

# DBA3702 Assignment 1

weRready

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# 1 Part 1: Data Wrangling with dplyr

## 1.1 Question 1.1: Data Exploration

### 1.1.1 a) Load packages and read data

```
library(dplyr)
library(tibble)

employees <- read.csv("data/employees.csv")
```

### 1.1.2 b) Convert to tibble and display first 10 rows

```
employees <- as_tibble(employees)
print(employees, n = 10)
```

```
## # A tibble: 50 x 8
##   employee_id name      department role  years_exp salary performance_score
##       <int> <chr>      <chr>     <chr>    <int>   <int>             <dbl>
## 1          1 Alice Chen  Engineeri~ Seni~        8  95000            4.5
## 2          2 Bob Martinez Engineeri~ Lead       12 120000            4.8
## 3          3 Charlie Kim  Engineeri~ Juni~        2  65000            3.8
## 4          4 Diana Patel  Engineeri~ Seni~        7  92000            4.2
## 5          5 Eve Thompson Engineeri~ Mana~       15 140000            4.6
## 6          6 Frank Liu   Engineeri~ Juni~        1  58000            3.2
## 7          7 Grace Okonkwo Engineeri~ Seni~        9  98000            4.4
## 8          8 Henry Wang   Marketing  Lead       10 105000            4.3
## 9          9 Iris Nakamura Marketing  Seni~        6  82000            3.9
## 10         10 Jack Brown  Marketing  Juni~        2  55000            3.5
## # i 40 more rows
## # i 1 more variable: projects_completed <int>
```

### 1.1.3 c) Data summary

```
cat("Rows:", nrow(employees), "\n")
```

```
## Rows: 50
```

```
cat("Columns:", ncol(employees), "\n")
```

```
## Columns: 8
```

```
sapply(employees, typeof)
```

```
##      employee_id           name      department        role
##      "integer"     "character"     "character"     "character"
##      years_exp       salary  performance_score projects_completed
##      "integer"     "integer"      "double"       "integer"
```

```
summary(employees)
```

```
##   employee_id      name      department        role
##   Min. : 1.00  Length:50      Length:50      Length:50
##   1st Qu.:13.25 Class :character  Class :character  Class :character
##   Median :25.50 Mode  :character  Mode  :character  Mode  :character
##   Mean   :25.50
##   3rd Qu.:37.75
##   Max.   :50.00
##   years_exp       salary  performance_score projects_completed
##   Min.   : 1.00  Min.   :48000  Min.   :2.900  Min.   : 2.00
##   1st Qu.: 3.00  1st Qu.:65750  1st Qu.:3.600  1st Qu.: 6.00
##   Median : 6.50  Median :85000  Median :4.000  Median :11.50
##   Mean   : 6.68  Mean   :86420  Mean   :3.970  Mean   :12.24
##   3rd Qu.: 9.00  3rd Qu.:101500 3rd Qu.:4.375  3rd Qu.:17.00
##   Max.   :16.00  Max.   :145000  Max.   :4.900  Max.   :30.00
```

The dataset includes information about 50 employees with 8 variables. This includes basic information, such as employee name and department, as well as quantitative information, such as salary, years of experience, performance scores, and number of projects completed.

## 1.2 Question 1.2: Selecting and Filtering

### 1.2.1 d) Select specific columns

```
employees %>%
  select(name, department, role, performance_score)
```

```
## # A tibble: 50 x 4
##   name      department  role  performance_score
##   <chr>     <chr>       <chr>          <dbl>
## 1 Alice Chen  Engineering Senior        4.5
## 2 Bob Martinez Engineering Lead         4.8
## 3 Charlie Kim  Engineering Junior      3.8
## 4 Diana Patel  Engineering Senior      4.2
## 5 Eve Thompson Engineering Manager     4.6
## 6 Frank Liu    Engineering Junior      3.2
## 7 Grace Okonkwo Engineering Senior     4.4
## 8 Henry Wang   Marketing Lead          4.3
## 9 Iris Nakamura Marketing Senior       3.9
## 10 Jack Brown  Marketing Junior        3.5
## # i 40 more rows
```

### 1.2.2 e) Select employees with performance > 4.0

```
high_performers <- employees %>%
  filter(performance_score > 4.0)
high_performers
```

```
## # A tibble: 23 x 8
##   employee_id name      department  role  years_exp salary performance_score
##   <int> <chr>     <chr>       <chr>  <int>  <int>          <dbl>
## 1 1 Alice Chen  Engineering Senior     8  95000        4.5
## 2 2 Bob Martinez Engineering Lead      12 120000       4.8
## 3 4 Diana Patel  Engineering Senior    7  92000        4.2
## 4 5 Eve Thompson Engineering Manager  15 140000       4.6
## 5 7 Grace Okonkwo Engineering Senior   9  98000        4.4
## 6 8 Henry Wang   Marketing Lead        10 105000       4.3
## 7 11 Kate Wilson Marketing Manager    14 125000       4.5
## 8 14 Nathan Lee  Sales Lead           11 115000       4.7
## 9 15 Olivia Davis Sales Senior        8  88000        4.1
## 10 18 Rachel Green Sales Manager     13 130000       4.4
## # i 13 more rows
## # i 1 more variable: projects_completed <int>
```

### 1.2.3 f) Select employees in Engineering/Marketing with > 5 years experience

```
employees %>%
  filter((department == "Engineering" | department == "Marketing") & years_exp > 5)

## # A tibble: 14 x 8
##   employee_id name      department role    years_exp salary performance_score
##       <int> <chr>     <chr>   <chr>     <int>   <dbl>             <dbl>
## 1          1 Alice Chen  Engineeri~ Seni~        8  95000            4.5
## 2          2 Bob Martinez  Engineeri~ Lead        12 120000           4.8
## 3          4 Diana Patel  Engineeri~ Seni~        7  92000            4.2
## 4          5 Eve Thompson  Engineeri~ Mana~       15 140000           4.6
## 5          7 Grace Okonkwo  Engineeri~ Seni~        9  98000            4.4
## 6          8 Henry Wang    Marketing  Lead        10 105000           4.3
## 7          9 Iris Nakamura Marketing  Seni~        6  82000            3.9
## 8         11 Kate Wilson   Marketing  Mana~       14 125000           4.5
## 9         31 Eric Zhang    Engineeri~ Seni~        6  88000            4
## 10        33 George Park   Marketing  Seni~        7  80000            3.7
## 11        41 Oscar Rivera   Engineeri~ Lead       11 118000           4.5
## 12        42 Paula Hughes   Engineeri~ Mana~       16 145000           4.9
## 13        43 Quentin Price  Marketing  Lead        8 100000            4.1
## 14        47 Ulrich Weber   Engineeri~ Seni~        7  94000            4.2
## # i 1 more variable: projects_completed <int>
```

### 1.2.4 g) Select columns using helpers

```
employees %>%
  select(contains("score") | starts_with("p"))

## # A tibble: 50 x 2
##   performance_score projects_completed
##       <dbl>              <int>
## 1          4.5                15
## 2          4.8                22
## 3          3.8                 5
## 4          4.2                12
## 5          4.6                28
## 6          3.2                 3
## 7          4.4                16
## 8          4.3                18
## 9          3.9                11
## 10         3.5                 4
## # i 40 more rows
```

There are two columns, *performance\_score* and *projects\_completed*, that meet the given condition.

