Basic analysis and Network statistics

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set up

```
library(readr)
library(igraph)
library(RColorBrewer)
library(ggplot2)
library(reshape2)
library(scales)
set.seed(48528608)

# Create output directory for saving plots
if (!dir.exists("plots")) {
  dir.create("plots", recursive = TRUE)
}
```

```
# Basic Analysis (Jinxi Hu)
# this file is for do some most basic analysis to the data we collected.
nodes <- read.csv("data/nodes.csv")
# only keep the node with title
nodes_clean <- subset(nodes, !(is.na(title) | trimws(title) == ""))

# head of data
head(nodes_clean)
```

```
##   local_id                       paper_id
## 1    P0001 https://openalex.org/W4365143687
## 2    P0002 https://openalex.org/W4205164650
## 3    P0003 https://openalex.org/W4295951577
## 4    P0004 https://openalex.org/W2947423323
## 5    P0005 https://openalex.org/W3042276730
## 6    P0006 https://openalex.org/W3180959755
##
## 1
## 2
## 3
## 4                                                                                                    I
## 5
## 6 Protocol for development of a reporting guideline (TRIPOD-AI) and risk of bias tool (PROBAST-AI) fo
##   year       first_author             institution country
## 1 2023       Michael Moor     Stanford University      US
```

```
## 2 2022   Pranav Rajpurkar      Harvard University      US
## 3 2022   Julián N. Acosta         Yale University      US
## 4 2019 Philippe Schwaller   Ibm Research - Zurich      CH
## 5 2020     Jessica Morley    University Of Oxford      GB
## 6 2021     Gary S Collins John Radcliffe Hospital      GB
##                       venue                                          subtopic
## 1                    Nature                      Machine Learning in Healthcare
## 2           Nature Medicine Artificial Intelligence in Healthcare and Education
## 3           Nature Medicine Artificial Intelligence in Healthcare and Education
## 4       ACS Central Science               Machine Learning in Materials Science
## 5 Social Science & Medicine Artificial Intelligence in Healthcare and Education
## 6                 BMJ Open Artificial Intelligence in Healthcare and Education
##   citations references n_authors author_share
## 1      1155         50         7   0.14285714
## 2      1931        127         4   0.25000000
## 3       810        180         4   0.25000000
## 4       722         40         7   0.14285714
## 5       671        174         7   0.14285714
## 6       667         33        13   0.07692308
```

```
# row and colum number
dim(nodes_clean)
```

```
## [1] 2610   13
```

```
# colum names
names(nodes_clean)
```

```
##  [1] "local_id"     "paper_id"     "title"        "year"         "first_author"
##  [6] "institution"  "country"      "venue"        "subtopic"     "citations"
## [11] "references"   "n_authors"    "author_share"
```

```
# type of colums
str(nodes_clean)
```

