PSTAT 194CS Final Project Appendix - Code

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```
library(igraphdata)
library(igraph)
```

```
## Warning: package 'igraph' was built under R version 4.3.2
```

```
##
## Attaching package: 'igraph'
```

```
## The following objects are masked from 'package:stats':
##
##     decompose, spectrum
```

```
## The following object is masked from 'package:base':
##
##     union
```

Reading and Loading the Network Data from Txt File

```
# read in the raw edgelist
email.data = read.table("~/Desktop/PSTAT 194CS/email-EuAll.txt", sep = "\t", header = TRUE, stringsAsFa

# convert data to matrix
email.edgelist = matrix(unlist(email.data), ncol = 2) + 1
```

```
# set up 'user' vertex attribute
vertex_ids <- unique(c(email.data$X0, email.data$X1))
vertex_users <- paste(vertex_ids)
```

Setting Up the Margins

```
# default margins
def_marg = c(5.1, 4.1, 4.1, 2.1)

# no margins
no_marg = c(0, 0, 0, 0)
```

Converting the Network Data to Igraph Object

```
email <- graph.edgelist((email.edgelist), directed = TRUE)
```

```
## Warning: ‘graph.edgelist()‘ was deprecated in igraph 2.0.0.
## i Please use ‘graph_from_edgelist()‘ instead.
## This warning is displayed once every 8 hours.
## Call ‘lifecycle::last_lifecycle_warnings()‘ to see where this warning was
## generated.
```

```
email
```

```
## IGRAPH 33ba425 D--- 265214 420044 --
## + edges from 33ba425:
##  [1] 1->    5 1->    6 1->    9 1->   12 1->   21 1->   49 1->  131 1->  161
##  [9] 1->  431 1->  669 1->  737 1-> 3613 1-> 4253 1->16688 2->    2 2->   45
## [17] 2->   51 2->   57 2->   99 2->  100 2->  107 2->  147 2->  148 2->  150
## [25] 2->  159 2->  172 2->  176 2->  185 2->  207 2->  260 2->  334 2->  337
## [33] 2->  393 2->  398 2->  407 2->  423 2->  447 2->  458 2->  586 2->  603
## [41] 2->  621 2->  641 2->  733 2->  734 2->  780 2->  842 2-> 1034 2-> 1119
## [49] 2-> 1262 2-> 1263 2-> 1291 2-> 1371 2-> 1426 2-> 1459 2-> 1516 2-> 1519
## [57] 2-> 1522 2-> 1547 2-> 1620 2-> 1624 2-> 1777 2-> 1804 2-> 1967 2-> 1970
## [65] 2-> 2015 2-> 2038 2-> 2059 2-> 2245 2-> 2357 2-> 2559 2-> 2875 2-> 2925
## + ... omitted several edges
```

```
# add 1 to values of email.data so that they match the values of email
email.data$X0 <- email.data$X0 +1
email.data$X1 <- email.data$X1 +1
```

Check Attributes of the Data

```
graph.attributes(email)
```

```
## named list()
```

```
vertex.attributes(email)
```

```
## named list()
```

```
edge.attributes(email)
```

```
## named list()
```

This shows that our network data has no attributes

```r
# create user as a vertex attribute
V(email)$user <- vertex_users
```

```r
# Basic network properties
num_vertices = vcount(email)
num_edges = ecount(email)

# Print properties
cat("Number of vertices:", num_vertices, "\n")
```

```
## Number of vertices: 265214
```

```r
cat("Number of edges:", num_edges, "\n")
```

```
## Number of edges: 420044
```

Initial Metric Analysis of the Whole Network Data

```r
# Density to look at how connected each nodes are with each other
graph.density(email)
```

```
## Warning: ‘graph.density()‘ was deprecated in igraph 2.0.0.
## i Please use ‘edge_density()‘ instead.
## This warning is displayed once every 8 hours.
## Call ‘lifecycle::last_lifecycle_warnings()‘ to see where this warning was
## generated.
```

```
## [1] 5.971776e-06
```

```r
# Reciprocity
reciprocity(email)
```

```
## [1] 0.2600518
```

```r
# Dyad Census
dyad_census(email) # tell how many mutual, asymmetric, and null
```

```
## $mut
## [1] 54475
##
## $asym
## [1] 310005
##
## $null
## [1] 35168735811
```

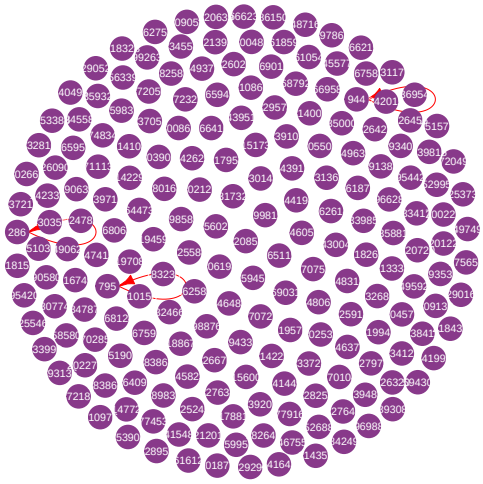
```r
# Transitivity
transitivity(email)
```