### 1.3 Question 1.3: Sorting and Ranking

#### 1.3.1 h) Identify top 5 highest-paid employees

```
employees %>%
  arrange(desc(salary)) %>%
  head(5)
```

```
## # A tibble: 5 x 8
##   employee_id name      department role    years_exp salary performance_score
##       <int> <chr>     <chr>     <chr>     <int> <int>          <dbl>
## 1        42 Paula Hughes Engineering Manag~      16 145000        4.9
## 2         5 Eve Thompson Engineering Manag~      15 140000        4.6
## 3        28 Bella Moore  Finance     Manag~      14 135000        4.7
## 4        18 Rachel Green Sales      Manag~      13 130000        4.4
## 5        11 Kate Wilson Marketing Manag~      14 125000        4.5
## # i 1 more variable: projects_completed <int>
```

#### 1.3.2 i) Sort by department, then performance

```
employees %>%
  arrange(department, desc(performance_score))
```

```
## # A tibble: 50 x 8
##   employee_id name      department role    years_exp salary performance_score
##       <int> <chr>     <chr>     <chr>     <int> <int>          <dbl>
## 1        42 Paula Hughes Engineering Mana~      16 145000        4.9
## 2         2 Bob Martinez Engineering Lead      12 120000        4.8
## 3         5 Eve Thompson  Engineering Mana~      15 140000        4.6
## 4         1 Alice Chen   Engineering Seni~      8  95000        4.5
## 5        41 Oscar Rivera Engineering Lead      11 118000        4.5
## 6         7 Grace Okonkwo Engineering Seni~      9  98000        4.4
## 7         4 Diana Patel  Engineering Seni~      7  92000        4.2
## 8        47 Ulrich Weber  Engineering Seni~      7  94000        4.2
## 9        31 Eric Zhang   Engineering Seni~      6  88000        4
## 10        32 Fiona O'Brien Engineering Juni~      3  68000        3.9
## # i 40 more rows
## # i 1 more variable: projects_completed <int>
```

#### 1.3.3 j) Identify employee with lowest salary in each department

```
employees %>%
  arrange(department, salary) %>%
  group_by(department) %>%
  slice_head(n = 1) %>%
  ungroup()

## # A tibble: 5 x 8
##   employee_id name      department role  years_exp salary performance_score
##       <int> <chr>    <chr>     <chr>     <int>   <int>          <dbl>
## 1           6 Frank Liu  Engineeri~ Juni~        1   58000        3.2
## 2           30 Dana Hill Finance    Juni~        1   55000        3
## 3           22 Victor Nguyen HR        Juni~        1   48000        3.1
## 4           13 Maya Rodriguez Marketing Juni~        1   52000        3.3
## 5           36 Julia Foster  Sales     Juni~        1   53000        2.9
## # i 1 more variable: projects_completed <int>
```

## 1.4 Question 1.4: Creating New Variables

### 1.4.1 k) Salary per year of experience

```
employees %>%
  mutate(salary_per_year_exp = salary / years_exp) %>%
  select(name, salary, years_exp, salary_per_year_exp)
```

```
## # A tibble: 50 x 4
##   name      salary years_exp salary_per_year_exp
##   <chr>     <int>    <int>          <dbl>
## 1 Alice Chen  95000       8        11875
## 2 Bob Martinez 120000      12       10000
## 3 Charlie Kim  65000       2        32500
## 4 Diana Patel  92000       7       13143.
## 5 Eve Thompson 140000      15       9333.
## 6 Frank Liu    58000       1        58000
## 7 Grace Okonkwo 98000       9       10889.
## 8 Henry Wang   105000      10       10500
## 9 Iris Nakamura 82000       6       13667.
## 10 Jack Brown  55000       2        27500
## # i 40 more rows
```

### 1.4.2 l) Performance category

```
employees_cat <- employees %>%
  mutate(performance_category = case_when(
    performance_score >= 4.5 ~ "Outstanding",
    performance_score >= 3.5 ~ "Exceeds Expectations",
    performance_score >= 2.5 ~ "Meets Expectations",
    TRUE ~ "Needs Improvement"
  ))
```

```
employees_cat %>%
  select(name, performance_score, performance_category)
```

```
## # A tibble: 50 x 3
##   name      performance_score performance_category
##   <chr>           <dbl> <chr>
## 1 Alice Chen        4.5 Outstanding
## 2 Bob Martinez      4.8 Outstanding
## 3 Charlie Kim       3.8 Exceeds Expectations
## 4 Diana Patel       4.2 Exceeds Expectations
## 5 Eve Thompson      4.6 Outstanding
```

```

## 6 Frank Liu           3.2 Meets Expectations
## 7 Grace Okonkwo      4.4 Exceeds Expectations
## 8 Henry Wang          4.3 Exceeds Expectations
## 9 Iris Nakamura       3.9 Exceeds Expectations
## 10 Jack Brown         3.5 Exceeds Expectations
## # i 40 more rows

```

#### 1.4.3 m) Experience level

```

employees_exp <- employees %>%
  mutate(experience_level = case_when(
    years_exp <= 3 ~ "Entry",
    years_exp <= 7 ~ "Mid",
    years_exp <= 12 ~ "Senior",
    TRUE ~ "Expert"
  ))

employees_exp %>%
  select(name, years_exp, experience_level)

```

```

## # A tibble: 50 x 3
##   name      years_exp experience_level
##   <chr>     <int> <chr>
## 1 Alice Chen        8 Senior
## 2 Bob Martinez     12 Senior
## 3 Charlie Kim       2 Entry
## 4 Diana Patel      7 Mid
## 5 Eve Thompson     15 Expert
## 6 Frank Liu         1 Entry
## 7 Grace Okonkwo     9 Senior
## 8 Henry Wang        10 Senior
## 9 Iris Nakamura      6 Mid
## 10 Jack Brown       2 Entry
## # i 40 more rows

```

#### 1.4.4 n) High performer flag

```

employees %>%
  mutate(is_high_performer = performance_score > 4.0 & projects_completed >= 10) %>%
  filter(is_high_performer) %>%
  select(name, department, performance_score, projects_completed)

## # A tibble: 23 x 4
##   name      department  performance_score projects_completed

```

```
##   <chr>     <chr>      <dbl>    <int>
## 1 Alice Chen  Engineering  4.5      15
## 2 Bob Martinez Engineering  4.8      22
## 3 Diana Patel  Engineering 4.2      12
## 4 Eve Thompson Engineering 4.6      28
## 5 Grace Okonkwo Engineering 4.4      16
## 6 Henry Wang   Marketing   4.3      18
## 7 Kate Wilson  Marketing   4.5      24
## 8 Nathan Lee   Sales      4.7      21
## 9 Olivia Davis Sales      4.1      14
## 10 Rachel Green Sales     4.4      25
## # i 13 more rows
```

## 1.5 Question 1.5: Aggregation and Grouping

### 1.5.1 o) Company-wide summary

```
employees %>%
  summarise(
    total_employees = n(),
    avg_salary = mean(salary),
    avg_performance = mean(performance_score),
    total_projects = sum(projects_completed)
  )

## # A tibble: 1 x 4
##   total_employees avg_salary avg_performance total_projects
##             <int>      <dbl>            <dbl>        <int>
## 1                 50       86420            3.97         612
```

### 1.5.2 p) Summary by department

```
employees %>%
  group_by(department) %>%
  summarise(
    count = n(),
    avg_salary = mean(salary),
    avg_perf = mean(performance_score),
    min_exp = min(years_exp),
    max_exp = max(years_exp)
  )

## # A tibble: 5 x 6
##   department  count avg_salary avg_perf min_exp max_exp
##   <chr>      <int>      <dbl>     <dbl>    <int>    <int>
## 1 Engineering    12     98417.    4.25      1       16
## 2 Finance        9     86333.    3.96      1       14
## 3 HR              9     75556.    3.76      1       12
## 4 Marketing      10     80700.    3.86      1       14
## 5 Sales           10     87600.    3.95      1       13
```

### 1.5.3 q) Summary by department and role

```
dept_role <- employees %>%
  group_by(department, role) %>%
  summarise(avg_salary = mean(salary), count = n(), .groups = "drop") %>%
```

```

arrange(desc(avg_salary))

dept_role

## # A tibble: 20 x 4
##   department role     avg_salary count
##   <chr>      <chr>     <dbl> <int>
## 1 Engineering Manager    142500     2
## 2 Finance     Manager    135000     1
## 3 Sales       Manager    130000     1
## 4 Marketing    Manager    125000     1
## 5 Engineering  Lead      119000     2
## 6 Sales       Lead      113500     2
## 7 HR          Manager    110000     1
## 8 Finance     Lead      105000     2
## 9 Marketing    Lead      102500     2
## 10 HR         Lead      93500      2
## 11 Engineering Senior    93400      5
## 12 Sales       Senior    87250      4
## 13 Finance     Senior    85667.     3
## 14 Marketing   Senior    79000      4
## 15 HR          Senior    71250      4
## 16 Engineering Junior   63667.     3
## 17 Finance     Junior   58333.     3
## 18 Sales       Junior   56667.     3
## 19 Marketing   Junior   53667.     3
## 20 HR          Junior   49000      2

```

```

# Highest combo:
dept_role %>% head(1)

```

```

## # A tibble: 1 x 4
##   department role     avg_salary count
##   <chr>      <chr>     <dbl> <int>
## 1 Engineering Manager    142500     2

```

Managers in the Engineering department have the highest salary on average.