```
## 'data.frame':    2610 obs. of  13 variables:
##  $ local_id    : chr  "P0001" "P0002" "P0003" "P0004" ...
##  $ paper_id    : chr  "https://openalex.org/W4365143687" "https://openalex.org/W4205164650" "https:/
##  $ title       : chr  "Foundation models for generalist medical artificial intelligence" "AI in heal
##  $ year        : int  2023 2022 2022 2019 2020 2021 2016 2020 2020 2024 ...
##  $ first_author: chr  "Michael Moor" "Pranav Rajpurkar" "Julián N. Acosta" "Philippe Schwaller" ...
##  $ institution : chr  "Stanford University" "Harvard University" "Yale University" "Ibm Research - Z
##  $ country     : chr  "US" "US" "US" "CH" ...
##  $ venue       : chr  "Nature" "Nature Medicine" "Nature Medicine" "ACS Central Science" ...
##  $ subtopic    : chr  "Machine Learning in Healthcare" "Artificial Intelligence in Healthcare and Edu
##  $ citations   : int  1155 1931 810 722 671 667 351 445 762 833 ...
##  $ references  : int  50 127 180 40 174 33 22 42 60 99 ...
##  $ n_authors   : int  7 4 4 7 7 13 4 9 44 34 ...
##  $ author_share: num  0.143 0.25 0.25 0.143 0.143 ...
```

```r
# summary
summary(nodes_clean)
```

```
##    local_id           paper_id            title                year
##  Length:2610        Length:2610        Length:2610        Min.   :2015
##  Class :character   Class :character   Class :character   1st Qu.:2022
##  Mode  :character   Mode  :character   Mode  :character   Median :2023
##                                                           Mean   :2023
##                                                           3rd Qu.:2024
##                                                           Max.   :2025
##  first_author       institution          country            venue
##  Length:2610        Length:2610        Length:2610        Length:2610
##  Class :character   Class :character   Class :character   Class :character
##  Mode  :character   Mode  :character   Mode  :character   Mode  :character
##
##
##
##    subtopic           citations         references      n_authors
##  Length:2610        Min.   :   0.00   Min.   :  0.0   Min.   :  1.000
##  Class :character   1st Qu.:   1.00   1st Qu.: 10.0   1st Qu.:  3.000
##  Mode  :character   Median :   6.00   Median : 27.0   Median :  5.000
##                     Mean   :  34.77   Mean   : 36.2   Mean   :  7.654
##                     3rd Qu.:  25.00   3rd Qu.: 48.0   3rd Qu.:  9.000
##                     Max.   :2383.00   Max.   :629.0   Max.   :100.000
##   author_share
##  Min.   :0.0100
##  1st Qu.:0.1111
##  Median :0.2000
##  Mean   :0.2622
##  3rd Qu.:0.3333
##  Max.   :1.0000
```

```r
# read edge
edges = read.csv("data/edges.csv")
# only keep valid edges
edges_clean <- subset(edges, source %in% nodes_clean$local_id &
                        target %in% nodes_clean$local_id)
# number of cititations
dim(edges_clean)
```

```
## [1] 3757    2
```

```r
# form graph
graph <- graph_from_data_frame(edges_clean, nodes_clean, directed = FALSE)
# remove the parallel edges and self loops
graph <- simplify(graph, remove.multiple = TRUE, remove.loops = TRUE)
# nodes in graph
vcount(graph)
```

```
## [1] 2610
```