```
## [1] 0.004106451
```

Generating Induced Subgraphs Using Random Sampling

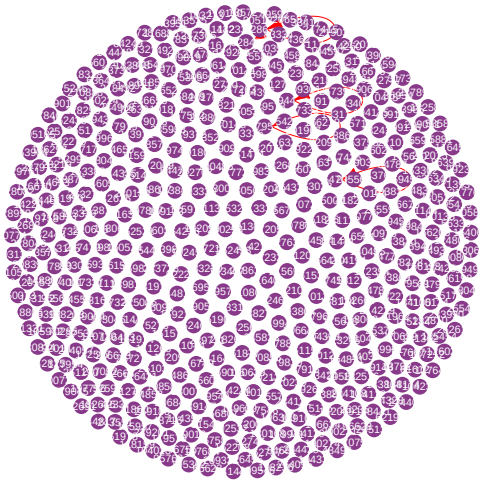
200 Nodes

```r
# 1st subgraph with 200 nodes
set.seed(111)

V(email)$name = as.character(1:vcount(email))

sampled_vertices = sample(V(email), 200)

email_sub1 = induced_subgraph(email, sampled_vertices)

plot(email_sub1,
     # === vertex properties
     vertex.color = "#88398A",
     vertex.frame.color = "#88398A",
     vertex.size = 10,
     # === vertex label properties
     vertex.label.cex = 0.3,
     vertex.label.color = "white",
     vertex.label.family = "Helvetica",
     # === edge properties
     edge.color = "red",
     edge.width = 0.5,
     edge.arrow.size = 0.4)
```



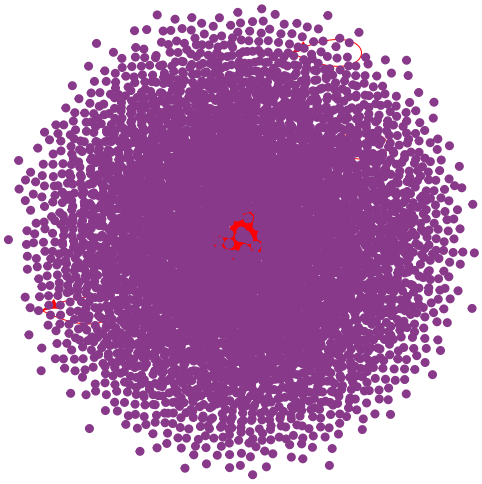
500 Nodes

```
# 2nd subgraph with 500 nodes
set.seed(111)

V(email)$name = as.character(1:vcount(email))

sampled_vertices = sample(V(email), 500)


email_sub2 = induced_subgraph(email, sampled_vertices)

plot(email_sub2,
     # === vertex properties
     vertex.color = "#88398A",
     vertex.frame.color = "#88398A",
     vertex.size = 6,
     # === vertex label properties
     vertex.label.cex = 0.3,
     vertex.label.color = "white",
     vertex.label.family = "Helvetica",
     # === edge properties
     edge.color = "red",
     edge.width = 0.5,
     edge.arrow.size = 0.4)
```



5000 Nodes

```
# 3rd subgraph with 5000 nodes
set.seed(111)

V(email)$name = as.character(1:vcount(email))

sampled_vertices = sample(V(email), 5000)


email_sub3 = induced_subgraph(email, sampled_vertices)

plot(email_sub3,
     # === vertex properties
     vertex.color = "#88398A",
     vertex.frame.color = "#88398A",
     vertex.size = 3,
     vertex.label = NA,
     # === edge properties
     edge.color = "red",
     edge.width = 0.5,
     edge.arrow.size = 0.4)
```



Based on the three plots of the induced subgraphs using random sampling (200, 500, and 5000), we can see that it is not effective to analyze the subgraphs of this network dataset using random sampling.

Exploring the Email Addresses that Sent Emails to the Most Recipients and Received Emails from the Most Senders

```
# Finding the email addresses that sent and received the most emails

x = table(email.data$X0)
paste("User who send out the most email: " , names(which.max(x))) # send out the most email
```

```
## [1] "User who send out the most email:  84"
```

```
paste("How many emails send out: " , max(x)) # User 84 send out 930 recipients
```

```
## [1] "How many emails send out:  930"
```

```
y = table(email.data$X1)
paste("User who receive the most email: ", names(which.max(y))) # receive the most email
```

