visualization, or modeling tasks. It provides a convenient way to work with relationship data and can be input to functions or algorithms that require relationship data in this format.

We make use of **graph_from_data_frame()** function to create a data frame and then a graph. Once dataframe is created, we move forward towards plotting the graphs. We make use of **plot** function and define the parameters as given in the snippets.



Applying functions to the given dataset

Following the rubric, we apply the functions in the Introduction to Graph Analytics document and describe the results as screenshots, along with a description what the results can tell us about the problem domain.

Vertices

The vertices of a graph are returned by the **V(g)** function, and we can observe that graph g has 75879 vertices. Here, we see labels for the nodes since in this collection, names have been eliminated and replaced with numbers.

```
> # Determining the. vertices of a graph
> V(g)
+ 75879/75879 vertices, named, from ca72a26:
   [1] 3     4     115   150   182   226   282   337   371   448   559   670   780   826   875   891
  [17] 897   925   1002  1111  1112  1122  1223  1334  1445  1556  1667  1778  1834  1889  2000  2001
  [33] 2080  2111  2149  2222  2223  2242  2334  2346  2434  2445  2501  2534  2556  2601  2623  2667
  [49] 2727  2778  2811  2889  3000  3041  3089  3110  3111  3145  3222  3305  3333  3334  3379  3410
  [65] 3445  3534  3556  3574  3667  3778  3889  3989  4000  4111  4158  4222  4333  4341  4444  4445
  [81] 4556  4563  4667  4778  4889  4978  5000  5111  5222  5289  5333  5367  5385  5444  5456  5489
  [97] 5554  5555  5556  5633  5666  5667  5744  5766  5777  5778  5804  5888  5911  5922  5999  6000
 [113] 6110  6155  6221  6244  6266  6332  6346  6355  6443  6554  6665  6666  6711  6777  6789  6855
 [129] 6888  6922  6999  7110  7221  7266  7332  7443  7444  7554  7665  7776  7777  7800  7888  7965
 [145] 7998  8109  8220  8331  8442  8553  8664  8691  8705  8775  8789  8886  8887  8998  9010  9072
+ ... omitted several vertices
```

Edges

The **E(g)** function returns the edges of a graph, and in our graph g we have 811480 edges. This gives us more information about the dataset.

```
> # Determining the edges of a graph
> E(g)
+ 811480/811480 edges from ca72a26 (vertex names):
  [1] 3   ->1 4   ->1 115 ->1 150 ->1 182 ->1 226 ->1 282 ->1 337 ->1 371 ->1 448 ->1 559 ->1 670 ->1
 [13] 780 ->1 826 ->1 875 ->1 891 ->1 897 ->1 925 ->1 1002->1 1111->1 1112->1 1122->1 1223->1 1334->1
 [25] 1445->1 1556->1 1667->1 1778->1 1834->1 1889->1 2000->1 2001->1 2080->1 2111->1 2149->1 2222->1
 [37] 2223->1 2242->1 2334->1 2346->1 2434->1 2445->1 2501->1 2534->1 2556->1 2601->1 2623->1 2667->1
 [49] 2727->1 2778->1 2811->1 2889->1 3000->1 3041->1 3089->1 3110->1 3111->1 3145->1 3222->1 3305->1
 [61] 3333->1 3334->1 3379->1 3410->1 3445->1 3534->1 3556->1 3574->1 3667->1 3778->1 3889->1 3989->1
 [73] 4000->1 4111->1 4158->1 4222->1 4333->1 4341->1 4444->1 4445->1 4556->1 4563->1 4667->1 4778->1
 [85] 4889->1 4978->1 5000->1 5111->1 5222->1 5289->1 5333->1 5367->1 5385->1 5444->1 5456->1 5489->1
 [97] 5554->1 5555->1 5556->1 5633->1 5666->1 5667->1 5744->1 5766->1 5777->1 5778->1 5804->1 5888->1
[109] 5911->1 5922->1 5999->1 6000->1 6110->1 6155->1 6221->1 6244->1 6266->1 6332->1 6346->1 6355->1
+ ... omitted several edges
```

Adjacency

The adjacency matrix for a graph is returned by the **get.adjacency()** method. This is our graph g's adjacency matrix, which measures 75879 x 75879. We can determine the density of our graph and even locate any isolated vertices with the aid of the adjacency matrix.

```
> g.adj = igraph::get.adjacency(g)
Warning message:
`get.adjacency()` was deprecated in igraph 2.0.0.
ℹ Please use `as_adjacency_matrix()` instead.
This warning is displayed once every 8 hours.
Call `lifecycle::last_lifecycle_warnings()` to
see where this warning was generated.
> g.adj
75879 x 75879 sparse Matrix of class "dgCMatrix"
  [[ suppressing 17 column names '3', '4', '115' ... ]]
  [[ suppressing 17 column names '3', '4', '115' ... ]]

3    . 1 . . 1 1 . 1 . 1 . . . . . . . . ......
4    1 . . . . 1 . 1 . 1 . 1 1 . . 1 . ......
115  . . . . . . . 1 . 1 1 . . . . 1 . ......
150  . . . . . . . . . . . . . . . . . ......
182  1 . . . . . . 1 1 1 . . . . . 1 . ......
226  1 1 . . . . . 1 1 1 . . 1 . . 1 . ......
282  . . . . . . . . . . . . . . . . . ......
337  1 1 1 . 1 1 . . . 1 . . 1 . . 1 . ......
371  . . . . 1 1 . . . . . . . . . . . ......
448  1 1 1 . 1 1 . 1 . . . . 1 . . . . ......
559  . . 1 . . . . . . . . . . . . . . ......
670  . 1 . . . . . . . . . . . . . . . ......
780  . 1 . . . 1 . 1 . 1 . . . . . . . ......
826  . . . . . . . . . . . . . . . . . ......
875  . . . . . . . . . . . . . . . . . ......
891  . 1 1 . 1 1 . 1 . . . . . . . . . ......
897  . . . . . . . . . . . . . . . . . ......
925  . . . . . . . . 1 . 1 . . . . . . ......
1002 . 1 . . . 1 . 1 . . . . 1 . . . . ......
1111 1 1 1 . . 1 . 1 1 . 1 1 . . . 1 . ......
1112 1 . . . . . 1 1 . 1 . . . . . . . ......
1122 . . . . . . . . . . . . . . . . . ......
1223 . . . . 1 . . . . . . . . . . . . ......
1334 . . . . 1 . . . . . . . . . . . . ......
1445 . . 1 . 1 . . . . . 1 . 1 . . 1 . ......
1556 . . . . . . . . . . . . . . . . . ......
1667 . . . . . . . . . . . . . . . . . ......
1778 . 1 . . . 1 . 1 . 1 . 1 . . . 1 . ......
1834 . . . . . . . 1 . 1 . . . . . . . ......
```

```
 ..............................
 ........suppressing 75862 columns and 75821 rows in show(); maybe adjust 'options(max.print= *, width = *)'
 ..............................
  [[ suppressing 17 column names ‘3’, ‘4’, ‘115’ ... ]]

41768 . . . . . . . . . . . . . . . . . . . .....
41769 . . . . . . . . . . . . . . . . . . . .....
41770 . . . . . . . . . . . . . . . . . . . .....
41772 . . . . . . . . . . . . . . . . . . . .....
7373  . . . . . . . . . . . . . . . . . . . .....
7374  . . . . . . . . . . . . . . . . . . . .....
7375  . . . . . . . . . . . . . . . . . . . .....
7376  . . . . . . . . . . . . . . . . . . . .....
7378  . . . . . . . . . . . . . . . . . . . .....
7387  . . . . . . . . . . . . . . . . . . . .....
7389  . . . . . . . . . . . . . . . . . . . .....
7397  . . . . . . . . . . . . . . . . . . . .....
7400  . . . . . . . . . . . . . . . . . . . .....
7403  . . . . . . . . . . . . . . . . . . . .....
7405  . . . . . . . . . . . . . . . . . . . .....
7409  . . . . . . . . . . . . . . . . . . . .....
7411  . . . . . . . . . . . . . . . . . . . .....
41774 . . . . . . . . . . . . . . . . . . . .....
41777 . . . . . . . . . . . . . . . . . . . .....
41780 . . . . . . . . . . . . . . . . . . . .....
41781 . . . . . . . . . . . . . . . . . . . .....
41782 . . . . . . . . . . . . . . . . . . . .....
41783 . . . . . . . . . . . . . . . . . . . .....
41784 . . . . . . . . . . . . . . . . . . . .....
41785 . . . . . . . . . . . . . . . . . . . .....
41786 . . . . . . . . . . . . . . . . . . . .....
41789 . . . . . . . . . . . . . . . . . . . .....
41790 . . . . . . . . . . . . . . . . . . . .....
41792 . . . . . . . . . . . . . . . . . . . .....
```

Graph Density

The **graph.density()** function determines a graph's density while accounting for the graph's type. As we can see, our graph's density is 0.000140942, indicating that it is quite sparse—that is, there are very few edges in it when compared to all the possible edges.

```
> #v Density of graph
> g.density <- graph.density(g)
> g.density
[1] 0.000140942
```

Edge Density

The **edge_density()** function computes the density of a graph, which is defined as the ratio of the number of edges in the graph to the maximum number of edges that might exist in the graph. It is evident that, even when loops are allowed in the graph, the density remains nearly constant. This suggests that the graph is most likely devoid of loops and may even be a simple graph.

```
> g.density
[1] 0.000140942
> igraph::edge_density(g)
[1] 0.000140942
> igraph::edge_density(g, loops=T)
[1] 0.0001409401
```

Degree

The **degree()** function is defined in several packages however here, we use the one defined in the igraph package. It returns the number of adjacent edges for each vertex.