#### 1.5.4 r) Individual employees' salary as % of department average

```

employees %>%
  group_by(department) %>%
  mutate(
    dept_avg = mean(salary),

```

```

    pct_of_avg = salary / dept_avg * 100
) %>%
ungroup() %>%
arrange(desc(pct_of_avg)) %>%
select(name, department, salary, dept_avg, pct_of_avg)

```

```

## # A tibble: 50 x 5
##   name      department  salary dept_avg pct_of_avg
##   <chr>     <chr>     <int>    <dbl>      <dbl>
## 1 Bella Moore  Finance  135000  86333.    156.
## 2 Kate Wilson  Marketing 125000  80700     155.
## 3 Rachel Green Sales    130000  87600     148.
## 4 Paula Hughes Engineering 145000  98417.    147.
## 5 Wendy Clark   HR      110000  75556.    146.
## 6 Eve Thompson  Engineering 140000  98417.    142.
## 7 Nathan Lee    Sales    115000  87600     131.
## 8 Henry Wang    Marketing 105000  80700     130.
## 9 Rosa Martinez Sales    112000  87600     128.
## 10 Tina White   HR      95000   75556.    126.
## # i 40 more rows

```

Bella Moore from Finance department earns the most relative to their department's average, with a relative percentage of 156.37%.

### 1.5.5 s) Top 3 departments by performance (only considering employees with 3+ years of experience)

```

employees %>%
  filter(years_exp >= 3) %>%
  group_by(department) %>%
  summarise(avg_perf = mean(performance_score)) %>%
  arrange(desc(avg_perf)) %>%
  head(3)

```

```

## # A tibble: 3 x 2
##   department  avg_perf
##   <chr>        <dbl>
## 1 Engineering  4.4
## 2 Finance     4.3
## 3 Sales       4.15

```

Only taking into account the work of employees with 3 or more years of experience, the Engineering, Finance, and Sales departments show the best average performance.

## 2 Part 2: Social Network Analysis

### 2.1 Question 2.1: Network Construction and Visualization

#### 2.1.1 t) Load network data

```
library(igraph)
library(RColorBrewer)

email_nodes <- read.csv("data/email_nodes.csv")
email_edges <- read.csv("data/email_edges.csv")

head(email_nodes)

##   id  department      role
## 1  1 Engineering Senior
## 2  2 Engineering    Lead
## 3  3 Engineering  Junior
## 4  4 Engineering Senior
## 5  5 Engineering Manager
## 6  6 Engineering  Junior

head(email_edges)

##   from to weight
## 1    1  2     25
## 2    1  3     15
## 3    1  4     20
## 4    1  5     30
## 5    1  7     18
## 6    2  3     22
```

#### 2.1.2 u) Construct undirected graph

```
email_graph <- graph.data.frame(email_edges, vertices = email_nodes, directed = FALSE)

cat("Nodes:", vcount(email_graph), "\n")

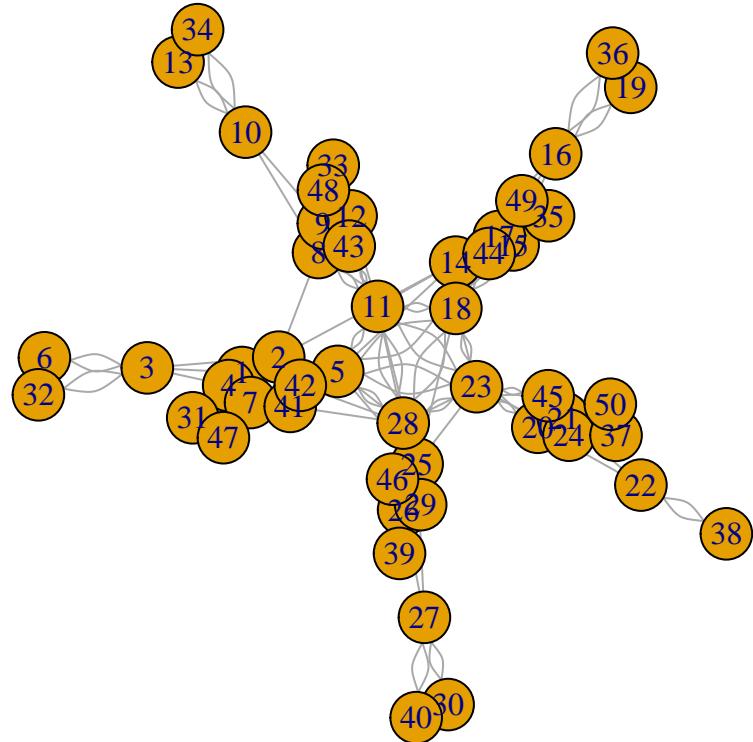
## Nodes: 50

cat("Edges:", ecount(email_graph), "\n")

## Edges: 207
```

### 2.1.3 v) Create plot of network

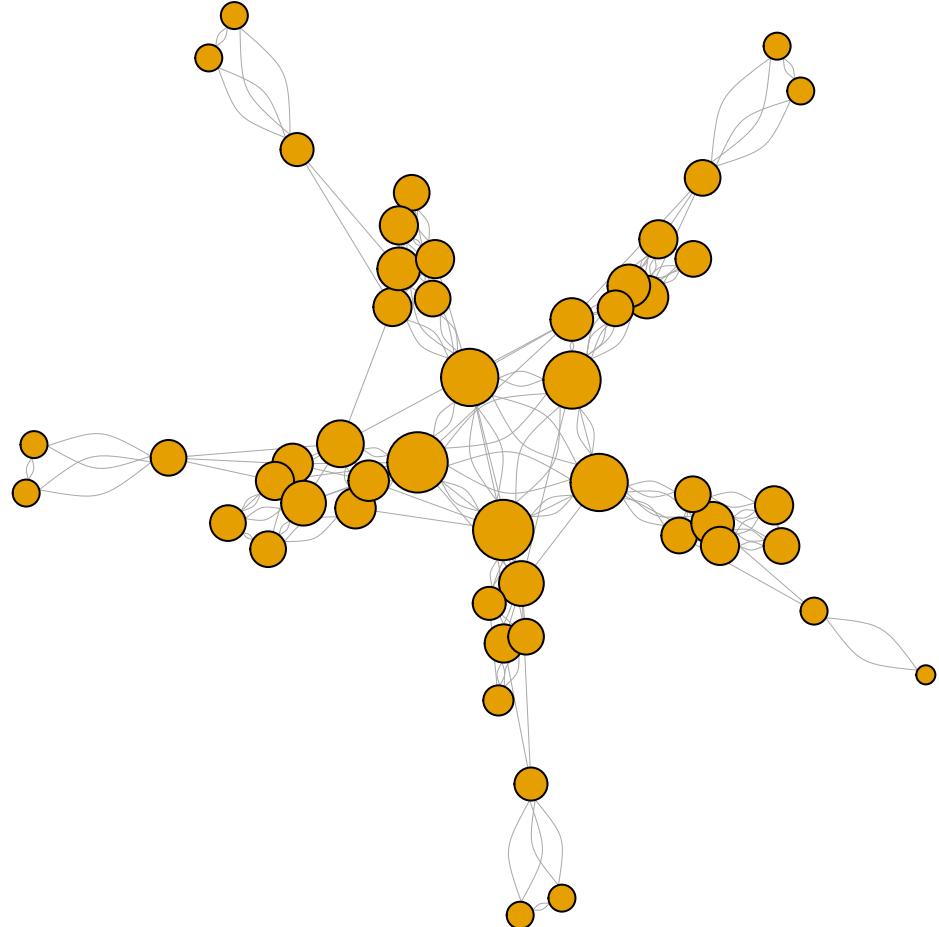
```
# v) Improved plot  
set.seed(45)  
mylayout <- layout.auto(email_graph)  
  
# Basic plot  
plot(email_graph, layout = mylayout)
```



```
# Improved plot  
par(mar = c(1, 1, 2, 1))  
deg <- degree(email_graph)
```

```
plot(email_graph, layout = mylayout, vertex.label = NA,
     vertex.size = sqrt(deg) * 3, edge.width = 0.5,
     main = "Improved Plot")
```