```
## [1] "User who receive the most email:  179171"
```

```r
paste("How many emails received: ", max(y)) # User 179171 received emails from 7631 senders
```

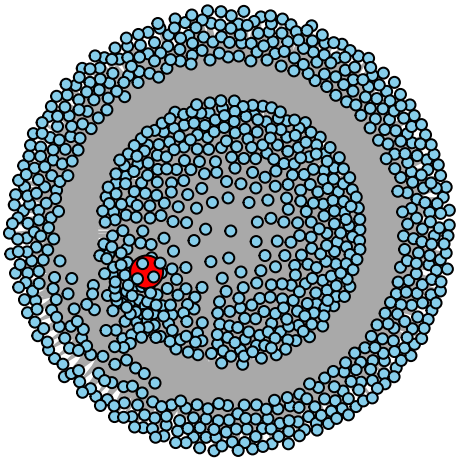
```
## [1] "How many emails received:  7631"
```

We discovered that Node 84, identified as User 84, sent out emails to the most recipients, totaling 930 recipients. Additionally, User 179171 received emails from the most senders, amounting to 7631 senders. These users likely hold significant roles within the network. We hypothesize that a user receiving a high volume of emails may be more deeply connected to their community and potentially hold a leadership position. It's possible that many individuals are reporting back to them.

Looking Closer at Node 84: The User Who Sends to the Most Recipients

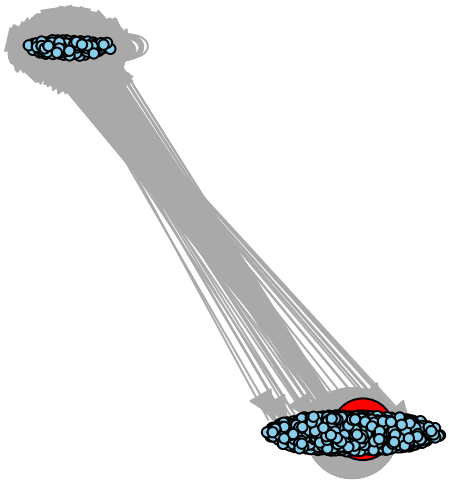
```r
# Separate plots for User 84's sent and received emails

node_of_interest = '84'

# SENT
sent_edges <- email.data[email.data$X0 == node_of_interest, ]
sent_nodes <- unique(sent_edges$X1)
sent_subgraph1 <- induced_subgraph(email, c(node_of_interest, sent_nodes))
if (vcount(sent_subgraph1) == 0) {
  print("No nodes found to which mails were sent by the node of interest.")
} else {
  # node colors
  vertex_colors <- rep("skyblue", vcount(sent_subgraph1))
  vertex_colors[which(V(sent_subgraph1) == node_of_interest)] <- "red"
  V(sent_subgraph1)$color <- vertex_colors
  #node sizes
  vertex_sizes <- rep(5, vcount(sent_subgraph1))
  vertex_sizes[which(V(sent_subgraph1) == node_of_interest)] <- 15
  V(sent_subgraph1)$size <- vertex_sizes
  #plot
  plot(sent_subgraph1, vertex.label = NA, main = paste("Subgraph of Node", node_of_interest, "and Sent
}
```

Subgraph of Node 84 and Sent Mails



```
# RECEIVED
received_edges <- email.data[email.data$X1 == node_of_interest, ]
received_nodes <- unique(received_edges$X0)
received_subgraph1 <- induced_subgraph(email, c(node_of_interest, received_nodes))
if (vcount(received_subgraph1) == 0) {
  print("No nodes found from which mails were received by the node of interest.")
} else {
  # node colors
  vertex_colors <- rep("skyblue", vcount(received_subgraph1))
  vertex_colors[which(V(received_subgraph1) == node_of_interest)] <- "red"
  V(received_subgraph1)$color <- vertex_colors
  #node sizes
  vertex_sizes <- rep(5, vcount(received_subgraph1))
  vertex_sizes[which(V(received_subgraph1) == node_of_interest)] <- 30
  V(received_subgraph1)$size <- vertex_sizes
  #plot
  plot(received_subgraph1, vertex.label = NA, main = paste("Subgraph of Node", node_of_interest, "and Re
}
```

Subgraph of Node 84 and Received Mails



```
# Community detection and visualization for User 84's sent emails

print(vcount(sent_subgraph1))
```

```
## [1] 930
```

```
print(vcount(received_subgraph1))
```

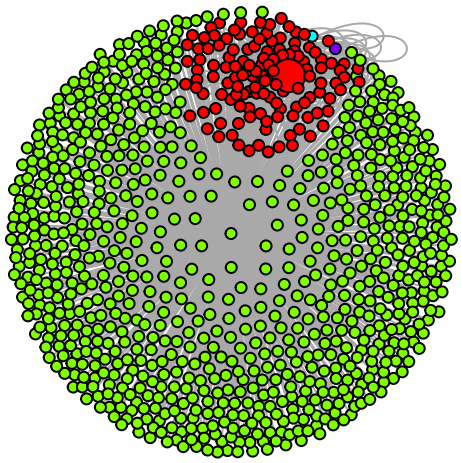
```
## [1] 2696
```

```
und_1 <- as.undirected(sent_subgraph1)
und_2 <- as.undirected(received_subgraph1)
community11 <- fastgreedy.community(und_1)
```

```
## Warning: `fastgreedy.community()` was deprecated in igraph 2.0.0.
## i Please use `cluster_fast_greedy()` instead.
## This warning is displayed once every 8 hours.
## Call `lifecycle::last_lifecycle_warnings()` to see where this warning was
## generated.
```