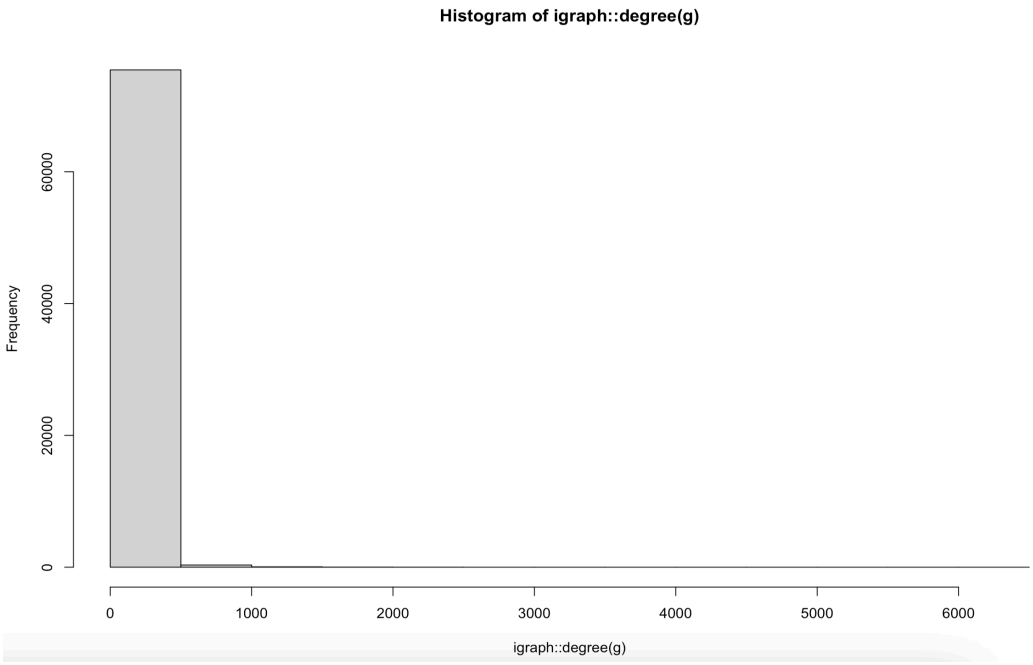
```
> igraph::degree(g)
    3     4   115   150   182   226   282   337
  572   690   686    48   636   880   266   924
  371   448   559   670   780   826   875   891
  342   826   618   226   828    38    14   324
  897   925  1002  1111  1112  1122  1223  1334
   40   372   332   448   498    22   362   830
 1445  1556  1667  1778  1834  1889  2000  2001
  508    82   366   432   216   524  2014   210
 2080  2111  2149  2222  2223  2242  2334  2346
   30   832    26   834   542    30    24   176
 2434  2445  2501  2534  2556  2601  2623  2667
  252   422  1046   224   602   352   170   510
 2727  2778  2811  2889  3000  3041  3089  3110
   38  1366    22   396   730    36   314    36
 3111  3145  3222  3305  3333  3334  3379  3410
 1736   814   104    20   732   820   666    12
 3445  3534  3556  3574  3667  3778  3889  3989
  144   206   362    28   390   262  1296    96
 4000  4111  4158  4222  4333  4341  4444  4445
 2410   236     8   664   364    20   412   640
 4556  4563  4667  4778  4889  4978  5000  5111
.
.
.

25776 25998 26098 26109 26132 26209 26220 26262
  206   158   146   388   366    52   148    20
26276 26331 26442 26553 26576 26665 26776 26998
  142    24    54   154   132   448   122   474
27109 27110 27220 27331 27442 27533 27553 27664
  242   160   350   172     2     6   120   306
27776 27799 27887 27910 27998 28109 28221 28331
  464   546    22   100   370   206   780   102
28431 28442 28553 28653 28664 28775 28853 28887
  146   228   452   182   218   190    80   352
28998 29109 29331 29442 29553 29664 29775 29886
   24   130   120   328   264   140   510   516
29998 30109 30220 30331 30442 30553 30664 30775
  398    62   184   168   708   470   266   198
30886 30997 31109 31220 31331 31352 31387 31442
  336   148   102   644   732     8   124   550
31553 31665 31775 31831 31853 31886 31898 31920
  300  1034   348   432   316   142   168   252
31953 31997 32108 32220 32331 32442 32487 32553
  150   888   190   454   104    68  1954    46
 [ reached getOption("max.print") -- omitted 74879 entries ]
```

Histogram

To generate a histogram and see the degrees of the graph's nodes, we utilize the **hist()** function. We may deduce from the histogram that the majority of nodes have degrees between 0 and 500, while the remaining nodes have degrees between 500 and 1000.

```
> # Histogram
> hist(igraph::degree(g))
```