**Improved Plot**



#### 2.1.4 w) Department-colored network

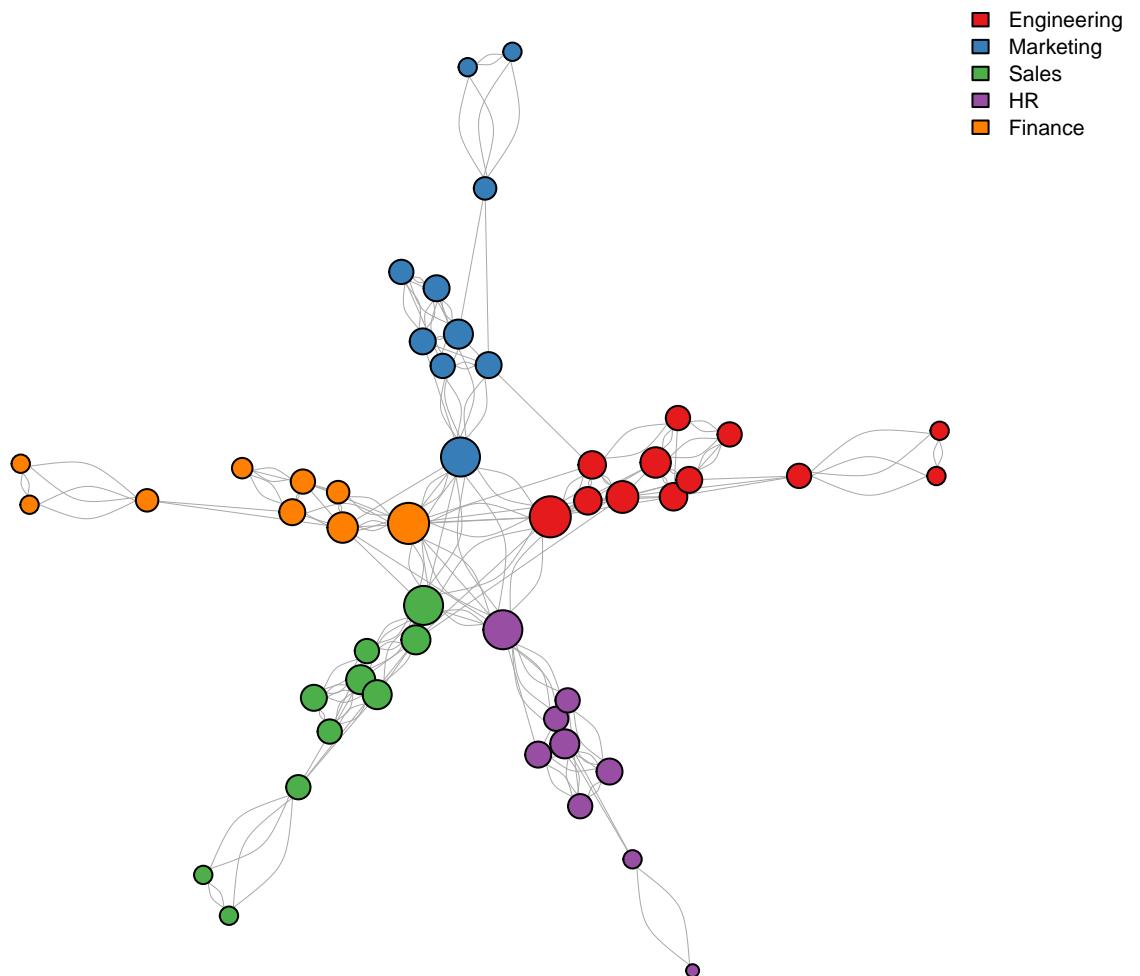
```
deps <- V(email_graph)$department
unique_depts <- unique(deps)
colors <- brewer.pal(length(unique_depts), "Set1")
names(colors) <- unique_depts
```

```

par(mfrow = c(1, 1), mar = c(1, 1, 2, 5))
plot(email_graph, vertex.label = NA, vertex.size = sqrt(deg) * 2,
      vertex.color = colors[depts], edge.width = 0.5,
      main = "Network (colored by Department)")
legend("topright", unique_depts, fill = colors, cex = 0.7, bty = "n")

```

**Network (colored by Department)**



## 2.2 Question 2.2: Connected Components

### 2.2.1 x) Find connected components

```
comp <- components(email_graph)
cat("Number of components:", comp$no, "\n")
```

```
## Number of components: 1
```

### 2.2.2 y) Largest component size

```
lcc_size <- max(comp$csize)
cat("Largest component:", lcc_size, "employees\n")
```

```
## Largest component: 50 employees
```

```
cat(round(lcc_size / vcount(email_graph) * 100, 1), "% of employees are in this component\n")
```

```
## 100 % of employees are in this component
```

### 2.2.3 z) Extract and plot largest component

```
lcc_id <- which.max(comp$csize)
lcc_nodes <- which(comp$membership == lcc_id)
lcc <- induced_subgraph(email_graph, lcc_nodes)

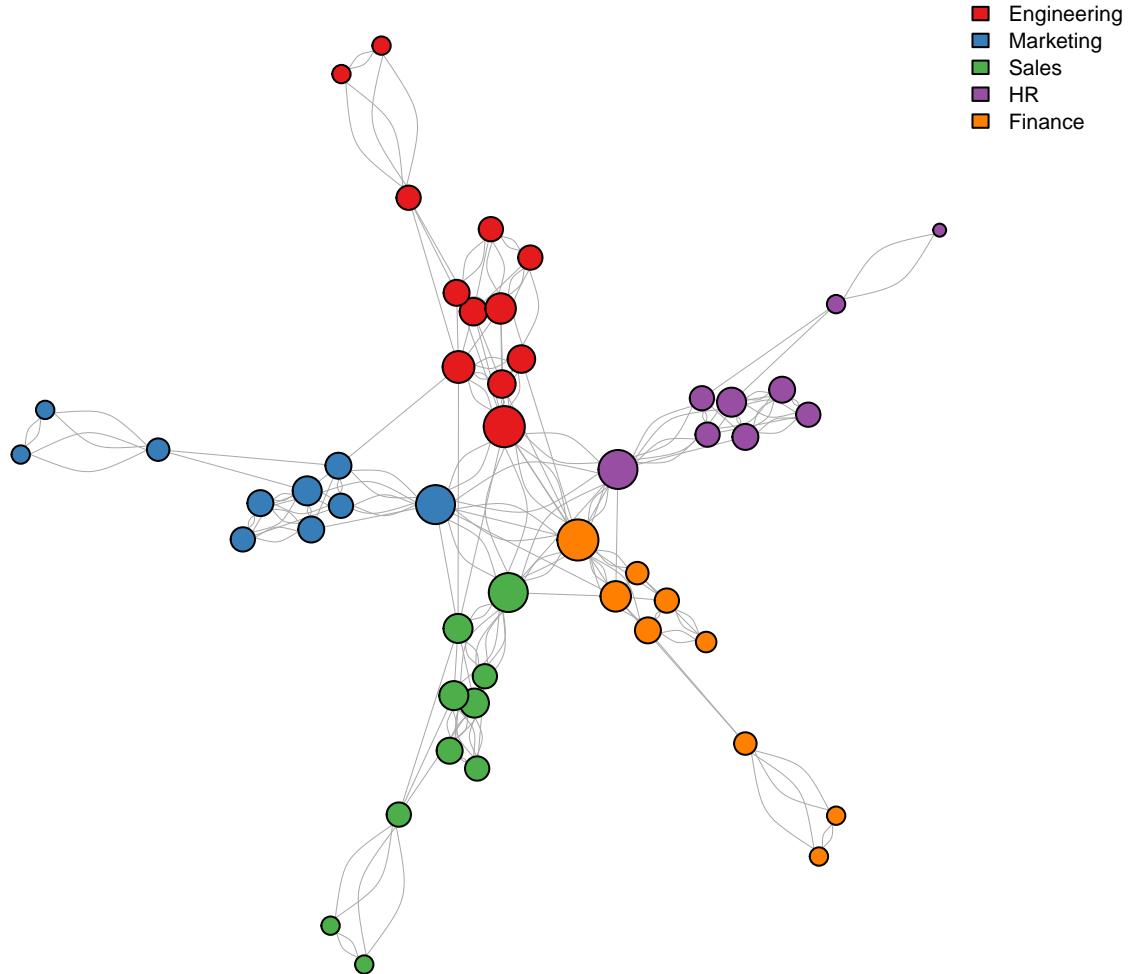
cat("LCC has", vcount(lcc), "nodes and", ecount(lcc), "edges\n")
```

```
## LCC has 50 nodes and 207 edges
```

```
deg_lcc <- degree(lcc)
depts_lcc <- V(lcc)$department

par(mar = c(1, 1, 2, 5))
plot(lcc, vertex.label = NA, vertex.size = sqrt(deg_lcc) * 2,
     vertex.color = colors[depts_lcc], edge.width = 0.5,
     main = "Largest Connected Component")
legend("topright", unique_depts, fill = colors, cex = 0.7, bty = "n")
```