```
community12 <- fastgreedy.community(und_2)

clusters <- cluster_fast_greedy(und_1)
```

```r
V(und_1)$group <- membership(clusters)
num_groups <- length(unique(V(und_1)$group))
group_colors <- rainbow(num_groups)
V(und_1)$color <- group_colors[V(und_1)$group]
plot(und_1, vertex.label = NA, main = "Graph with Nodes Colored by Group")
```

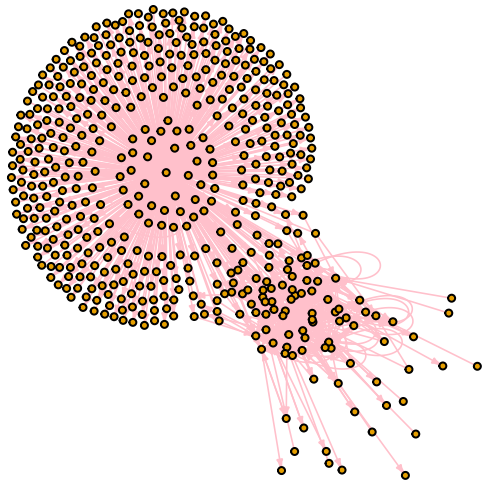



```r
# Taking a random sample of User 84's sent email connections

set.seed(123)
node_of_interest <- '84'

# SENT
sent_edges <- email.data[email.data$X0 == node_of_interest, ]
sent_nodes <- unique(sent_edges$X1)
sent_subgraph1 <- induced_subgraph(email, c(node_of_interest, sent_nodes))
edge_sample <- sample(E(sent_subgraph1), 930)
sub.network1 <- subgraph.edges(sent_subgraph1, edge_sample)
edge_count <- ecount(sub.network1)
print(paste("Number of edges in the subgraph: ", edge_count))
```

```
## [1] "Number of edges in the subgraph:  930"
```

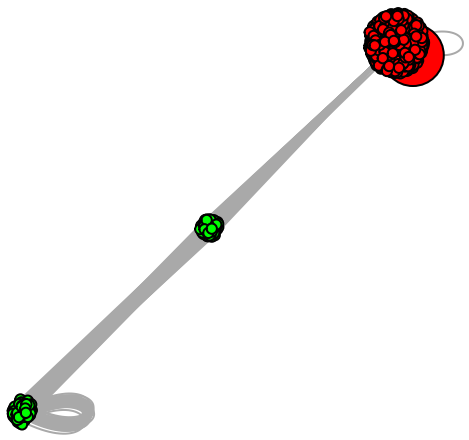
```r
vertex_colors <- rep("skyblue", vcount(sub.network1))
vertex_colors[sub.network1 == node_of_interest] <- "red"
```

```r
plot(sub.network1, vertex.label = NA, vertex.size = 3,
     edge.arrow.size = 0.2, edge.width = 0.8, edge.color = "pink")
```



Community Detection of Node 84

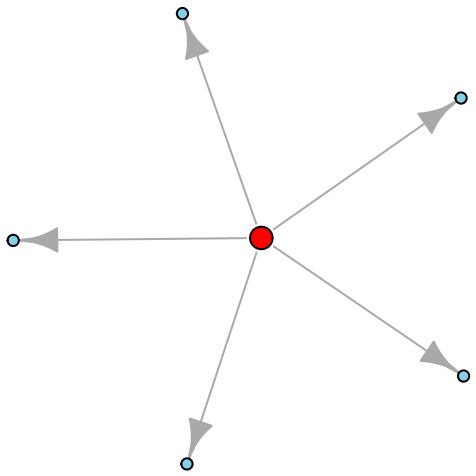
```r
# Community detection and visualization for User 84's received emails

clusters <- cluster_fast_greedy(und_2)
V(und_2)$group <- membership(clusters)
num_groups <- length(unique(V(und_2)$group))
group_colors <- rainbow(num_groups)
V(und_2)$color <- group_colors[V(und_2)$group]
plot(und_2, vertex.label = NA, main = "Graph with Nodes Colored by Group")
```



Looking Closer at Node 179171: The User Who Received Emails from the Most Senders

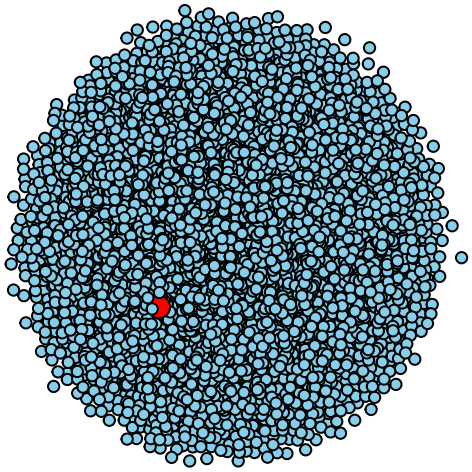
```
# Separate plots for User 179171's sent and received emails

node_of_interest <- '179171'