Betweenness Centrality

The betweenness centrality of a network can be ascertained using the **centr_betw()** function. We can determine the number of shortest paths that travel through each vertex by looking at the betweenness centrality. Overall, we can observe that the nodes in our graph g have comparatively lower betweenness, indicating that there are fewer nodes with high betweenness (i.e., nodes that significantly impact the network's connectedness).

```
> g.between = igraph::centr_betw(g)
> g.between
$res
   [1] 3.151719e+06 3.981881e+06 3.266552e+06 1.206334e+05 7.363342e+06 9.469315e+06 1.701157e+06
   [8] 8.122346e+06 2.725038e+06 5.273894e+06 3.744818e+06 4.063249e+05 8.692060e+06 2.335483e+06
  [15] 8.783339e+02 1.474652e+06 3.244700e+05 3.461340e+06 2.436035e+06 1.039556e+06 7.101634e+06
  [22] 9.004451e+05 2.007443e+06 1.553106e+07 2.858003e+06 1.403503e+05 4.735297e+06 1.712402e+06
  [29] 2.053627e+06 2.216830e+06 5.637427e+07 2.877706e+06 1.921803e+05 1.090843e+07 2.662356e+03
  [36] 5.445164e+06 4.715068e+06 4.811867e+05 1.129239e+04 5.629457e+05 9.515164e+05 2.272398e+06
  [43] 2.380167e+07 1.479723e+06 2.850635e+06 4.453057e+06 9.638072e+05 3.046881e+06 1.930011e+05
  [50] 2.534605e+07 3.859493e+04 2.311553e+06 6.605852e+06 7.532751e+05 6.104356e+06 5.109320e+05
  [57] 4.907386e+07 1.259179e+07 3.950718e+05 2.408225e+03 1.068249e+07 1.672638e+07 7.387049e+06
  [64] 1.527451e+05 1.285051e+06 1.412434e+06 2.400280e+06 1.313003e+04 3.802958e+06 4.471660e+06
  [71] 2.173360e+07 3.344439e+05 8.976368e+07 1.215126e+06 1.577523e+04 1.594366e+07 2.546772e+06
  [78] 1.589372e+05 4.050165e+06 5.511125e+06 1.211066e+07 1.410818e+04 3.086957e+06 1.609299e+08
  [85] 8.555053e+05 2.563614e+06 2.308962e+07 4.421859e+05 1.343681e+06 8.883725e+06 7.132626e+03
  [92] 9.118853e+06 9.727240e+05 3.628466e+03 2.363156e+06 8.622036e+06 6.774917e+05 1.973869e+05
  [99] 9.096726e+05 4.077454e+06 4.890626e+02 5.032214e+06 1.153062e+07 2.657635e+06 3.215569e+01
 [106] 3.119489e+06 2.223556e+05 2.428348e+04 3.576354e+06 2.992492e+07 6.872374e+06 5.773731e+06
 [113] 6.494667e+05 1.308536e+06 4.799707e+05 2.080087e+06 1.582126e+06 1.539632e+05 1.296378e+03
 [120] 7.188281e+06 1.513014e+05 1.261128e+05 1.018983e+06 1.520621e+05 1.951136e+05 2.601437e+06
 [127] 3.520919e+05 2.423314e+07 2.710753e+02 2.146971e+07 1.378418e+06 1.856139e+05 2.377946e+06
 [134] 2.163510e+06 6.646553e+04 1.181188e+06 1.112392e+06 6.558604e+04 9.329885e+06 4.793107e+06
```

```
 [911] 3.699075e+05 4.319918e+05 4.918855e+05 5.855767e+05 9.524471e+05 3.419097e+04 6.812148e+06
 [918] 1.102528e+06 1.713223e+06 3.308208e+01 1.360030e+06 6.556471e+05 1.753463e+06 8.204644e+05
 [925] 3.164228e+06 4.854558e+05 3.767764e+05 4.591628e+05 5.510034e+05 3.323746e+03 1.365638e+04
 [932] 1.585927e+05 1.733604e+06 1.978938e+06 2.914033e+05 7.865149e+06 3.969551e+05 9.768958e+05
 [939] 1.208389e+06 1.634546e+06 0.000000e+00 1.015647e+02 1.600146e+06 5.689131e+05 3.056968e+06
 [946] 1.128253e+07 9.022492e+02 1.764749e+06 5.131798e+06 5.613639e+05 1.042252e+07 3.413214e+05
 [953] 1.180260e+06 2.864004e+06 1.831078e+06 1.770580e+06 1.046662e+06 1.033573e+06 1.179021e+05
 [960] 9.361194e+05 1.518796e+05 3.266932e+05 2.991570e+05 2.559759e+06 1.350596e+06 2.981400e+05
 [967] 6.275796e+06 2.968178e+06 2.268620e+06 1.542616e+04 6.550544e+05 1.684846e+06 1.027345e+07
 [974] 1.358577e+06 3.269994e+06 4.239067e+05 2.237957e+06 5.055153e+05 2.921046e+05 3.301058e+06
 [981] 4.078889e+06 2.041223e+03 8.165402e+05 2.235724e+06 6.009564e+05 3.427375e+07 1.131710e+06
 [988] 8.442873e+06 1.852482e+06 2.690190e+05 4.862595e+05 1.667332e+06 4.150323e+05 8.909589e+06
 [995] 1.117529e+06 1.650705e+07 1.983223e+05 1.918185e+05 6.836492e+07 1.724489e+05
 [ reached getOption("max.print") -- omitted 74879 entries ]

$centralization
[1] 0.0721838

$theoretical_max
[1] 4.368596e+14
```

Closeness Centrality

The closeness centrality of each graph node is returned by the **centr_clo()** function. The node in the graph is closer to other nodes the higher its proximity value. The network g's nodes are reasonably well connected and reachable from the majority of other nodes, as evidenced by the average proximity centrality of 0.3 that we have seen. The evidence for this is also readily apparent to us thanks to our previous plots.

```
> g.closeness = igraph::centr_clo(g)
> g.closeness
$res
   [1] 0.3235830 0.3182144 0.3204927 0.2823251
   [5] 0.3207840 0.3293043 0.3087729 0.3229494
   [9] 0.3021660 0.3246296 0.3207826 0.2975331
  [13] 0.3315679 0.2943417 0.2642594 0.3140524
  [17] 0.2716610 0.3160723 0.3123369 0.3177786
  [21] 0.3239823 0.2667126 0.3209699 0.3424100
  [25] 0.3161158 0.2923683 0.3077684 0.3178638
  [29] 0.3058456 0.3158092 0.3518479 0.3082924
  [33] 0.2727371 0.3334139 0.2699349 0.3197984
  [37] 0.3230250 0.2749230 0.2786445 0.3031511
  [41] 0.3050439 0.3111585 0.3431999 0.3161987
  [45] 0.3207338 0.3198981 0.3099168 0.3268967
  [49] 0.2949711 0.3353028 0.2754350 0.3199953
  [53] 0.3284334 0.2871730 0.3058234 0.2739839
  [57] 0.3554810 0.3386626 0.2808288 0.2706291
  [61] 0.3264200 0.3364954 0.3282544 0.2685268
  [65] 0.3009913 0.3027798 0.3189461 0.2903622
  [69] 0.3216570 0.3056891 0.3388955 0.3063370
  [73] 0.3585687 0.3120068 0.2611470 0.3222253
  [77] 0.3155636 0.2713161 0.3162277 0.3303021
  [81] 0.3366984 0.2834219 0.3070088 0.3623253
```

```
 [945] 0.3145184 0.3305496 0.2706793 0.2972557
 [949] 0.3263975 0.3060763 0.3196933 0.2980591
 [953] 0.3049850 0.3216884 0.3169582 0.3056644
 [957] 0.3111942 0.3041390 0.2980017 0.3049286
 [961] 0.2745490 0.3032153 0.2996671 0.3035368
 [965] 0.3085594 0.2990541 0.3130547 0.3215466
 [969] 0.3201154 0.2888061 0.3084716 0.3004895
 [973] 0.3184642 0.3216120 0.3025866 0.2936480
 [977] 0.3206810 0.3072027 0.3037908 0.3250593
 [981] 0.3229920 0.2702685 0.3041598 0.3224745
 [985] 0.3144077 0.3419578 0.3067221 0.3210229
 [989] 0.3088433 0.2847995 0.2897225 0.3112453
 [993] 0.2906280 0.3286895 0.2938527 0.3077734
 [997] 0.2953293 0.2978929 0.3435402 0.2820784
 [ reached getOption("max.print") -- omitted 74879 entries ]

$centralization
[1] 0.7633521

$theoretical_max
[1] 75877
```

Shortest Path Between Two Nodes

We can get the shortest path between any two nodes in a graph g using the function **shortest.paths()**. In this instance, they are shown as a matrix for the shortest route between nodes I and J. This allows us to identify more isolated nodes or vertices that are more central than others.

```
> # Shortest Path between two nodes
> g.sp = igraph::shortest.paths(newG70)
Warning message:
`shortest.paths()` was deprecated in igraph 2.0.0.
ℹ Please use `distances()` instead.
This warning is displayed once every 8 hours.
Call `lifecycle::last_lifecycle_warnings()` to see
where this warning was generated.
> g.sp
      3 4 115 182 226 282 337 371 448 559 670 780 891
      925 1002 1111 1112 1223 1334 1445 1556 1667 1778
      1834 1889 2000 2001 2111 2222 2223 2346 2434
      2445 2501 2534 2556 2601 2623 2667 2778 2889
      3000 3089 3111 3145 3222 3333 3334 3379 3445
      3534 3556 3667 3778 3889 3989 4000 4111 4222
      4333 4444 4445 4556 4667 4778 4889 4978 5000
      5111 5222 5289 5367 5489 5554 5556 5633 5667
      5744 5766 5778 5911 5922 5999 6000 6110 6155
      6221 6244 6266 6355 6443 6554 6665 6711 6777
      6789 6855 6922 6999 7110 7221 7266 7332 7443
      7444 7554 7665 7776 7800 7965 7998 8331 8664
      8789 8886 8887 9010 9220 9442 9553 9664 9775
```

```
      73288 74558 75709 23510 23721 33142 11753 21964
      14097 73515 64606 10317 13488 10787 63772 1670
      817 11551 39387 1108 62395 59750 44186 2487
      67451 37398 67617 1232 73390 11737 4261 71082
      3336 5285 61129 28709 1370 4518 23309 67506
      14825 23876 8631 13719 291 10069 23743 73827
      3852 13320 5125 3083 3085 16479 20889 39372
      39373 41169 45504 45505 45508 73728 6366 74795
      74453 6990 3094 10899 34545 45664 45667 45672
      35991 17772 1643 11583 5082 7381 38487 20691
      9278 73825 75621 74429 74454 73758 64217 73406
      63194 63294 68627 75475 25487 9763 68224 66773
      68772 74733 6648 44253 23165
 [ reached getOption("max.print") -- omitted 4322 rows ]
```

