NETWORK SCIENCE

Assignment 4

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1 Summary

In this assignment, a Graph is plotted in which the nodes are people involved in the terrorist attack on September 11, 2001 and the edges show which of them were somehow connected to each other before the attack. To be more specific, there would be an edge connecting terrorist A to terrorist B if A was in contact with B in some way before the attack. Then, some centrality measures are calculated for further analysis. At the end, a sub-graph of only hijackers is created and the largest cliques of the network is listed. The data for this assignment is downloaded from the assignment page on canvas.

2 Loading Data

As stated in the assignment guide file, these commands are used to load the data from the CSV files to the programming environment.

```
nodes <- read.csv("vertex911.csv", header = T) > adj <- read.csv("
adj911.csv", header=T)
adj <- as.matrix(adj) # convert to R matrix object
```

Then, a graph object is created from the loaded data using the command below:

```
g <- graph_from_adjacency_matrix(adj, mode = "undirected")
```

3 Question 1

First, I assigned red color to the nodes corresponding the hijackers and blue to others.

```
V(g)$color <- "blue"
V(g)$color[1:19] <- "red"
```

Next, The graph shown in Figure 1 is plotted using the code below:

```
customizing1 <- layout_(g, with_gem())
plot(g, vertex.size=8, vertex.label = NA, layout = customizing1)
```

Looking at the graph, We can see that hijackers(red nodes) are not highly interconnected. On the other hand, some of the blue nodes are highly interconnected. It seems that the blue nodes are somehow the coordinators of the operation and were more in contact with each other. Some hijackers are only connected to another hijacker. The graph does not seem to have any disconnected component, and the whole graph seems to be connected. To make sure that the graph is connected I ran this line of code:
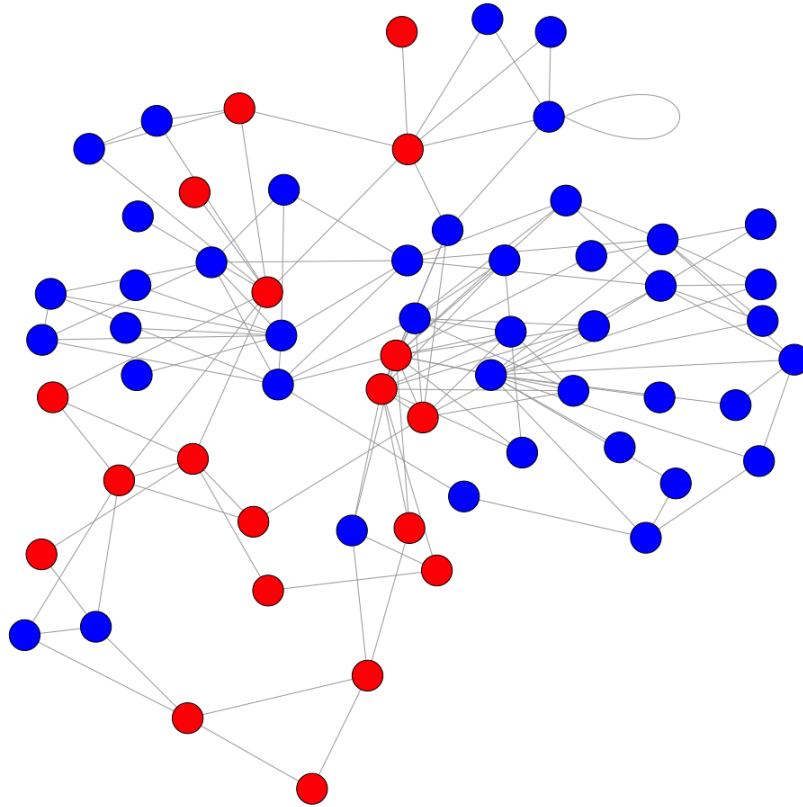
```
is_connected(g) #output: TRUE
```

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Figure 1: Network plot of Question 1

4 Question 2

I used the eigenvalue centrality measure to list the top five central members of the network by their name.

Calculating eigenvalue centralities and adding them to nodes object:

```
eigen.cent <- eigen_centrality(g)
nodes[,5] = eigen.cent$vector
colnames(nodes)[5] <-c("EigenCent")
```

Top five nodes based on eigenvalue centrality:

```
top5 = head(nodes[order(nodes$EigenCent, decreasing = TRUE), ][,1],5)
#output: "Mohamed Atta", "Marwan Al-Shehhi", "Ramzi Bin al-Shibh", "
Ziad Jarrah", "Said Bahaji"
```

Hijackers present in top 5:

```
intersect(top5, head(nodes[,1], 19))
#output: "Mohamed Atta", "Marwan Al-Shehhi", "Ziad Jarrah"
```

5 Question 3

Very similar to Question 2, this time calculating betweenness and closeness and adding them to nodes object as new columns:

```
1   nodes[,6] <- betweenness(g)
2   colnames(nodes)[6] <-c("betweenness")
3
4   nodes[,7] <- closeness(g)
5   colnames(nodes)[7] <-c("closeness")
```

Finding top 5 nodes based on betweenness:

```
1   top5_betweenness = head(nodes[order(nodes$betweenness, decreasing =
    TRUE), ][,1],5)
2   # "Mohamed Atta", "Essid Sami Ben Khemail", "Lofti Raissi", "Zacarias
    Moussaoui", "Hani Hanjour"
```