# SENT
sent_edges <- email.data[email.data$X0 == node_of_interest, ]
sent_nodes <- unique(c(node_of_interest, sent_edges$X1))
sent_subgraph <- induced_subgraph(email, sent_nodes)
if (vcount(sent_subgraph) == 0) {
  print("No nodes found to which mails were sent by the node of interest.")
} else {
  #node colors
  vertex_colors <- rep("skyblue", vcount(sent_subgraph))
  vertex_colors[which(V(sent_subgraph) == '1')] <- "red"
  V(sent_subgraph)$color <- vertex_colors
  #node sizes
  vertex_sizes <- rep(5, vcount(sent_subgraph))
  vertex_sizes[which(V(sent_subgraph) == '1')] <- 10
  V(sent_subgraph)$size <- vertex_sizes
  #plot
```

```
  plot(sent_subgraph, vertex.label = NA, main = paste("Subgraph of Node", node_of_interest, "and Sent Ma
}
```




```
# RECEIVED
received_edges <- email.data[email.data$X1 == node_of_interest, ]
received_nodes <- unique(c(node_of_interest, received_edges$X0))
received_subgraph <- induced_subgraph(email, which(V(email)$user %in% received_nodes))
if (vcount(received_subgraph) == 0) {
  print("No nodes found from which mails were received by the node of interest.")
} else {
  subgraph_users <- V(received_subgraph)$user
  #node colors
  vertex_colors <- rep("skyblue", vcount(received_subgraph))
  vertex_colors[subgraph_users == node_of_interest] <- "red"
  V(received_subgraph)$color <- vertex_colors
  #node sizes
  vertex_sizes <- rep(5, vcount(received_subgraph))
  vertex_sizes[subgraph_users == node_of_interest] <- 10
  V(received_subgraph)$size <- vertex_sizes
  #plot
  plot(received_subgraph, vertex.label = NA, main = paste("Subgraph of Node", node_of_interest, "and Re
}
```

Subgraph of Node 179171 and Received Mails



```
print(vcount(sent_subgraph))
```

```
## [1] 6
```

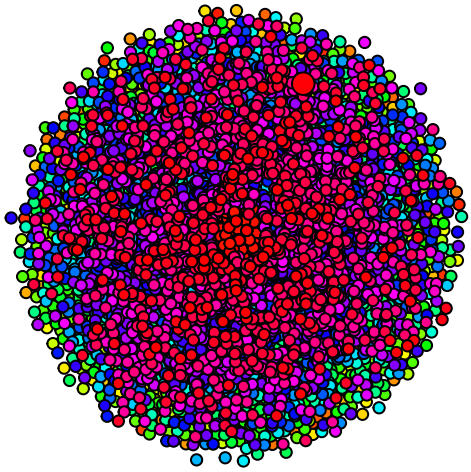
```
print(vcount(received_subgraph))
```

```
## [1] 7632
```

Community Detection of Node 179171

```
# Community detection and visualization for User 179171's received emails

und_22 <- as.undirected(received_subgraph)
clusters2 <- cluster_fast_greedy(und_22)
V(und_22)$group <- membership(clusters2)
num_groups <- length(unique(V(und_22)$group))
group_colors <- rainbow(num_groups)
V(und_22)$color <- group_colors[V(und_22)$group]
plot(und_22, vertex.label = NA, main = "Graph with Nodes Colored by Group")
```

Graph with Nodes Colored by Group



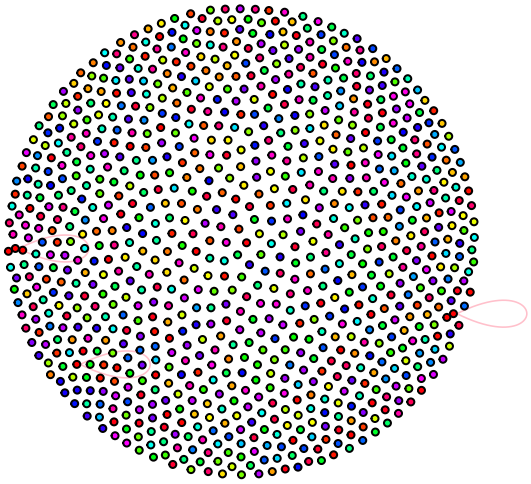
```
# Taking a random sample of User 179171's received email connections with the communitiy detection visu

set.seed(122)
sub.network2 <- induced.subgraph(und_22, sample(vcount(und_22), 900))
```

```
## Warning: ‘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.
```

```
edge_count <- ecount(sub.network2)
print(paste("Number of edges in the subgraph: ", edge_count))
```

```
## [1] "Number of edges in the subgraph:  6"
```

```
plot(sub.network2, vertex.label = NA, vertex.size = 3,
     edge.arrow.size = 0.2, edge.width = 0.8, edge.color = "pink")
```

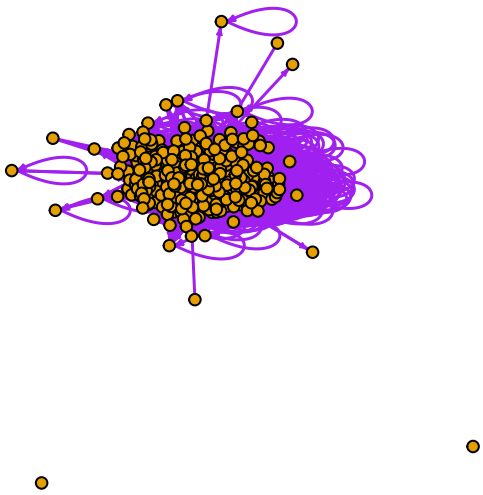


Exploring the Connections Between Email Addresses that Sent and Received Over 100 Emails