Max Clique

The igraph package's **max_cliques()** function can be used to calculate the size of a graph's largest clique. For example, the two nodes that make up the greatest clique of node 30 are 43506 and 1317. Though not necessary to the entire graph, the existence of two cliques indicates that these nodes are intimately related to one another. Furthermore, a higher clique would represent a higher density of nodes that are connected.

```
> # Max Clique
> node <- c(30)
> g.adj_graph <- igraph::graph_from_adjacency_matrix(g.adj)
> g.30clique = igraph::max_cliques(g.adj_graph,min = NULL, max = NULL, subset = node)
> g.30clique
[[1]]
+ 2/75879 vertices, named, from 7ae63df:
[1] 43506 1317
```

Clique num

The function **clique_num()** determines the size of the largest clique in the graph, which is 23 in our case.

```
> # Largest clique
> g.lgclique = igraph::clique_num(g.adj_graph)
Warning message:
In igraph::clique_num(g.adj_graph) :
  At vendor/cigraph/src/cliques/maximal_cliques_template.h:220 : Edge directions are ignored for maximal clique calculation.
> g.lgclique
[1] 23
```

Simplify() and is.simple()

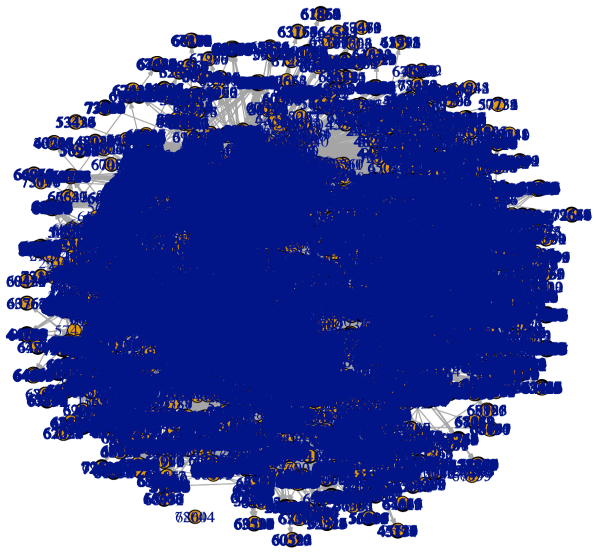
The **is.simple()** method tells us if our graph is simple i.e., if our graph has no loops and multiple edges between vertices. Without performing any simplification, we notice that our graph is

simple. This is verified when we apply the **simplify()** function on the graph after which, the is.simple() method still returns true.

```
> is.simple(g)
[1] TRUE
> sg <- simplify(g)
> is.simple(sg)
[1] TRUE
```

Simplification of the Graph

In the following steps we use brute force approach to simplify the graph.



Finding the vertex names

```
> # Finding the vertex names
> MyG <- igraph::V(g)
> MyG
+ 75879/75879 vertices, named, from ca72a26:
   [1] 3     4     115   150   182   226   282   337   371   448   559   670   780   826   875
  [16] 891   897   925   1002  1111  1112  1122  1223  1334  1445  1556  1667  1778  1834  1889
  [31] 2000  2001  2080  2111  2149  2222  2223  2242  2334  2346  2434  2445  2501  2534  2556
  [46] 2601  2623  2667  2727  2778  2811  2889  3000  3041  3089  3110  3111  3145  3222  3305
  [61] 3333  3334  3379  3410  3445  3534  3556  3574  3667  3778  3889  3989  4000  4111  4158
  [76] 4222  4333  4341  4444  4445  4556  4563  4667  4778  4889  4978  5000  5111  5222  5289
  [91] 5333  5367  5385  5444  5456  5489  5554  5555  5556  5633  5666  5667  5744  5766  5777
 [106] 5778  5804  5888  5911  5922  5999  6000  6110  6155  6221  6244  6266  6332  6346  6355
 [121] 6443  6554  6665  6666  6711  6777  6789  6855  6888  6922  6999  7110  7221  7266  7332
 [136] 7443  7444  7554  7665  7776  7777  7800  7888  7965  7998  8109  8220  8331  8442  8553
+ ... omitted several vertices
>
```

We start the simplification process by determining the nodes with degree below 1 and 2.

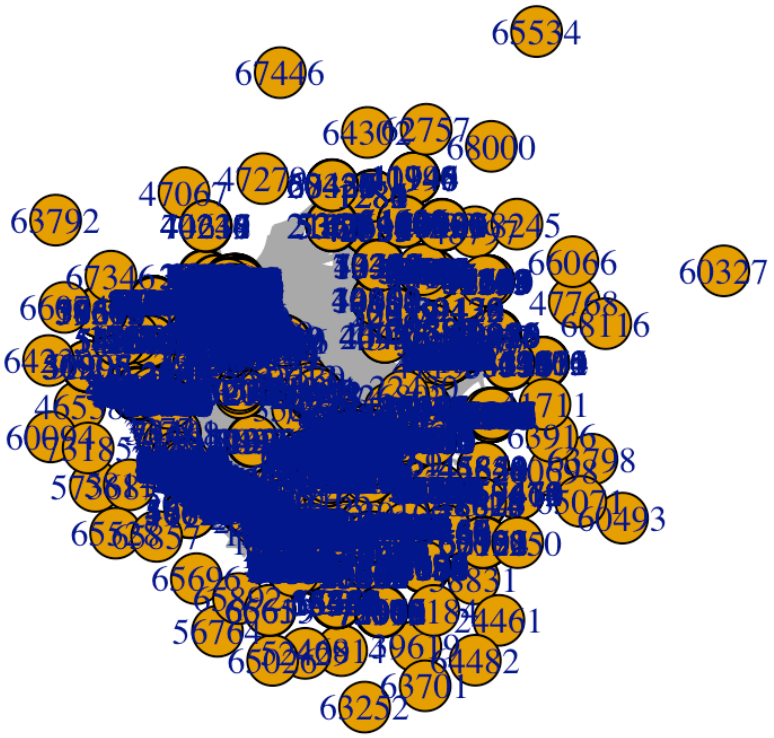
```
> # Nodes with degree 1
> MyG1 <- igraph::V(g)[igraph::degree(g)<1]
> MyG1
+ 0/75879 vertices, named, from ca72a26:
> # Nodes with degree 2
> MyG2 <- igraph::V(g)[igraph::degree(g)<2]
> MyG2
+ 0/75879 vertices, named, from ca72a26:
```

Since there are no nodes here, we go forward with determining the nodes with degree less than 10 and see if any.

```
> # Nodes with degree 10
> MyG10 <- igraph::V(g)[igraph::degree(g)<10]
> MyG10
+ 56412/75879 vertices, named, from ca72a26:
   [1] 4158  5777  7777  7888  8775  9109  10236 10664 11554 13109 13332
  [12] 14109 16998 17466 17553 18109 18867 18998 19442 19460 19754 19775
  [23] 23639 24864 27031 31575 32510 40439 49178 51108 53875 70811 70981
  [34] 72188 72189 73781 6128  8145  10961 10965 13642 16200 18246 25696
  [45] 27442 27533 31352 40220 40442 41331 41553 41775 41886 42108 42442
  [56] 42555 43219 43442 43997 44554 44776 44887 45109 45442 46665 46776
  [67] 46887 47442 48664 49109 49853 53657 65485 68311 72159 72161 72162
  [78] 72163 75028 75263 2145  2156  2257  2312  2368  2379  2446  2512
  [89] 70210 70211 70212 4435  49531 51820 51831 51875 69192 70051 70052
 [100] 7415  7417  17170 41796 41797 41799 41801 75002 41802 41803 13945
+ ... omitted several vertices
```