## Largest Connected Component



### 2.2.4 aa) Why use the largest connected component?

To calculate closeness centrality of nodes, every node must be reachable from every other node. If selected nodes are in different components (i.e., graph is disconnected), some distances become infinite or undefined and the calculation breaks. Focusing on the largest component helps avoid this problem and gives meaningful values that can be interpreted and compared. When computing closeness on the largest connected component, within the largest connected component, every node can reach every other node, so the closeness values are properly defined and thus, we can compare them fairly.

## 2.3 Question 2.3: Centrality Metrics

### 2.3.1 bb) Degree Centrality

```
deg_cent <- degree(lcc)
deg_df <- data.frame(id = as.integer(V(lcc)$name), degree = deg_cent) %>%
  left_join(employees %>% select(employee_id, name), by = c("id" = "employee_id")) %>%
  select(id, name, degree) %>%
  arrange(desc(degree))

cat("Top 5 by degree:\n")

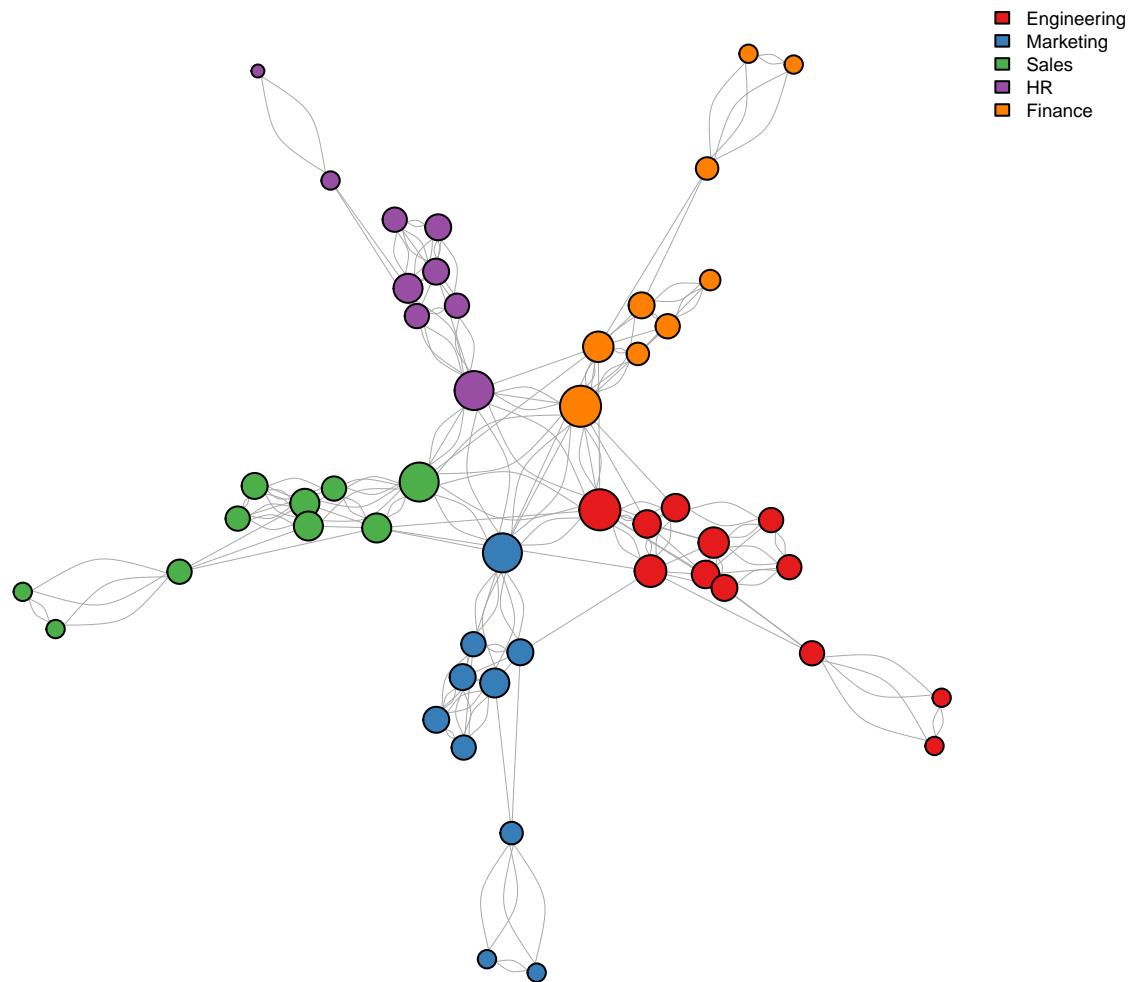
## Top 5 by degree:

head(deg_df, 5)

##      id          name degree
## 1  5 Eve Thompson     20
## 2 28 Bella Moore     20
## 3 11 Kate Wilson     18
## 4 18 Rachel Green    18
## 5 23 Wendy Clark     18

par(mar = c(1, 1, 2, 5))
plot(lcc, vertex.label = NA, vertex.label.cex = 0.5,
     vertex.size = 2 * sqrt(deg_cent), vertex.color = colors[depts_lcc],
     edge.width = 0.5, main = "Network (sized by Degree)")
legend("topright", unique_depts, fill = colors, cex = 0.6, bty = "n")
```

## Network (sized by Degree)



### 2.3.2 cc) Closeness Centrality

```
close_cent <- closeness(lcc, normalized = TRUE)
close_df <- data.frame(id = as.integer(V(lcc)$name), closeness = close_cent) %>%
  left_join(employees %>% select(employee_id, name), by = c("id" = "employee_id")) %>%
  select(id, name, closeness) %>%
  arrange(desc(closeness))

cat("Top 5 by closeness:\n")
```

```
## Top 5 by closeness:
```

```

head(close_df, 5)

##   id      name  closeness
## 1  5 Eve Thompson 0.02985984
## 2 25 Yuki Tanaka 0.02925373
## 3 14 Nathan Lee 0.02920143
## 4 11 Kate Wilson 0.02884049
## 5 28 Bella Moore 0.02719201

```

High closeness centrality means the employee is “near” a lot of other people in the network, so they can reach others quickly and information can get to them quickly too. In practical terms, they are usually well-positioned for fast coordination and spreading updates across the organization, even if they’re not necessarily the main bridge between different groups.