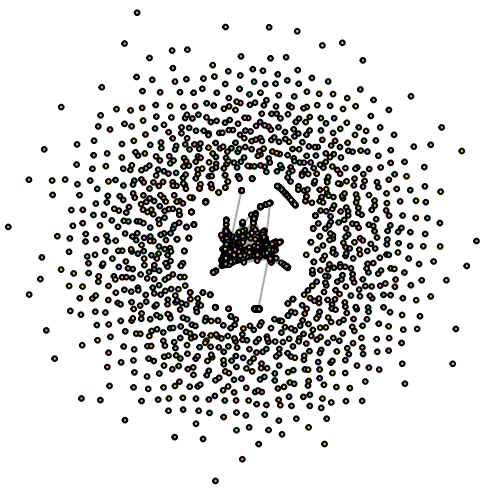
```r
# edges in graph
ecount(graph)
```

```
## [1] 3722
```

```r
# plot graph (color by university)
institutions <- unique(V(graph)$institution)
palette <- brewer.pal(min(length(institutions), 8), "Set2")
color_map <- setNames(rep(palette, length.out = length(institutions)),
                      institutions)
V(graph)$color <- color_map[V(graph)$institution]

# Save plot to file
png("plots/overall_network_by_university.png", width = 1200, height = 900, res = 150)
plot(graph, vertex.size=2, edge.size=0.1, vertex.color=V(graph)$color,
     main="Overall network (colored by university)", vertex.label=NA)
dev.off()
```

```
## pdf
##   2
```

```r
# Display plot in document
plot(graph, vertex.size=2, edge.size=0.1, vertex.color=V(graph)$color,
     main="Overall network (colored by university)", vertex.label=NA)
```



```r
# Initial Network Statistics (Samarth Grover)
cat("=== NETWORK STATISTICS ===\n")
```

```
## === NETWORK STATISTICS ===
```

```r
cat("Total nodes:", vcount(graph), "\n")
```

```
## Total nodes: 2610
```

```r
cat("Total edges (citations):", ecount(graph), "\n")
```

```
## Total edges (citations): 3722
```

```r
cat("Network density:", edge_density(graph), "\n")
```

```
## Network density: 0.00109318
```

```r
cat("Average degree:", mean(degree(graph, mode="all")), "\n")
```

```
## Average degree: 2.852107
```

```r
cat("Average in-degree (citations received):",
    mean(degree(graph, mode="in")), "\n")
```

```
## Average in-degree (citations received): 2.852107
```

```r
cat("Average out-degree (citations made):",
    mean(degree(graph, mode="out")), "\n\n")
```

```
## Average out-degree (citations made): 2.852107
```

```r
# Analyze isolated components
cat("=== COMPONENT ANALYSIS ===\n")
```

```
## === COMPONENT ANALYSIS ===
```

```r
components <- components(graph, mode="weak")
cat("Number of weakly connected components:", components$no, "\n")
```

```
## Number of weakly connected components: 1086
```

```r
cat("Size of largest component:", max(components$csize), "\n")
```

```
## Size of largest component: 1433
```

```r
cat("Proportion of nodes in largest component:",
    round(max(components$csize) / vcount(graph) * 100, 2), "%\n\n")
```

```
## Proportion of nodes in largest component: 54.9 %
```

```r
# Count isolated nodes
isolated_count <- sum(degree(graph, mode="all") == 0)
cat("Number of isolated nodes (no citations in or out):",
    isolated_count, "\n")
```

```
## Number of isolated nodes (no citations in or out): 1043
```

```r
cat("Proportion of isolated nodes:",
    round(isolated_count / vcount(graph) * 100, 2), "%\n")
```

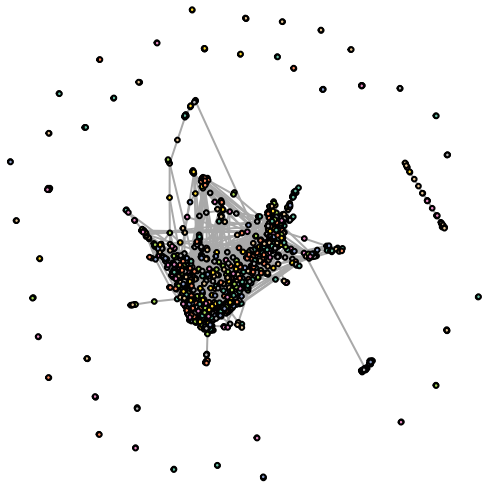
```
## Proportion of isolated nodes: 39.96 %
```

```r
# Remove isolated nodes for cleaner visualization
non_isolated <- V(graph)[degree(graph, mode="all") > 0]
graph_connected <- induced_subgraph(graph, non_isolated)

# plot graph without isolated nodes (color by university)
institutions_connected <- unique(V(graph_connected)$institution)
palette_connected <- brewer.pal(min(length(institutions_connected), 8), "Set2")