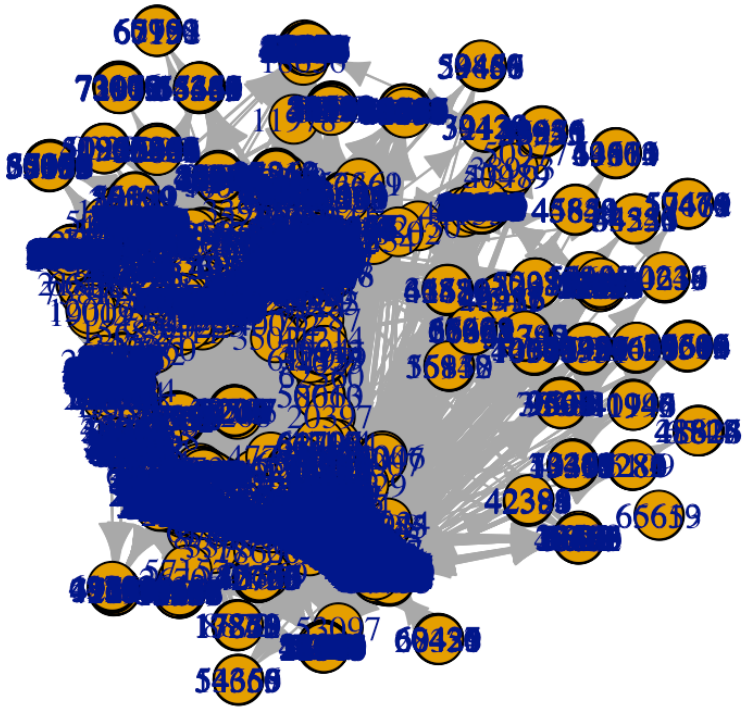
Now we go forward in removing the vertices with less than 10 edges. We store the resulting dataframe in a variable called newG.

```
> # Removing vertices with less than 10 edges
> newG <- igraph::delete.vertices(g,MyG10)
Warning message:
`delete.vertices()` was deprecated in igraph 2.0.0.
ℹ Please use `delete_vertices()` instead.
This warning is displayed once every 8 hours.
Call `lifecycle::last_lifecycle_warnings()` to see where this warning
was generated.
> newG
IGRAPH c05b22f DN-- 19467 649668 --
+ attr: name (v/c)
+ edges from c05b22f (vertex names):
 [1] 3   ->1 4   ->1 115 ->1 150 ->1 182 ->1 226 ->1 282 ->1 337 ->1
 [9] 371 ->1 448 ->1 559 ->1 670 ->1 780 ->1 826 ->1 875 ->1 891 ->1
[17] 897 ->1 925 ->1 1002->1 1111->1 1112->1 1122->1 1223->1 1334->1
[25] 1445->1 1556->1 1667->1 1778->1 1834->1 1889->1 2000->1 2001->1
[33] 2080->1 2111->1 2149->1 2222->1 2223->1 2242->1 2334->1 2346->1
[41] 2434->1 2445->1 2501->1 2534->1 2556->1 2601->1 2623->1 2667->1
[49] 2727->1 2778->1 2811->1 2889->1 3000->1 3041->1 3089->1 3110->1
[57] 3111->1 3145->1 3222->1 3305->1 3333->1 3334->1 3379->1 3410->1
+ ... omitted several edges
```



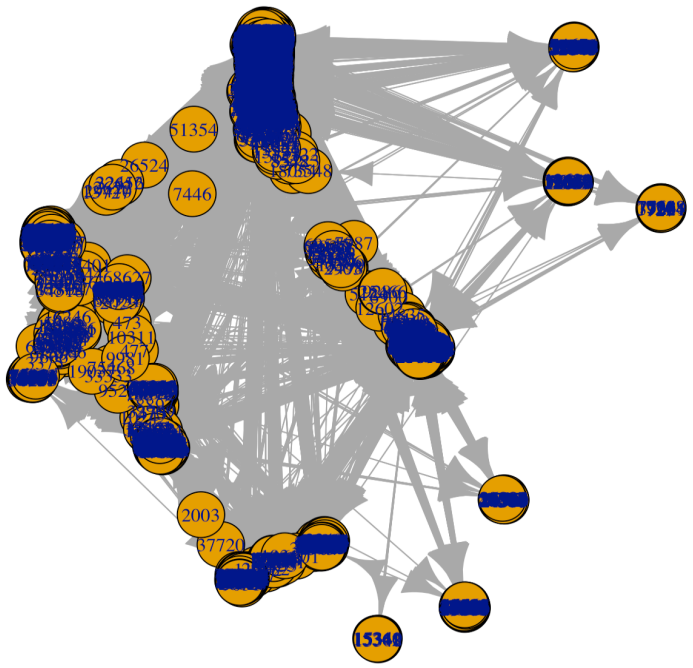
Lets now remove the vertices with degree 0 and replot.

```
> plot(newG) # Plotting
> # selecting vertices with 0 degree
> newG0 <- igraph::V(newG)[igraph::degree(newG)<1]
> newG0
+ 44/19467 vertices, named, from c05b22f:
 [1] 46538 46814 47067 47279 47768 48797 39619 52429 56764 57368 58114 58245 58831 60094 60327 60493 60698
[18] 24461 62757 63252 63701 63792 63798 63916 64230 64302 64482 65026 65071 65528 65534 65696 65857 65892
[35] 66066 66074 67250 67346 67446 41711 68000 68116 73184 73185
> plot(newG0)
> # Removing vertices with degree 0
> newG2 <- igraph::delete.vertices(newG,newG0)
> newG2
IGRAPH 57e75ac DN-- 19423 649668 --
+ attr: name (v/c)
+ edges from 57e75ac (vertex names):
  [1] 3   ->1 4   ->1 115 ->1 150 ->1 182 ->1 226 ->1 282 ->1 337 ->1 371 ->1 448 ->1 559 ->1 670 ->1
 [13] 780 ->1 826 ->1 875 ->1 891 ->1 897 ->1 925 ->1 1002->1 1111->1 1112->1 1122->1 1223->1 1334->1
 [25] 1445->1 1556->1 1667->1 1778->1 1834->1 1889->1 2000->1 2001->1 2080->1 2111->1 2149->1 2222->1
 [37] 2223->1 2242->1 2334->1 2346->1 2434->1 2445->1 2501->1 2534->1 2556->1 2601->1 2623->1 2667->1
 [49] 2727->1 2778->1 2811->1 2889->1 3000->1 3041->1 3089->1 3110->1 3111->1 3145->1 3222->1 3305->1
 [61] 3333->1 3334->1 3379->1 3410->1 3445->1 3534->1 3556->1 3574->1 3667->1 3778->1 3889->1 3989->1
 [73] 4000->1 4111->1 4222->1 4333->1 4341->1 4444->1 4445->1 4556->1 4563->1 4667->1 4778->1 4889->1
 [85] 4978->1 5000->1 5111->1 5222->1 5289->1 5333->1 5367->1 5385->1 5444->1 5456->1 5489->1 5554->1
+ ... omitted several edges
> plot(newG2)
```



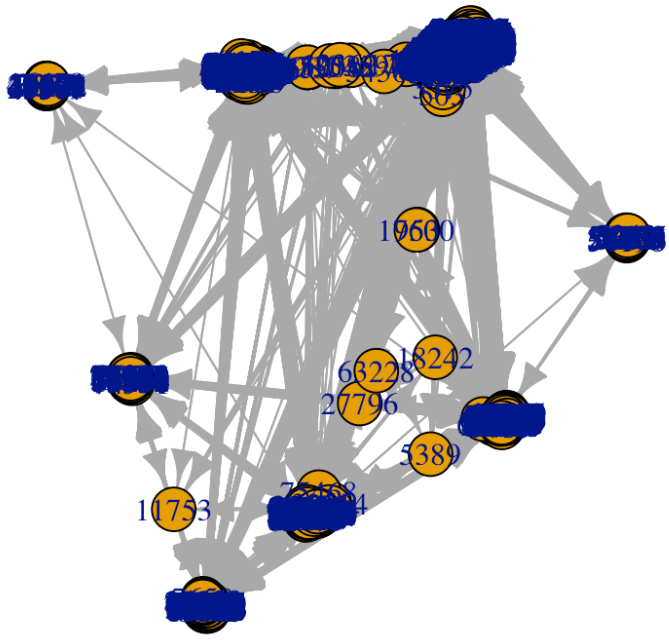
Still there is not much differentiation. Hence we go forward and remove the vertices with degree less than 30 and we increase until we get a proper simplification.

```
> # selecting vertices with degree les than 30
> newG30 <- igraph::V(newG)[igraph::degree(newG)<30]
> newG30
+ 11650/19467 vertices, named, from c05b22f:
   [1] 875   1122  2080  2149  2242  2334  2811  3305  3410  3574  4341  4563  5666  5804  6332  6346
  [17] 6666  6888  8109  8220  8442  8553  8691  8705  8998  9331  9646  9885  11479 11578 12109 12116
  [33] 12552 13448 13776 14443 14554 15554 17331 17532 17560 17664 17950 18220 18331 18442 18664 19109
  [49] 19166 19220 19331 20227 21179 21411 21997 22250 22665 22776 22781 25987 27387 29849 33231 36354
  [65] 52909 54264 64839 67007 68473 72660 73647 74397 74746 75324 75411 386   513   821   919   1043
  [81] 3054  4249  4391  4590  5237  6321  6814  9075  9978  10186 10799 10940 10955 10970 10973 10991
  [97] 11933 12587 12742 13829 13903 16560 17352 17376 18108 18458 19916 22872 24665 24810 25311 26262
 [113] 26331 27887 28998 32907 33607 39433 39664 39775 40331 40553 40886 41109 41220 41997 42886 43075
 [129] 43331 43775 43886 44219 44665 45220 45665 45887 46109 46331 47109 47220 47553 47887 52379 55721
 [145] 71919 73730 74172 74376 74641 74947 75698 2089  2167  2189  2200  2211  2235  2468  5150  9893
+ ... omitted several vertices
> # Removing vertices with degree less than 30
> newG30 <- igraph::delete.vertices(newG,newG30)
> newG30
IGRAPH 53c05a1 DN-- 7817 508082 --
+ attr: name (v/c)
+ edges from 53c05a1 (vertex names):
  [1] 3   ->1 4   ->1 115 ->1 150 ->1 182 ->1 226 ->1 282 ->1 337 ->1 371 ->1 448 ->1 559 ->1 670 ->1
 [13] 780 ->1 826 ->1 891 ->1 897 ->1 925 ->1 1002->1 1111->1 1112->1 1223->1 1334->1 1445->1 1556->1
 [25] 1667->1 1778->1 1834->1 1889->1 2000->1 2001->1 2111->1 2222->1 2223->1 2346->1 2434->1 2445->1
 [37] 2501->1 2534->1 2556->1 2601->1 2623->1 2667->1 2727->1 2778->1 2889->1 3000->1 3041->1 3089->1
 [49] 3110->1 3111->1 3145->1 3222->1 3333->1 3334->1 3379->1 3445->1 3534->1 3556->1 3667->1 3778->1
 [61] 3889->1 3989->1 4000->1 4111->1 4222->1 4333->1 4444->1 4445->1 4556->1 4667->1 4778->1 4889->1
 [73] 4978->1 5000->1 5111->1 5222->1 5289->1 5333->1 5367->1 5385->1 5444->1 5456->1 5489->1 5554->1
 [85] 5555->1 5556->1 5633->1 5667->1 5744->1 5766->1 5778->1 5888->1 5911->1 5922->1 5999->1 6000->1
+ ... omitted several edges
> plot(newG30)
```