Finding hijackers present in top 5 based on betweenness:

```
1   intersect(top5_betweenness, head(nodes[,1], 19))
2   #output: "Mohamed Atta", "Hani Hanjour"
```

Finding top 5 nodes based on closeness:

```
1   top5_closeness = head(nodes[order(nodes$closeness, decreasing = TRUE),
    ][,1],5)
2   # "Mohamed Atta", "Marwan Al-Shehhi", "Ziad Jarrah"        "Lofti
    Raissi", "Ramzi Bin al-Shibh"
```

Finding hijackers present in top 5 based on closeness:

```
1   intersect(top5_closeness, head(nodes[,1], 19))
2   #output: "Mohamed Atta", "Marwan Al-Shehhi", "Ziad Jarrah"
```

6 Question 4

Number of different clique sizes is shown in table 1. According to the table, largest clique size is 6 and there is only one clique with this size in the network.

```
1   table(sapply(cliques(g),length))
```

List of all the cliques with maximum size(6):

```
1   largest_clique_list = cliques(g) [sapply(cliques(g), length) == 6]
2   # 13 14 15 24 25 28
3   # Ziad.Jarrah, arwan.Al.Shehhi, Mohamed.Atta, Zakariya.Essabar, Said.
    Bahaji, Ramzi.Bin.al.Shibh
```

Which of the hijackers were part of these cliques? Three of the hijackers were part of this clique. Ziad.Jarrah, arwan.Al.Shehhi, and Mohamed.Atta.

Which of the pilots were and were not part of these cliques All the pilots were part of the largest clique except **Hani Hanjour**

Clique size	1	2	3	4	5	6
Count	61	131	87	34	9	1

Table 1: Question 4: number of cliques by size

7 Question 5

Create a sub-graph of 19 hijackers only:

```
1 g2 <- graph_from_adjacency_matrix(adj[1:19,1:19], mode = "undirected")
```
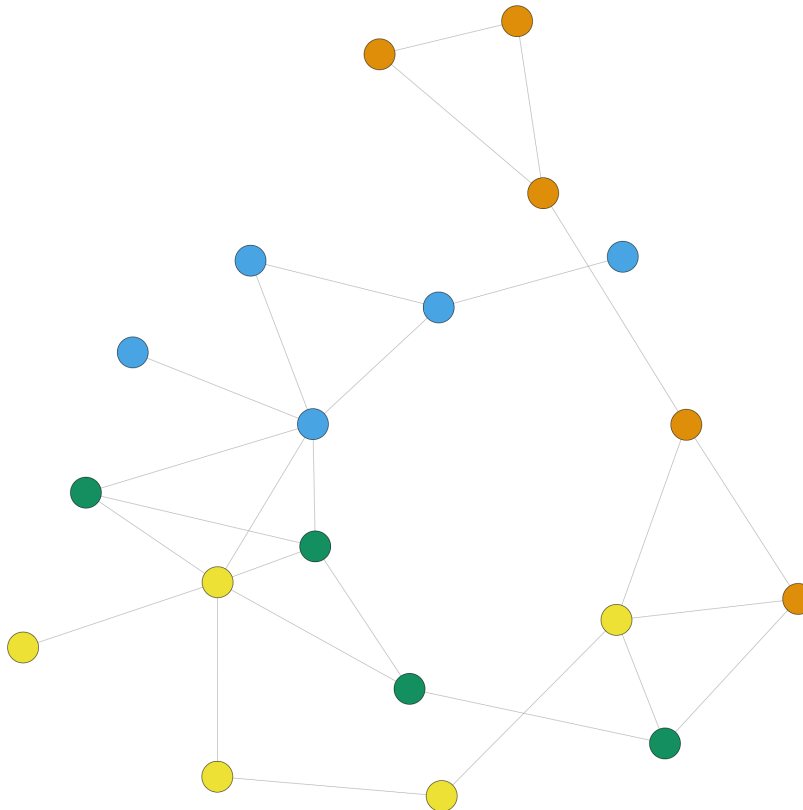
7.1 a

The graph is shown in Fig 2

Figure 2: Network plot of Question 5

Did all the hijackers on a given flight know the pilot hijacker of that flight? No, for example in nodes in orange color there is not any node that is connected to all other orange nodes. So, there is not any node in that flight that everybody know them.

7.2 b

Number of different clique sizes is shown in table 2.

```
1 table(sapply(cliques(g2),length))
```

Clique size	1	2	3
Count	19	23	5

Table 2: Question 5: number of cliques by size

List the cliques of the largest size in this subgraph.

- Waleed.Alshehri, Wail.Alshehri, Satam.Suqami

- Marwan.Al.Shehhi, Mohamed.Atta, Abdul.Aziz.Al.Omari

- Ziad.Jarrah, Marwan.Al.Shehhi, Mohamed.Atta

- Nawaf.Alhazmi, Ahmed.Alnami, Hamza.Alghamdi

- Khalid.Al.Mihdhar, Hani.Hanjour, Nawaf.Alhazmi

Did any pilot belong to these cliques? All 4 pilots are at least in one of the cliques.

Did all the four pilots know one another? No, In order for all the pilots to know each other, we should have a clique with size greater than 3 that all the pilots are part of. The largest clique in this network has size = 3. So, the answer is no.