### 2.3.3 dd) Betweenness Centrality

```

btw_cent <- betweenness(lcc, normalized = TRUE)
btw_df <- data.frame(id = as.integer(V(lcc)$name), betweenness = btw_cent) %>%
  left_join(employees %>% select(employee_id, name), by = c("id" = "employee_id")) %>%
  select(id, name, betweenness) %>%
  arrange(desc(betweenness))

cat("Top 5 by betweenness:\n")

```

## Top 5 by betweenness:

```

head(btw_df, 5)

##   id      name betweenness
## 1 14 Nathan Lee 0.3380244
## 2  5 Eve Thompson 0.2884010
## 3 25 Yuki Tanaka 0.2833759
## 4 23 Wendy Clark 0.2789116
## 5  2 Bob Martinez 0.2268282

```

Betweenness centrality measures how often an employee sits in the middle of the shortest routes connecting other employees. Thus, if someone has high betweenness, they usually act as a bridge between different clusters or teams, meaning they can connect communities that may otherwise be disconnected and shape how information moves across the organization, and if they step out or disengage, communication between groups can slow down or become more fragmented.

### 2.3.4 ee) PageRank

```

pr <- page_rank(lcc)$vector
pr_df <- data.frame(id = as.integer(V(lcc)$name), pagerank = pr) %>%
  left_join(employees %>% select(employee_id, name), by = c("id" = "employee_id")) %>%
  select(id, name, pagerank) %>%
  arrange(desc(pagerank))

cat("Top 5 by PageRank:\n")

```

## Top 5 by PageRank:

```
head(pr_df, 5)
```

```

##   id      name    pagerank
## 1  5 Eve Thompson 0.04219373
## 2 23 Wendy Clark 0.04049384
## 3 28 Bella Moore 0.03937716
## 4 18 Rachel Green 0.03930274
## 5 11 Kate Wilson 0.03894129

```

Degree centrality is the direct count of how many people an employee is connected to. PageRank is different because it also cares who those connections are with, meaning being connected to important people boosts the score more than being connected to less influential ones. In practical terms, a high degree can mean talking to a lot of people, but PageRank can still rate someone highly even with fewer connections if those connections are to very influential people (higher quality links).

### 2.3.5 ff) Comparing all metrics

```

all_cent <- data.frame(
  id = as.integer(V(lcc)$name),
  degree = deg_cent,
  closeness = close_cent,
  betweenness = btw_cent,
  pagerank = pr
) %>%
  left_join(employees %>% select(employee_id, name, department, role),
            by = c("id" = "employee_id")) %>%
  select(id, name, dept = department, role, degree, closeness, betweenness, pagerank)

top10 <- all_cent %>% arrange(desc(degree)) %>% head(10)
top10

```

```

##   id      name      dept    role degree  closeness  betweenness
## 1  5 Eve Thompson Engineering Manager      20 0.02985984 0.288400956

```

```

## 2 28 Bella Moore      Finance Manager      20 0.02719201 0.115949951
## 3 11 Kate Wilson     Marketing Manager    18 0.02884049 0.160501701
## 4 18 Rachel Green    Sales Manager       18 0.02606383 0.046541950
## 5 23 Wendy Clark     HR Manager        18 0.02603613 0.278911565
## 6 2 Bob Martinez    Engineering Lead     12 0.02704194 0.226828231
## 7 7 Grace Okonkwo   Engineering Senior   11 0.01952969 0.005668934
## 8 25 Yuki Tanaka    Finance Lead       11 0.02925373 0.283375850
## 9 9 Iris Nakamura   Marketing Senior    10 0.01954527 0.068664966
## 10 14 Nathan Lee     Sales Lead        10 0.02920143 0.338024376
##      pagerank
## 1 0.04219373
## 2 0.03937716
## 3 0.03894129
## 4 0.03930274
## 5 0.04049384
## 6 0.03100845
## 7 0.02454985
## 8 0.02689045
## 9 0.02448814
## 10 0.02545679

```

```

# Rankings
top10 %>%
  mutate(
    deg_r = rank(-degree),
    close_r = rank(-closeness),
    btw_r = rank(-betweenness),
    pr_r = rank(-pagerank)
  ) %>%
  select(id, name, deg_r, close_r, btw_r, pr_r)

```

```

##   id      name deg_r close_r btw_r pr_r
## 1  5 Eve Thompson  1.5     1     2     1
## 2 28 Bella Moore  1.5     5     7     3
## 3 11 Kate Wilson  4.0     4     6     5
## 4 18 Rachel Green 4.0     7     9     4
## 5 23 Wendy Clark  4.0     8     4     2
## 6  2 Bob Martinez 6.0     6     5     6
## 7  7 Grace Okonkwo 7.5    10    10    9
## 8 25 Yuki Tanaka  7.5     2     3     7
## 9  9 Iris Nakamura 9.5     9     8    10
## 10 14 Nathan Lee  9.5     3     1     8

```

Yes, Eve Thompson (ID 5) ranks highly on all metrics. She's tied-highest on degree (20), has the highest closeness (~0.0299) and highest PageRank (~0.0422) among the top 10 employees by degree, and very high betweenness (~0.288) as well. This pattern shows that Eve is someone who is both broadly connected (degree), centrally positioned in terms of short paths (closeness),

frequently sits on key routes between others (betweenness), and is connected to other important nodes (PageRank). Other employees, such as Yuki Tanaka (ID 25) and Nathan Lee (ID 14), have high betweenness (~0.283 and ~0.338, respectively) but only moderate degree centrality (11 and 10, respectively), which suggests that they may not know many other employees but are still central to facilitating communication. There are also employees, such as Wendy Clark (ID 23), who have a high PageRank score (~0.040) but moderate closeness centrality (~0.026), which implies that while they may not be able to spread information fast, they have connections with influential people in the network. On the other hand, Grace Okonkwo (ID 7) ranks within the top 10 by degree (11) but has very low betweenness (~0.0057), which fits the idea of being connected within her immediate team, but is not a main connector between different teams.

## 2.4 Question 2.4: Community Detection

### 2.4.1 gg) Spinglass clustering

```
set.seed(42)
comm <- cluster_spinglass(lcc)

cat("Communities found:", length(comm$csizes), "\n")
```