We now increase degree to 70 and plot the graph.

```
> # selecting vertices with degree les than 70
> newG70 <- igraph::V(newG)[igraph::degree(newG)<70]
> newG70
+ 15145/19467 vertices, named, from c05b22f:
   [1] 150   826   875   897   1122  2080  2149  2242  2334  2727  2811  3041  3110  3305  3410  3574
  [17] 4341  4563  5333  5385  5444  5456  5555  5666  5804  5888  6332  6346  6666  6888  8109  8220
  [33] 8442  8553  8691  8705  8998  9072  9331  9646  9885  9886  9998  10175 10720 11332 11479 11578
  [49] 11665 11866 11887 12109 12116 12552 12625 12665 13220 13443 13448 13776 14198 14331 14443 14554
  [65] 15554 16331 17010 17220 17331 17532 17560 17664 17950 18220 18331 18442 18553 18664 19109 19166
  [81] 19220 19331 19553 20227 20442 21179 21411 21997 22250 22665 22776 22781 23220 23320 25987 27387
  [97] 27676 29849 33231 33421 36354 39443 41354 42720 43053 43264 43297 43609 45454 50831 51465 51787
 [113] 52842 52909 53398 54142 54264 54286 54642 56807 59972 63573 64673 64695 64839 66050 67007 67462
 [129] 68118 68201 68417 68473 72660 73347 73573 73647 74397 74399 74746 74769 75214 75324 75325 75411
 [145] 75453 386   513   545   816   821   895   919   939   1043  1646  1672  1692  1977  3054  3100
+ ... omitted several vertices
> # Removing vertices with degree less than 80
> newG70 <- igraph::delete.vertices(newG,newG70)
> newG70
IGRAPH 153b195 DN-- 4322 384422 --
+ attr: name (v/c)
+ edges from 153b195 (vertex names):
  [1] 3   ->1 4   ->1 115 ->1 182 ->1 226 ->1 282 ->1 337 ->1 371 ->1 448 ->1 559 ->1 670 ->1 780 ->1
 [13] 891 ->1 925 ->1 1002->1 1111->1 1112->1 1223->1 1334->1 1445->1 1556->1 1667->1 1778->1 1834->1
 [25] 1889->1 2000->1 2001->1 2111->1 2222->1 2223->1 2346->1 2434->1 2445->1 2501->1 2534->1 2556->1
 [37] 2601->1 2623->1 2667->1 2778->1 2889->1 3000->1 3089->1 3111->1 3145->1 3222->1 3333->1 3334->1
 [49] 3379->1 3445->1 3534->1 3556->1 3667->1 3778->1 3889->1 3989->1 4000->1 4111->1 4222->1 4333->1
 [61] 4444->1 4445->1 4556->1 4667->1 4778->1 4889->1 4978->1 5000->1 5111->1 5222->1 5289->1 5367->1
 [73] 5489->1 5554->1 5556->1 5633->1 5667->1 5744->1 5766->1 5778->1 5911->1 5922->1 5999->1 6000->1
 [85] 6110->1 6155->1 6221->1 6244->1 6266->1 6355->1 6443->1 6554->1 6665->1 6711->1 6777->1 6789->1
+ ... omitted several edges
> plot(newG70)
```



Determining the alpha centrality, central node in the graph, longest paths, largest cliques, egos, and power centrality

Alpha Centrality

Using igraph's **alpha_centrality()** function, we attempt to determine the alpha centrality of our subgraph. Even after hours of operation, the alpha centrality on our network did not produce a result due to excessive processing costs. In terms of the alpha centrality, we observe the following outcome:

```
> # Alpha Centrality
> acsg <- alpha.centrality(newG70)
> sort(acsg,decreasing = TRUE)
    34309      2679     40221      1378     52553     10737     73317     29764     48720     58872     41842
19.933240 19.805783 19.326839 18.479848 18.441035 18.262928 18.022887 17.692362 17.666506 17.542556 17.533378
     4056     66250     74398     47132     13888     73678     74552     38687     51409     32164     10622
16.836112 16.790174 16.763320 16.758678 16.717930 16.321660 16.250039 16.236249 15.984612 15.926812 15.876868
    33308     64128        72      7918     68928     23444      6448     27753     31287     27910     53831
15.862836 15.840416 15.776413 15.542957 15.513030 15.469949 15.371618 15.163816 15.147805 15.123024 14.985749
    35420     68827      5700     56818     74861     45143      2613      5328     39676      7566     33432
14.737541 14.644284 14.551796 14.420710 14.415411 14.328322 14.120628 14.034627 13.966719 13.801855 13.731484
    33666     74384     34987     72871     36999     39665     71705      9873     49187      2841     13366
13.728975 13.725893 13.718125 13.664235 13.645679 13.607389 13.587286 13.534688 13.512505 13.425873 13.424558
    75092     16554      8731     37110     33086     11507      7381     63340      6521     21276      1644
13.312278 13.290914 13.214822 13.135566 13.086692 13.038966 13.028398 13.021705 13.010355 12.979723 12.958889
    13699     17465      5016     14688      7477      2256      1401     45932     74968     17254     57018
12.927484 12.924017 12.886971 12.800665 12.730273 12.581008 12.446029 12.435245 12.378461 12.343220 12.337927
     5640     74481     40143     16121      6443     27642     62528     74540      8243      2503     12721
12.315058 12.184325 12.175136 12.111066 12.087931 12.017504 12.017202 12.015282 11.970865 11.882887 11.871932
    37843      7122     12244     17132     20665     34545     21520      7244     35287     73956      8887
11.836337 11.819320 11.774921 11.750415 11.692184 11.675305 11.543765 11.493558 11.427344 11.399147 11.384657
    16721     23109      4001     34543     44319     34365     60861      3103     74144     71439      5388
11.374482 11.372076 11.352023 11.292017 11.222914 11.191917 11.157324 11.155687 11.152290 11.139242 11.026298
    55453     62105     48476     75483     62817     73934     64939     22277     22765     12057     64039
10.990973 10.972101 10.958767 10.903650 10.899677 10.871018 10.856034 10.850393 10.847522 10.844974 10.789911
    45976      6016     67184       453     12628     13320     66106     74409     73830     23788       265
10.667539 10.654416 10.563463 10.553771 10.544720 10.540266 10.498367 10.494934 10.492117 10.477339 10.474891
    13577      2507     68198     10825     12567     30220       752      6441     62584      1072     73580
10.462288 10.455232 10.433090 10.428644 10.419034 10.399399 10.396477 10.375565 10.372516 10.366785 10.327756
    72361     74544     73793     24577     74475     58784     74411     61795       548      1321     11248
10.285911 10.285487 10.258719 10.253054 10.252084 10.251565 10.244806 10.236382 10.201818 10.197988 10.188328
 4.036109  4.035629  4.034951  4.029745  4.022428  4.019221  4.017913  4.017268  4.015592  4.004132  4.000832
     5965     52220     23998      7000     73835     37998     19909     74389     67440     61140     20642
 3.999352  3.996883  3.996679  3.995185  3.989776  3.986705  3.982851  3.974237  3.965520  3.964734  3.956667
    15943      2917     57495     59828     38442     11724      2346     31909     15921     13788     24443
 3.953222  3.950676  3.947066  3.945885  3.941418  3.938078  3.926752  3.926611  3.923872  3.919631  3.917580
    21097     31986     48065      3336      2889      4931      1292     39143     27542     14932     74516
 3.910663  3.910039  3.908333  3.896985  3.896952  3.884783  3.876262  3.875065  3.862349  3.843082  3.838572
    74447     64383      1864     44075     75133      7622     24455     13801     14087     29698      2906
 3.835325  3.832287  3.824540  3.820029  3.819836  3.819125  3.811162  3.804250  3.794464  3.788160  3.770851
     1939       769     34754     25354     29376       617     75621     43920     18943      1375     24732
 3.763158  3.759452  3.756282  3.746919  3.744317  3.744097  3.744066  3.742642  3.734205  3.726825  3.724722
    50953     22998      5242     12366     46653     17265     22477     33275     27110     30886     13832
 3.724048  3.705560  3.703926  3.698005  3.697677  3.697403  3.696013  3.687579  3.684224  3.682320  3.681366
     5389     17520     58439     74017     74915     10154     13399     23054      1934     73863      2557
 3.675435  3.672976  3.662318  3.659418  3.654827  3.646382  3.644172  3.643856  3.640008  3.639026  3.637145
    64573     30664     11943      3380     31997     34666     32476     11594     20110     25287
 3.636042  3.633471  3.632161  3.627822  3.617851  3.615803  3.615740  3.615636  3.612112  3.609968
 [ reached getOption("max.print") -- omitted 3322 entries ]
```