color_map_connected <- setNames(rep(palette_connected,
                                    length.out = length(institutions_connected)),
                                    institutions_connected)
V(graph_connected)$color <- color_map_connected[V(graph_connected)$institution]

# Save plot to file
png("plots/network_without_isolated_nodes.png", width = 1200, height = 900, res = 150)
plot(graph_connected, vertex.size=2, edge.size=0.1,
     vertex.color=V(graph_connected)$color,
     main="Network without isolated nodes (colored by university)",
     vertex.label=NA)
dev.off()
```

```
## pdf
##   2
```

```r
# Display plot in document
plot(graph_connected, vertex.size=2, edge.size=0.1,
     vertex.color=V(graph_connected)$color,
     main="Network without isolated nodes (colored by university)",
     vertex.label=NA)
```

Network without isolated nodes (colored by university)



```
library(igraph)
nodes2 <- read.csv("data/nodes_connected.csv")
edges2 <- read.csv("data/edges_connected.csv")

head(nodes2)
```

```
##   local_id                         paper_id
## 1    P0001 https://openalex.org/W4365143687
## 2    P0002 https://openalex.org/W4205164650
## 3    P0003 https://openalex.org/W4295951577
## 4    P0004 https://openalex.org/W2947423323
## 5    P0005 https://openalex.org/W3042276730
## 6    P0006 https://openalex.org/W3180959755
##
## 1
## 2
## 3
## 4
## 5
## 6 Protocol for development of a reporting guideline (TRIPOD-AI) and risk of bias tool (PROBAST-AI) f
##   year       first_author             institution country
## 1 2023       Michael Moor     Stanford University      US
## 2 2022   Pranav Rajpurkar      Harvard University      US
## 3 2022   Julián N. Acosta         Yale University      US
## 4 2019 Philippe Schwaller   Ibm Research - Zurich      CH
## 5 2020     Jessica Morley    University Of Oxford      GB
```

```
## 6 2021     Gary S Collins John Radcliffe Hospital      GB
##                         venue                                          subtopic
## 1                      Nature                       Machine Learning in Healthcare
## 2           Nature Medicine Artificial Intelligence in Healthcare and Education
## 3           Nature Medicine Artificial Intelligence in Healthcare and Education
## 4       ACS Central Science               Machine Learning in Materials Science
## 5 Social Science & Medicine Artificial Intelligence in Healthcare and Education
## 6                  BMJ Open Artificial Intelligence in Healthcare and Education
##   citations references n_authors author_share
## 1      1155         50         7   0.14285714
## 2      1931        127         4   0.25000000
## 3       810        180         4   0.25000000
## 4       722         40         7   0.14285714
## 5       671        174         7   0.14285714
## 6       667         33        13   0.07692308
```

```
dim(nodes2)
```

```
## [1] 1582   13
```

```
names(nodes2)
```

```
##  [1] "local_id"     "paper_id"     "title"        "year"         "first_author"
##  [6] "institution"  "country"      "venue"        "subtopic"     "citations"
## [11] "references"   "n_authors"    "author_share"
```

```
str(nodes2)
```