## Communities found: 5

```
cat("Modularity:", round(modularity(comm), 3), "\n")
```

## Modularity: 0.028

### 2.4.2 hh) Community sizes

```
mem <- membership(comm)
table(mem)
```

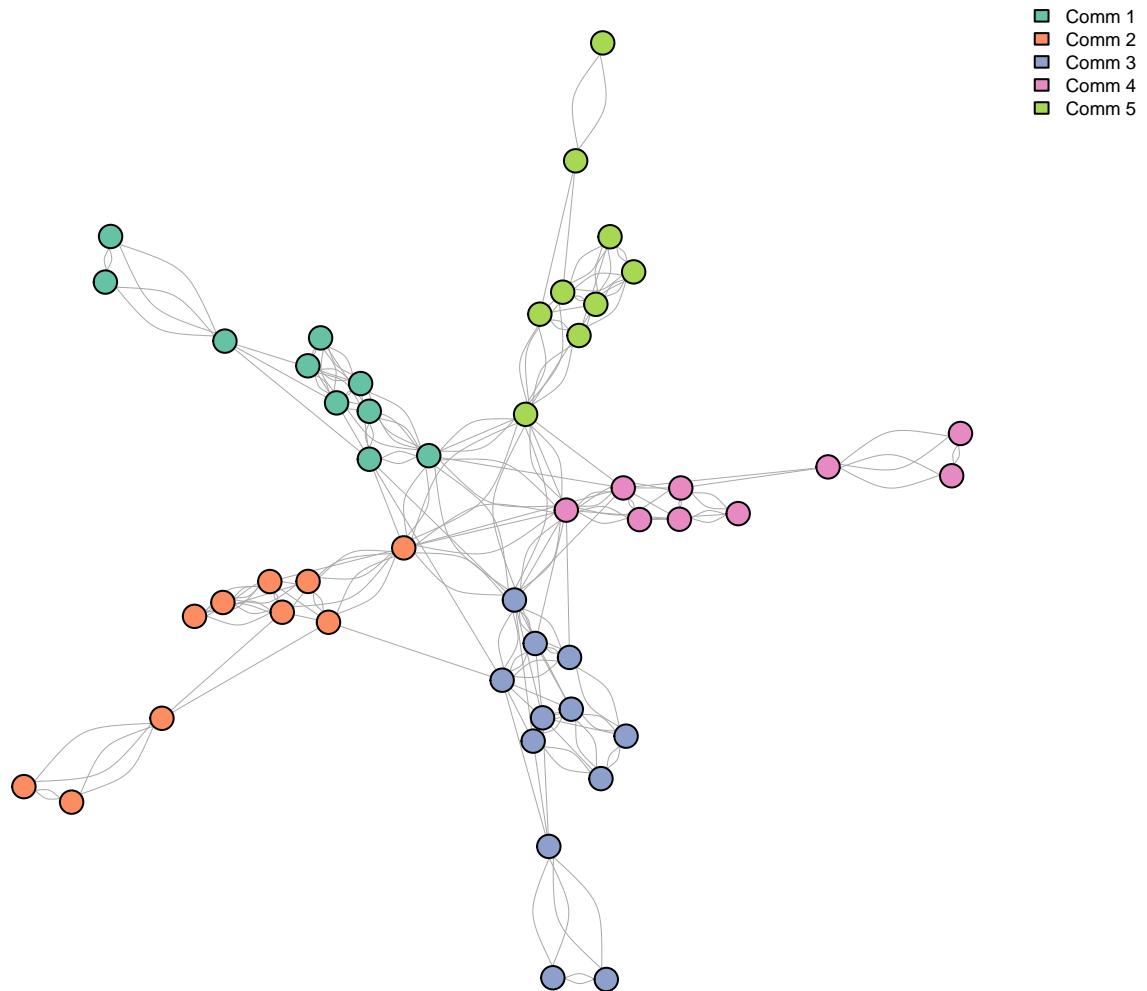
```
## mem
## 1 2 3 4 5
## 10 10 12 9 9
```

### 2.4.3 ii) Visualize by community

```
num_comm <- length(unique(mem))
comm_colors <- brewer.pal(max(3, num_comm), "Set2")

par(mar = c(1, 1, 2, 5))
plot(lcc, vertex.label = NA, vertex.label.cex = 0.5,
     vertex.size = 5, vertex.color = comm_colors[mem],
     edge.width = 0.5, main = "Network (colored by Community)")
legend("topright", paste("Comm", 1:num_comm), fill = comm_colors[1:num_comm],
       cex = 0.6, bty = "n")
```

## Network (colored by Community)



### 2.4.4 jj) Community vs Department

```
comm_dept <- data.frame(  
  id = as.integer(V(lcc)$name),  
  community = mem,  
  department = V(lcc)$department  
) %>%  
  left_join(employees %>% select(employee_id, name), by = c("id" = "employee_id"))  
  
xtab <- table(comm_dept$community, comm_dept$department)  
cat("\nNumber of employees:\n")
```

##

```

## Number of employees:

xtab

##          Engineering Finance HR Marketing Sales
## 1              0      0   0       0     10
## 2              0      0   0      10     0
## 3             12      0   0       0     0
## 4              0      9   0       0     0
## 5              0      0   9       0     0

cat("\nPercentages:\n")

## Percentages:

round(prop.table(xtab, 1) * 100, 1)

##          Engineering Finance HR Marketing Sales
## 1              0      0   0       0    100
## 2              0      0   0      100     0
## 3             100      0   0       0     0
## 4              0     100   0       0     0
## 5              0      0  100      0     0

```

Yes, the detected communities align strongly with departments as each community is dominated by one department. For every community, 100 percent of its members come from a single department, with no mixing across departments. This pattern suggests that communication within the organization is highly siloed. However, this community detection is based on who emails whom, thus it is possible that people still work cross-functionally physically but the email data is still primarily department-based.

#### 2.4.5 kk) Business insights

Understanding TechConnect's communication communities provides management with a practical lens for improving coordination and execution. Since communication largely occurs within well-defined groups, management should not assume that information or decisions naturally diffuse across the organization. Instead, communication across teams is likely to depend on deliberate intervention.

The community structure highlights the importance of individuals who connect different groups. These bridging employees play a disproportionate role in transmitting information across teams, coordinating work, and preventing misalignment. As a result, they represent both a strategic asset and a potential vulnerability if their roles are informal or unsupported.

Community insights can also inform how TechConnect designs cross-functional initiatives. Because collaboration does not emerge organically at the group level, cross-department projects may require explicit communication structures, such as designated liaisons or joint reporting mechanisms, to function effectively.

Finally, understanding community boundaries enables more targeted change management. When rolling out organizational changes, policies, or strategic initiatives, management can engage influential members within each community to improve adoption and reduce miscommunication, rather than relying solely on broad, organization-wide announcements.

### 3 Part 3: Integration and Insights

#### 3.1 Question 3.1: Joining Data

##### 3.1.1 ll) Join employee data with centrality metrics

```
cent_df <- data.frame(
  employee_id = as.integer(V(lcc)$name),
  degree = degree(lcc),
  closeness = closeness(lcc, normalized = TRUE),
  betweenness = betweenness(lcc, normalized = TRUE),
  pagerank = page_rank(lcc)$vector
)

combined <- employees %>%
  inner_join(cent_df, by = "employee_id")

combined %>%
  select(employee_id, name, department, performance_score,
         degree, closeness, betweenness, pagerank) %>%
  head(10)

## # A tibble: 10 x 8
##   employee_id name    department performance_score degree  closeness  betweenness
##       <int> <chr>   <chr>           <dbl>   <dbl>     <dbl>      <dbl>
## 1          1 Alice ~ Engineeri~        4.5      9  0.0203  0.0286
## 2          2 Bob Ma~ Engineeri~        4.8     12  0.0270  0.227 
## 3          3 Charli~ Engineeri~        3.8      7  0.0188  0.0799
## 4          4 Diana ~ Engineeri~        4.2      8  0.0198  0.0197
## 5          5 Eve Th~ Engineeri~        4.6     20  0.0299  0.288 
## 6          6 Frank ~ Engineeri~        3.2      4  0.0164  0      
## 7          7 Grace ~ Engineeri~        4.4     11  0.0195  0.00567
## 8          8 Henry ~ Marketing        4.3      8  0.0230  0.112 
## 9          9 Iris N~ Marketing        3.9     10  0.0195  0.0687
## 10         10 Jack B~ Marketing        3.5      6  0.0173  0.0799
## # i 1 more variable: pagerank <dbl>
```

##### 3.1.2 mm) Correlation analysis

```
cat("Degree vs Performance:", round(cor(combined$degree, combined$performance_score), 3), "\n")
## Degree vs Performance: 0.691
```

```

cat("Closeness vs Performance:", round(cor(combined$closeness, combined$performance_score), 3)

## Closeness vs Performance: 0.702

cat("Betweenness vs Performance:", round(cor(combined$betweenness, combined$performance_score)

## Betweenness vs Performance: 0.477

cat("PageRank vs Performance:", round(cor(combined$pagerank, combined$performance_score), 3),

## PageRank vs Performance: 0.745

```

Network centrality does have a moderate positive relationship with performance since all four centrality scores are correlated positively with performance, from 0.477 (Betweenness vs Performance) to 0.745 (PageRank vs Performance). PageRank has the strongest relationship with performance, so being connected to other important people seems most related to a better performance. Closeness (0.70) and degree (0.69) are also important to doing well, signaling that shorter distances and number of connections are important to performance. Betweenness (0.48) is weaker, which means bridging between groups is less important than the other centrality scores for performance.

Correlation of degree centrality and performance score is 0.691.