Central Node

We can find the central node in two ways,

First, based on the sum of in and out degree.

```
> # Central Node
> central_node <- which.max(degree(g, mode = "all"))
> central_node
8886
 156
```

Second, based on the node with the highest betweenness

```
> bet <- betweenness(g)
> central_node <- which.max(bet)
> central_node
8886
 156
```

Longest Path

We use the **components()** function to extract the longest path, which must be in the greatest connected component. We then construct a subgraph with vertices inside that largest connected component. We also give each vertex attribute a degree.
Next, we can calculate the greatest distance from a single vertex using DFS.

```
> # Longest Path
> sg = induced.subgraph(g, which(components (g) $membership == 1))
Warning message:
`induced.subgraph()` was deprecated in igraph 2.0.0.
i Please use `induced_subgraph()` instead.
This warning is displayed once every 8 hours.
Call `lifecycle::last_lifecycle_warnings()` to see
where this warning was generated.
> V(sg)$degree = degree(sg)
> result = dfs(sg, root = 1, dist = TRUE)$dist
> sort(result, decreasing = TRUE)
61710 67561 36935 61709 61711 63401 63893 38748 69949
 9955  9955  9954  9954  9954  9954  9954  9953  9953
57193 61679 61680 61681 61682 41214 41212 41213 32077
 9953  9953  9953  9953  9953  9953  9953  9953  9952
75287 24951 55548 57192 59268 59269 59582 59583 60676
 9952  9952  9952  9952  9952  9952  9952  9952  9952
60677 68358 68359 61180 61687 61688 67355  4166  9044
 9952  9952  9952  9952  9952  9952  9952  9951  9951
32087 49257 24360 30164 55547 32139 39283 57788 57789
 9951  9951  9951  9951  9951  9951  9951  9951  9951
28171 59581 61099 28673 62459 67773 30931 13882 25170
 9951  9951  9951  9951  9951  9950  9950  9950  9950
46825 32078 32079 25244 15469 54098 18327 55830 55831
```

```
17257 74395 43558 15942 44629 40125 65806 24995  9705
 9926  9926  9926  9926  9926  9926  9926  9926  9926
34314 73720 15532 49896 49897 50160 50682 25764 41294
 9926  9926  9926  9926  9926  9926  9926  9926  9926
50697 50699 53932 38680 57888 57889 58316 58318 58425
 9926  9926  9926  9926  9926  9926  9926  9926  9926
21792 37351 61176 61177 37100 39607 39612 65386 65387
 9926  9926  9926  9926  9926  9926  9926  9926  9926
65388 65389 65390 37101 37102 39203 39601 39602 70975
 9926  9926  9926  9926  9926  9926  9926  9926  9925
 7750
 9925
 [ reached getOption("max.print") -- omitted 74877 entries ]
```

Largest Clique

We get the minimal degree needed for every vertex in the greatest clique, as well as the largest cliques in our graph g directly using the **largest_cliques()** method. To find the greatest cliques, we utilize the binary search approach and the splitting graph.

```
> # Largest Clique
> largest_cliques(g)
[[1]]
+ 23/75879 vertices, named, from b69a5b5:
 [1] 26109 45553 75103 38109 226   44441 68882 15553 337   22220 49998 56661 2111  2556  74770 31442 2222  1111  50109
[20] 38775 75547 17775 21108

[[2]]
+ 23/75879 vertices, named, from b69a5b5:
 [1] 26109 45553 75103 38109 226   44441 68882 15553 337   22220 14776 56661 75436 1889  2556  17775 38775 75547 21108
[20] 50109 59883 74770 62661

[[3]]
+ 23/75879 vertices, named, from b69a5b5:
 [1] 26109 45553 75103 38109 226   44441 68882 15553 337   22220 14776 56661 75436 1889  2556  17775 38775 75547 21108
[20] 50109 59883 74770 2222

[[4]]
+ 23/75879 vertices, named, from b69a5b5:
 [1] 26109 45553 33443 68882 38109 226   44441 2222  337   22220 15553 56661 2111  31442 1111  17775 49998 50109 21108
[20] 74770 75547 2556  38775

[[5]]
+ 23/75879 vertices, named, from b69a5b5:
 [1] 26109 45553 33443 68882 38109 226   44441 2222  337   22220 15553 56661 1889  14776 75436 38775 21108 17775 50109
[20] 2556  75547 74770 59883
```

```
[[6]]
+ 23/75879 vertices, named, from b69a5b5:
 [1] 26109 45553 33443 68882 38109 27775 74770 2556  44441 2222  31442 50109 337   22220 15553 17775 56661 2111  21108
[20] 38775 1111  75547 49998

[[7]]
+ 23/75879 vertices, named, from b69a5b5:
 [1] 71104 45553 75103 38109 68882 226   44441 448   15553 337   22220 14776 1889  75436 7221  2222  44442 69993 19997
[20] 62550 1778  33554 49997

[[8]]
+ 23/75879 vertices, named, from b69a5b5:
 [1] 71104 45553 75103 38109 68882 226   44441 56661 15553 337   33554 2222  44442 22220 62550 49997 14776 1889  7221
[20] 1778  69993 19997 75436

[[9]]
+ 23/75879 vertices, named, from b69a5b5:
 [1] 71104 45553 33443 68882 38109 337   2222  226   448   22220 14776 44441 15553 1889  7221  62550 75436 69993 19997
[20] 44442 1778  33554 49997

[[10]]
+ 23/75879 vertices, named, from b69a5b5:
 [1] 71104 45553 33443 68882 38109 337   2222  226   56661 15553 44441 33554 22220 14776 1889  42219 62550 7221  75436
[20] 69993 49997 44442 1778

[[11]]
+ 23/75879 vertices, named, from b69a5b5:
 [1] 71104 45553 33443 68882 38109 337   2222  226   56661 15553 44441 33554 22220 14776 1889  42219 62550 7221  75436
[20] 69993 49997 44442 17775

[[12]]
+ 23/75879 vertices, named, from b69a5b5:
 [1] 71104 45553 33443 68882 38109 337   2222  226   56661 15553 44441 33554 22220 14776 1889  19997 1778  62550 69993
[20] 7221  75436 49997 44442

[[13]]
+ 23/75879 vertices, named, from b69a5b5:
 [1] 71104 44441 75103 226   38109 18886 68882 448   2222  1889  337   22220 7221  15553 44442 14776 49997 62550 33554
[20] 1778  19997 69993 75436


[[14]]
+ 23/75879 vertices, named, from b69a5b5:
 [1] 71104 44441 75103 226   38109 18886 68882 56661 337   15553 33554 2222  75436 1889  14776 22220 62550 49997 44442
[20] 69993 7221  1778  19997

[[15]]
+ 23/75879 vertices, named, from b69a5b5:
 [1] 71104 44441 33443 18886 38109 226   68882 337   2222  22220 1889  448   75436 14776 7221  62550 69993 19997 15553
[20] 1778  33554 44442 49997

[[16]]
+ 23/75879 vertices, named, from b69a5b5:
 [1] 71104 44441 33443 18886 38109 226   68882 337   2222  22220 1889  56661 15553 69993 75436 14776 33554 62550 7221
[20] 49997 44442 17775 42219

[[17]]
+ 23/75879 vertices, named, from b69a5b5:
 [1] 71104 44441 33443 18886 38109 226   68882 337   2222  22220 1889  56661 15553 69993 75436 14776 33554 62550 7221
[20] 49997 44442 1778  42219

[[18]]
+ 23/75879 vertices, named, from b69a5b5:
 [1] 71104 44441 33443 18886 38109 226   68882 337   2222  22220 1889  56661 15553 69993 75436 14776 33554 62550 7221
[20] 49997 44442 1778  19997
```