```
set.seed(123)

# SENT
send <- as_ids(V(email)[degree(email, mode = "out") > 100]) # convert igraph.vs to vector
email_sent_over100 = induced_subgraph(email, send)
email_sent_over100
```

```
## IGRAPH fb255cb DN-- 374 14659 --
## + attr: user (v/c), name (v/c)
## + edges from fb255cb (vertex names):
##  [1] 2->2      2->51     2->57     2->100    2->107    2->147    2->148
##  [8] 2->150    2->159    2->176    2->207    2->260    2->334    2->337
## [15] 2->398    2->407    2->423    2->447    2->458    2->603    2->621
## [22] 2->641    2->780    2->842    2->1034   2->1119   2->1371   2->1426
## [29] 2->1516   2->1620   2->1624   2->1804   2->2245   2->9395   2->21443
## [36] 2->30332  2->60577  2->75913  2->118337 4->4      4->11     4->176
## [43] 4->314    4->315    4->389    4->390    4->458    4->510    4->511
## [50] 4->809    4->1012   4->1086   4->1346   4->1418   4->1697   4->1974
## + ... omitted several edges
```

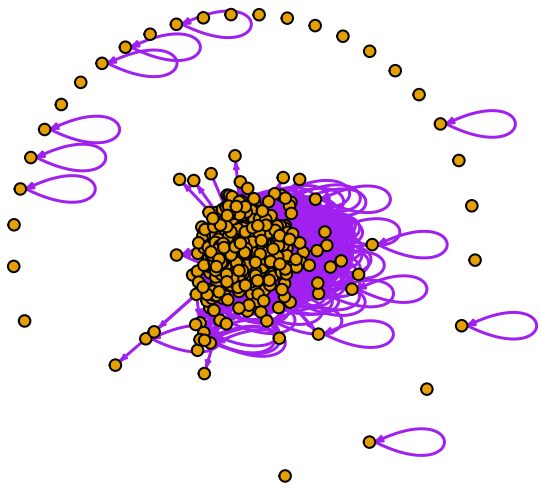
```r
plot(email_sent_over100,
     vertex.size = 5,
     edge.color = "purple",
     edge.width = 1.5,
     edge.arrow.size = 0.2,
     vertex.label = NA)
```



```r
# RECEIVED
receive <- as_ids(V(email)[degree(email, mode = "in") > 100]) # convert igraph.vs to vector
email_receive_over100 = induced_subgraph(email, receive)
email_receive_over100
```

```
## IGRAPH 5096891 DN-- 702 20507 --
## + attr: user (v/c), name (v/c)
## + edges from 5096891 (vertex names):
##  [1] 2->2      2->45     2->51     2->57     2->100    2->107    2->147
##  [8] 2->148    2->150    2->159    2->172    2->176    2->185    2->207
## [15] 2->260    2->334    2->337    2->393    2->398    2->407    2->423
## [22] 2->447    2->458    2->586    2->603    2->621    2->641    2->734
## [29] 2->780    2->842    2->1034   2->1119   2->1371   2->1426   2->1459
## [36] 2->1516   2->1620   2->1624   2->1777   2->1804   2->2245   2->6120
## [43] 2->21443  2->23784  2->30332  2->60577  2->75913  2->92477  2->118337
## [50] 4->4      4->11     4->176    4->314    4->315    4->348    4->389
## + ... omitted several edges
```

```r
plot(email_receive_over100,
     vertex.size = 5,
     edge.color = "purple",
     edge.width = 1.5,
     edge.arrow.size = 0.2,
     vertex.label = NA)
```



Exploring the Top 3 Email Addresses that Sent Emails to the Most Recipients

We focused on the number of emails sent rather than received because receiving many emails doesn't necessarily indicate activity. Sending emails suggests active engagement and potential leadership roles. Therefore, analyzing senders provides insight into proactive involvement and network dynamics.

Finding Top 5

```r
sort_x <- sort(x, decreasing = TRUE)
top_5_send <- sort_x[1:5]
top_5_send
```

```
##
##   84  869  193 2372   11
##  930  871  854  811  761
```

```r
sort_y <- sort(y, decreasing = TRUE)
top_5_receive <- sort_y[1:5]
top_5_send
```

```
##
##   84  869  193 2372   11
##  930  871  854  811  761
```

```r
names(top_5_send) # gives the names
```

```
## [1] "84"   "869"  "193"  "2372" "11"
```

Creating 3 Subgraphs for 3 Nodes (Top 3 Email Addresses that Sent Emails to the Most Recipients) and Perform Analysis

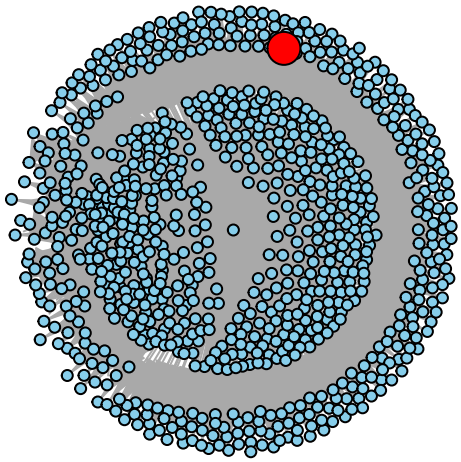
The top 1 email address that sent emails to the most recipients is Node 84, which we already analyzed earlier. We are analyzing the other two.