### 3.1.3 nn) High performers with low centrality

```

med_deg <- median(combined$degree)
cat("Median degree:", med_deg, "\n\n")

## Median degree: 7

combined %>%
  filter(performance_score > 4.0 & degree < med_deg) %>%
  select(employee_id, name, department, role, performance_score, degree, projects_completed) %
  arrange(desc(performance_score))

## # A tibble: 1 x 7
##   employee_id name  department role  performance_score degree projects_completed
##       <int> <chr> <chr>     <chr>           <dbl>    <dbl>             <int>
## 1          46 Tara~ Finance   Lead        4.3         6            17

```

While employees like Tara Jenkins (employee ID: 46) do great work, they are flying under the radar network-wise. They may be specialists who do not need to talk to other employees as much, or more introverted. Management should make sure these employees are not overlooked for promotions simply because they are not as visible in the network. Additionally, these employees could be underutilized and could benefit from more collaboration opportunities. They may also need mentorship to expand their network influence and visibility within the organization.

## 3.2 Question 3.2: Executive Summary

### 3.2.1 Additional Analyses Supporting the Executive Summary\*\*

This section summarises supporting analyses referenced in the Executive Summary. It provides compact tables for management interpretation.

#### A1. Top performers by combined performance and network position

The following table highlights employees who rank highly on both performance score and network degree (as a proxy for connectivity).

```
## # A tibble: 5 x 5
##   name      department role  performance_score degree
##   <chr>     <chr>    <chr>        <dbl>    <dbl>
## 1 Bella Moore Finance Manager        4.7      20
## 2 Eve Thompson Engineering Manager  4.6      20
## 3 Bob Martinez Engineering Lead    4.8      12
## 4 Kate Wilson Marketing Manager   4.5      18
## 5 Wendy Clark  HR Manager        4.5      18
```

#### A2. Department summary with performance and network metrics

This table summarises average performance and network position by department.

```
## # A tibble: 5 x 5
##   department      n avg_perf avg_deg avg_btw
##   <chr>        <int>    <dbl>    <dbl>    <dbl>
## 1 Engineering    12     4.25     8.92  0.0599
## 2 Finance         9     3.96     7.89  0.0580
## 3 Sales           10     3.95     8.5   0.0548
## 4 Marketing       10     3.86     8     0.0464
## 5 HR              9     3.76     7.89  0.0527
```

#### A3. Performance by experience level

To examine how performance and coordination responsibilities evolve with tenure, we analyze average performance, project involvement, and network position across experience levels.

```
## # A tibble: 16 x 6
##   years_exp      n avg_perf avg_projects avg_degree avg_pagerank
##   <int> <int>    <dbl>        <dbl>      <dbl>        <dbl>
## 1 1          1     6     3.13        2.33       4      0.0108
## 2 2          2     6     3.47        4          4.83      0.0132
## 3 3          3     2     3.75        6.5        5.5      0.0131
## 4 4          4     2     3.55        6.5        7.5      0.0145
## 5 5          5     4     3.85        8.5        7.75      0.0178
## 6 6          6     5     3.96       11.4       8.6      0.0201
## 7 7          7     4     4.03       11.5       7.5      0.0164
```

|       |    |   |      |      |      |        |
|-------|----|---|------|------|------|--------|
| ## 8  | 8  | 5 | 4.2  | 14.6 | 8    | 0.0215 |
| ## 9  | 9  | 4 | 4.28 | 16.5 | 7.75 | 0.0205 |
| ## 10 | 10 | 3 | 4.43 | 18.7 | 8.67 | 0.0244 |
| ## 11 | 11 | 2 | 4.6  | 20.5 | 9.5  | 0.0231 |
| ## 12 | 12 | 2 | 4.65 | 21   | 15   | 0.0358 |
| ## 13 | 13 | 1 | 4.4  | 25   | 18   | 0.0393 |
| ## 14 | 14 | 2 | 4.6  | 25   | 19   | 0.0392 |
| ## 15 | 15 | 1 | 4.6  | 28   | 20   | 0.0422 |
| ## 16 | 16 | 1 | 4.9  | 30   | 9    | 0.0237 |

#### A4. Performance by project load

Employees are grouped into low, medium, and high project load bands to assess how workload relates to performance and communication roles.

|                      |       |          |            |                 |
|----------------------|-------|----------|------------|-----------------|
| ## # A tibble: 3 x 5 |       |          |            |                 |
| ##   project_band    | n     | avg_perf | avg_degree | avg_betweenness |
| ##   <chr>           | <int> | <dbl>    | <dbl>      | <dbl>           |
| ## 1 High load       | 14    | 4.53     | 12.4       | 0.137           |
| ## 2 Medium load     | 22    | 4.02     | 7.86       | 0.0204          |
| ## 3 Low load        | 14    | 3.34     | 4.86       | 0.0258          |

#### A5. Key communication hubs

The following table lists employees with the highest betweenness centrality, highlighting individuals who play critical bridging roles in internal communication.

|                      |            |       |             |        |          |           |                   |
|----------------------|------------|-------|-------------|--------|----------|-----------|-------------------|
| ## # A tibble: 5 x 8 |            |       |             |        |          |           |                   |
| ##   name            | department | role  | betweenness | degree | pagerank | closeness | performance_score |
| ##   <chr>           | <chr>      | <chr> | <dbl>       | <dbl>  | <dbl>    | <dbl>     | <dbl>             |
| ## 1 Nath~           | Sales      | Lead  | 0.338       | 10     | 0.0255   | 0.0292    | 4.7               |
| ## 2 Eve ~           | Engineeri~ | Mana~ | 0.288       | 20     | 0.0422   | 0.0299    | 4.6               |
| ## 3 Yuki~           | Finance    | Lead  | 0.283       | 11     | 0.0269   | 0.0293    | 4.6               |
| ## 4 Wend~           | HR         | Mana~ | 0.279       | 18     | 0.0405   | 0.0260    | 4.5               |
| ## 5 Bob ~           | Engineeri~ | Lead  | 0.227       | 12     | 0.0310   | 0.0270    | 4.8               |

### 3.2.2 Executive Summary for TechConnect Management

#### Overview

We analyzed TechConnect's employees and email communication data to assess performance and information flow. While overall performance is strong, communication and workload are concentrated within departments and among a small group of highly connected employees, creating coordination and resilience risks as the organization scales.

#### Performance Findings

TechConnect's average performance score is 3.97 out of 5, with 612 projects completed, indicating strong organization-wide performance. We identified 23 standout performers (performance > 4.0

with 10+ projects each). Performance varies across departments, with Engineering leading (average ~4.25), while Marketing (~3.86) and HR (~3.76) lag, indicating scope for targeted capability development in latter teams.

Employee performance increases steadily with experience and stabilizes after approximately 7–8 years. Experienced employees take on more projects and exhibit higher network centrality, indicating expertise, influence, and coordination responsibilities accumulate with tenure. However, at senior levels, project load and communication demands continue to rise while performance gains plateau, suggesting diminishing returns and potential coordination overload. Performance is also strongly associated with project involvement: employees handling higher project loads consistently outperform their peers.

## **Network Structure**

The email network is largely connected through one dominant component, enabling organization-wide information flow. However, community detection shows communication remains strongly clustered by department. This reflects strong within-department coordination but limited cross-functional exchange, creating functional silos that may slow decision-making and increase friction in multi-department initiatives.

## **Key Employees**

Nathan has the highest betweenness, making him a critical bridge in the network. Eve ranks highly across multiple centrality metrics, emerging as the most important overall hub with broad reach, while Yuki and Wendy also serve as key connectors. Overreliance on them creates vulnerability, as overload or exit would disrupt company-wide information flow.

## **Recommendations**

1. To address siloed communication patterns, TechConnect should define shared OKRs and institutionalize regular cross-functional forums (e.g., monthly syncs) to ensure organization moves toward a common vision and prevent small disconnects from becoming bottlenecks.
2. Employees with high betweenness centrality (e.g. Eve, Nathan) should be formally deployed as cross-functional coordinators, with clear role definitions and resourcing. To avoid coordination overload as tenure increases, senior employees should focus on high-impact decision-making and mentoring, supported by delegation structures, while mid-tenure staff take on greater project ownership to build capacity.
3. Not all top contributors are highly networked. Employees like Tara Jenkins may deliver strong performance but remain under-recognized. Proactively acknowledging their contributions and involving them in strategic initiatives reinforces engagement and supports talent retention.