Ego(s)

We calculated the egos for all the vertices as shown. In our result, most of the values get omitted.

```
 [55] 55086 66416 75784 75835 35121 25732 54820 20554 54931 13677 13965 8198  33743 40964 13666 61750 75126 74148
 [73] 73311 10021 75831 45443 38376 64327 74281 9953  6833  11111 13999 37221 44999 75764 593   75852 65216 60506
 [91] 10254 73299 75767 75860 33532 53131 6822  63539 75773 75810 74981 75857 54020 17465 20187 75854 16143 73693
[109] 73499 44987 75842 991   75771 75859 13011 75845 75765 59007 30021 75794 36631 75782 75818 75749 75844 73808
[127] 75849 75766 70550 60883 72005 75841 75371 75850 75768 75809 75824 27698 75856 75798 75861 75780 73757 75853
[145] 75811 75756 16209 75796 75512 75761 21347 75760 22274 75808 75828 75802 75375 30752 67501 69241 69266 71914
[163] 71915 71917 71918 71920 74758 75750 75751 75752 75753 75754 75755 75757 75759 75762 75763 75772 75774 75775
+ ... omitted several vertices

[[997]]
+ 53/75879 vertices, named, from b69a5b5:
 [1] 32331 4222  5000  8886  13554 19886 20886 23331 33330 33776 44441 63327 73658 326   24220 30442 34554 37998 45331
[20] 2     75647 55552 4457  93    70993 1734  66549 16043 1434  73392 73614 75571 1401  74118 48431 24265 66516 9887
[39] 75059 60    24466 20809 28498 72771 1512  73213 74314 73642 28409 75634 74355 40243 75862

[[998]]
+ 35/75879 vertices, named, from b69a5b5:
 [1] 32442 7800  8886  12187 12788 15331 15921 20220 58883 16265 16332 25442 70549 2     2112  35409 47365 25398 11743
[20] 35132 12444 74636 9953  7599  31409 36221 43942 62806 75176 74615 54620 75864 26987 45599 75863

[[999]]
+ 978/75879 vertices, named, from b69a5b5:
  [1] 32487 1334  2778  2889  3111  3145  3334  4778  5778  6855  7665  12388 13065 14276 19997 21109 21553 22332
 [19] 31664 32576 36553 37775 42031 43330 47876 48886 49886 54441 59994 61106 67051 67106 73281 74103 83    326
 [37] 354   939   1337  1375  1589  1750  2301  4211  4531  4801  4890  5001  5056  5145  5278  5655  5678  6889
 [55] 6955  9431  10132 10965 12987 18376 18932 24154 24443 27331 27799 31920 35554 36887 36998 39409 44197 44330
 [73] 47121 49553 54498 55264 55331 57473 70039 70549 70882 71305 72550 73249 74212 74443 74747 74867 74925 2
 [91] 2056  2112  74870 3501  9054  15209 17854 65883 75581 2232  11888 14643 55020 61784 74970 75847 1952  28032
[109] 29498 75479 7954  37954 1689  33943 35221 75138 2013  73485 16043 60628 69105 74735 2608  7088  7099  7458
[127] 7460  7462  9243  55086 73326 71038 18032 29831 8343  15566 21731 27487 54875 9043  74993 4545  34232 61262
[145] 567   31742 46843 55242 227   3200  4119  7108  8076  9387  14329 14447 15773 18365 18720 30032 34699 35365
[163] 44264 45932 54909 61240 61795 62972 63795 1386  15767 18232 53653 68771 74725 38864 7508  1975  4756  6281
+ ... omitted several vertices

[[1000]]
+ 24/75879 vertices, named, from b69a5b5:
 [1] 32553 448   1889  2222  5000  7221  9442  13331 26664 44442 60550 2     6621  238   3845  73270 3923  18132 3335
[20] 3579  44364 19631 31042 75865

 [ reached getOption("max.print") -- omitted 74879 entries ]
```

Power Centrality

Because it is less computationally demanding than operating on the original graph, we run the **power_centrality()** function on the subgraph and obtain the following outcome:

```
> # Power Centrality
> pc <- power_centrality(sg, exponent = 0.8)
> sort(pc,decreasing = TRUE)
    50898     74398     18943      2557     17065
3.8065708 3.4263058 3.3555889 3.2372445 3.1841918
    30565     43975     11865     23309     75092
3.0756045 3.0654297 3.0593137 3.0570830 3.0474227
     7778      1975      6077     75231     55555
2.9999894 2.9886769 2.8507025 2.7802631 2.7800905
     7949     13788     73727      9873      1601
2.7579463 2.7408055 2.7396547 2.7308880 2.7045923
    11952     10013     47154     33799     12965
2.6992216 2.6592313 2.6024564 2.5967170 2.5747038
    73934     75593      2668     27520     72071
2.5589962 2.5291807 2.5269885 2.4998050 2.4982015
     2256        76     39465     68705     59872
2.4620935 2.4546216 2.4522640 2.4411813 2.4212111
     5055     74739     50465      1044     14566
2.4184768 2.4113449 2.3999751 2.3849355 2.3450448
0.5158922 0.5157707 0.5151705 0.5145553 0.5124539
     4667      7388     10737     55153     23499
0.5118930 0.5116844 0.5111054 0.5105826 0.5099342
    64772     73684     61428      6033      1334
0.5075373 0.5073847 0.5072200 0.5062557 0.5051748
     4955     52864     75139     73770     58661
0.5050106 0.4975121 0.4967682 0.4957897 0.4947362
    14887      6213     66250     10432     45710
0.4943133 0.4943075 0.4939097 0.4937603 0.4932935
    62484     24087     34420     74231      3083
0.4928185 0.4920372 0.4884251 0.4874478 0.4873675
    43764     73517     25976      3244     66884
0.4861649 0.4851846 0.4846476 0.4843152 0.4840420
     7443     10646     74559      5711      4568
0.4834032 0.4830957 0.4821473 0.4820341 0.4798337
 [ reached getOption("max.print") -- omitted 3322 entries ]
```

Discussion

Our understanding of working with datasets and creating graphs from them—especially medium- to large-scale datasets—is improved by this study. We gained practical experience in building our own functions, using the igraph and sna packages, and utilizing R. We improved our abilities to plot and visualize graphs, simplify them, and change their parameters to make them easier to read. We obtain important insights into the structure and relationships inside the graph using the numerous graph analytics functions that are described in this project.

We gained knowledge of key metrics for comprehending the issue space, including power centrality, greatest cliques, egos, longest paths, and alpha centrality. We also studied how random walks can be used to locate communities in a graph. We can find patterns, structures, and links in the data and create efficient methods for examining and visualizing big, intricate networks by comprehending these metrics.

After completing this project, we can confidently work with R to generate and plot graphs, perform graph analytics on large datasets, apply various functions and measures/metrics to the graph that allow us to draw different conclusions about the graph and the problem domain, and simplify graphs for better analysis.