```r
neighbors_1 <- neighbors(email, 84, mode = "out") #email is our graph
neighbors_2 <- neighbors(email, 179171, mode = "in")

neighbors_1 <- as.vector(neighbors_1)
neighbors_2 <- as.vector(neighbors_2)

subgraph_nodes <- unique(c(neighbors_1, neighbors_2, c(84, 179171)))

subgraph <- induced_subgraph(email, subgraph_nodes)
```

Node 869

```r
set.seed(111)
# Node 869
neighbors_869 <- neighbors(email, 869, mode = "out") #email is our graph

neighbors_869 <- as.vector(neighbors_869)

subgraph_nodes_869 <- unique(c(neighbors_869, 869))

subgraph_869 <- induced_subgraph(email, subgraph_nodes_869)

vertex_colors <- rep("skyblue", vcount(subgraph_869))
vertex_colors[which(V(subgraph_869) == '869')] <- "red"
V(subgraph_869)$color <- vertex_colors

# node sizes
vertex_sizes <- rep(5, vcount(subgraph_869))
vertex_sizes[which(V(subgraph_869) == '869')] <- 15
V(subgraph_869)$size <- vertex_sizes

# plot
plot(subgraph_869, vertex.label = NA, main = paste("Subgraph of Node 869", "and Send Emails"))
```

Subgraph of Node 869 and Send Emails



```
print(paste("Graph Density:" , graph.density(subgraph_869)))
```

```
## [1] "Graph Density: 0.00381118281272682"
```

```
print(paste("Average Path Length:", average.path.length(subgraph_869)))
```

```
## Warning: ‘average.path.length()‘ was deprecated in igraph 2.0.0.
## i Please use ‘mean_distance()‘ instead.
## This warning is displayed once every 8 hours.
## Call ‘lifecycle::last_lifecycle_warnings()‘ to see where this warning was
## generated.
```

```
## [1] "Average Path Length: 2.13816219196675"
```

```
print(paste("Number of Articulation Point: ", length(articulation.points(subgraph_869))))
```

```
## Warning: ‘articulation.points()‘ was deprecated in igraph 2.0.0.
## i Please use ‘articulation_points()‘ instead.
## This warning is displayed once every 8 hours.
## Call ‘lifecycle::last_lifecycle_warnings()‘ to see where this warning was
## generated.
```

```
## [1] "Number of Articulation Point:  1"
```

```r
print(paste("Farthest Vertices: ", farthest_vertices(subgraph_869)))
```

```
## [1] "Farthest Vertices:  c(‘1336‘ = 51, ‘75296‘ = 423)"
## [2] "Farthest Vertices:  4"
```

```r
undirected869 <- as.undirected(subgraph_869)

kc_869 <- fastgreedy.community(undirected869)

print(paste("Number of communities: ", length(kc_869)))
```

```
## [1] "Number of communities:  4"
```

```r
sizes(kc_869)
```

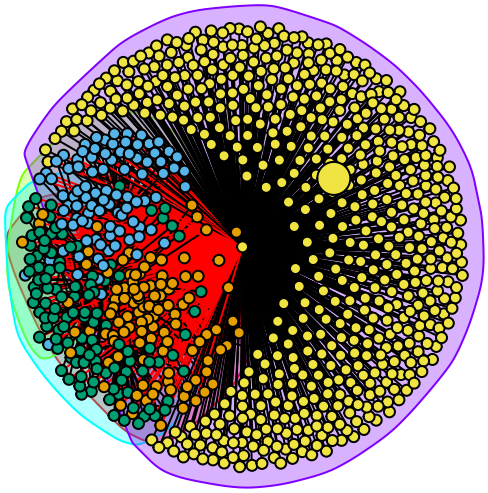
```
## Community sizes
##   1   2   3   4
## 107  93 111 560
```

```r
modularity(kc_869)
```

```
## [1] 0.41622
```

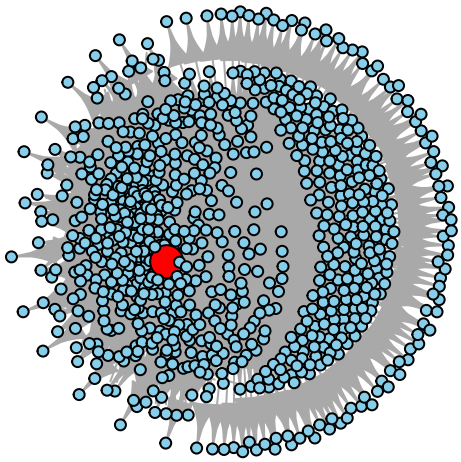
```r
plot(kc_869, undirected869, vertex.label = NA, main = paste("Subgraph of Node 869", "and Send Emails wi

sub869.adjacency <- as_adj(subgraph_869)
```

Subgraph of Node 869 and Send Emails with Cluster Communities



Node 193

```
neighbors_193 <- neighbors(email, 193, mode = "out") #email is our graph

neighbors_193 <- as.vector(neighbors_193)

subgraph_nodes_193 <- unique(c(neighbors_193, 193))

subgraph_193 <- induced_subgraph(email, subgraph_nodes_193)

vertex_colors <- rep("skyblue", vcount(subgraph_193))
vertex_colors[which(V(subgraph_193) == '193')] <- "red"
V(subgraph_193)$color <- vertex_colors

# node sizes
vertex_sizes <- rep(5, vcount(subgraph_193))
vertex_sizes[which(V(subgraph_193) == '193')] <- 15
V(subgraph_193)$size <- vertex_sizes

# plot
plot(subgraph_193, vertex.label = NA, main = paste("Subgraph of Node 193", "and Send Emails"))
```




```
print(paste("Graph Density: ", graph.density(subgraph_193)))
```

```
## [1] "Graph Density:  0.00918373230175356"
```

```
print(paste("Average path Length: ", average.path.length(subgraph_193)))
```

```
## [1] "Average path Length:  2.09453885470046"
```

```
print(paste("Number of Articulation Point: ", length(articulation.points(subgraph_193))))
```

```
## [1] "Number of Articulation Point:  1"
```

```
print(paste("Farthest Vertices: ", farthest_vertices(subgraph_193)))
```

```
## [1] "Farthest Vertices:  c(‘9680‘ = 229, ‘207‘ = 24)"
## [2] "Farthest Vertices:  4"
```

```
undirected193 <- as.undirected(subgraph_193)

kc_193 <- fastgreedy.community(undirected193)

print(paste("Number of communities: ", length(kc_193)))
```

```
## [1] "Number of communities:  6"
```

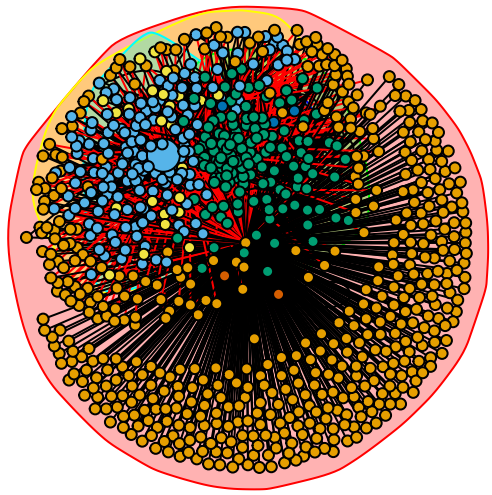
```
sizes(kc_193)
```

```
## Community sizes
##   1   2   3   4   5   6
## 512 174 138  25   3   2
```

```
modularity(kc_193)
```

```
## [1] 0.3727053
```

```
plot(kc_193, undirected193, vertex.label = NA, main = paste("Subgraph of Node 193", "and Send Emails wi
```




```
sub193.adjacency <- as_adj(subgraph_193)
```

Top 5 Email Addresses Sending Emails to the Most Recipients and Receiving Emails from the Most Senders

```
for (i in names(top_5_send)){
  for (j in names(top_5_receive)){
```

```
    if (email[as.numeric(i),as.numeric(j)] == 0){
      print(paste("No Connections between node " , i, " and node ", j))
    }
    else{
      print(paste("There are connections between node ", i, " and node ", j))
    }
  }
}
```

```
## [1] "No Connections between node  84  and node  179171"
## [1] "No Connections between node  84  and node  423"
## [1] "No Connections between node  84  and node  31"
## [1] "No Connections between node  84  and node  73"
## [1] "No Connections between node  84  and node  299"
## [1] "No Connections between node  869  and node  179171"
## [1] "No Connections between node  869  and node  423"
## [1] "No Connections between node  869  and node  31"
## [1] "No Connections between node  869  and node  73"
## [1] "No Connections between node  869  and node  299"
## [1] "No Connections between node  193  and node  179171"
## [1] "There are connections between node  193  and node  423"
## [1] "No Connections between node  193  and node  31"
## [1] "No Connections between node  193  and node  73"
## [1] "No Connections between node  193  and node  299"
## [1] "No Connections between node  2372  and node  179171"
## [1] "No Connections between node  2372  and node  423"
## [1] "No Connections between node  2372  and node  31"
## [1] "No Connections between node  2372  and node  73"
## [1] "No Connections between node  2372  and node  299"
## [1] "There are connections between node  11  and node  179171"
## [1] "There are connections between node  11  and node  423"
## [1] "There are connections between node  11  and node  31"
## [1] "No Connections between node  11  and node  73"
## [1] "No Connections between node  11  and node  299"
```