```
## 'data.frame':    1582 obs. of  13 variables:
##  $ local_id    : chr  "P0001" "P0002" "P0003" "P0004" ...
##  $ paper_id    : chr  "https://openalex.org/W4365143687" "https://openalex.org/W4205164650" "https:/
##  $ title       : chr  "Foundation models for generalist medical artificial intelligence" "AI in heal
##  $ year        : int  2023 2022 2022 2019 2020 2021 2016 2020 2020 2024 ...
##  $ first_author: chr  "Michael Moor" "Pranav Rajpurkar" "Julián N. Acosta" "Philippe Schwaller" ...
##  $ institution : chr  "Stanford University" "Harvard University" "Yale University" "Ibm Research - Z
##  $ country     : chr  "US" "US" "US" "CH" ...
##  $ venue       : chr  "Nature" "Nature Medicine" "Nature Medicine" "ACS Central Science" ...
##  $ subtopic    : chr  "Machine Learning in Healthcare" "Artificial Intelligence in Healthcare and Edu
##  $ citations   : int  1155 1931 810 722 671 667 351 445 762 833 ...
##  $ references  : int  50 127 180 40 174 33 22 42 60 99 ...
##  $ n_authors   : int  7 4 4 7 7 13 4 9 44 34 ...
##  $ author_share: num  0.143 0.25 0.25 0.143 0.143 ...
```

```
summary(nodes2)
```

```
##    local_id           paper_id            title                year
##  Length:1582        Length:1582        Length:1582        Min.   :2015
##  Class :character   Class :character   Class :character   1st Qu.:2022
##  Mode  :character   Mode  :character   Mode  :character   Median :2023
##                                                           Mean   :2023
##                                                           3rd Qu.:2024
```

```
##                                                        Max.   :2025
##  first_author       institution          country            venue
##  Length:1582        Length:1582        Length:1582        Length:1582
##  Class :character   Class :character   Class :character   Class :character
##  Mode  :character   Mode  :character   Mode  :character   Mode  :character
##
##
##
##    subtopic           citations         references       n_authors
##  Length:1582        Min.   :   0.00   Min.   :  0.00   Min.   :  1.000
##  Class :character   1st Qu.:   2.00   1st Qu.: 18.00   1st Qu.:  3.000
##  Mode  :character   Median :  12.00   Median : 33.00   Median :  6.000
##                     Mean   :  50.88   Mean   : 45.12   Mean   :  8.419
##                     3rd Qu.:  42.00   3rd Qu.: 56.00   3rd Qu.: 10.000
##                     Max.   :2383.00   Max.   :629.00   Max.   :100.000
##   author_share
##  Min.   :0.0100
##  1st Qu.:0.1000
##  Median :0.1667
##  Mean   :0.2322
##  3rd Qu.:0.3333
##  Max.   :1.0000
```

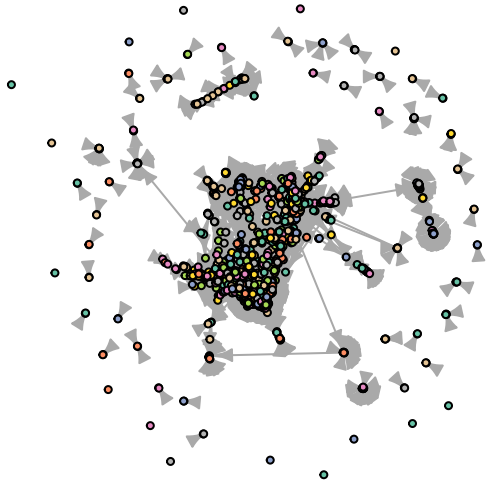
```r
graph2 <- graph_from_data_frame(edges2, vertices = nodes2, directed = TRUE)
graph2 <- simplify(graph2, remove.multiple = TRUE, remove.loops = TRUE)
```

```r
# plot graph (color by university)
institutions <- unique(V(graph2)$institution)
palette <- brewer.pal(min(length(institutions), 8), "Set2")
color_map <- setNames(rep(palette, length.out = length(institutions)),
                      institutions)
V(graph2)$color <- color_map[V(graph2)$institution]

# Save plot to file
png("plots/connected_network_by_university.png", width = 1200, height = 900, res = 150)
plot(graph2, vertex.size=3, edge.size=1, vertex.color=V(graph2)$color,
     main="Overall network (colored by university)",
     vertex.label=NA, edge.arrow.size=0.5)
dev.off()
```

```
## pdf
##   2
```

```r
# Display plot in document
plot(graph2, vertex.size=3, edge.size=1, vertex.color=V(graph2)$color,
     main="Overall network (colored by university)",
     vertex.label=NA, edge.arrow.size=0.5)
```

Overall network (colored by university)



```
cat("Total nodes:", vcount(graph2), "\n")
```

```
## Total nodes: 1582
```

```
cat("Total edges (citations):", ecount(graph2), "\n")
```

```
## Total edges (citations): 3730
```

```
cat("Network density:", edge_density(graph2), "\n")
```

```
## Network density: 0.001491319
```

```
cat("Average degree:", mean(degree(graph2, mode="all")), "\n")
```

```
## Average degree: 4.71555
```

```
cat("Average in-degree (citations received):",
    mean(degree(graph2, mode="in")), "\n")
```

```
## Average in-degree (citations received): 2.357775
```

```r
cat("Average out-degree (citations made):",
    mean(degree(graph2, mode="out")), "\n\n")
```

```
## Average out-degree (citations made): 2.357775
```

```r
# Component Analysis
cat("=== COMPONENT ANALYSIS ===\n")
```

```
## === COMPONENT ANALYSIS ===
```

```r
components <- components(graph2, mode="weak")
cat("Number of weakly connected components:", components$no, "\n")
```

```
## Number of weakly connected components: 58
```

```r
cat("Size of largest component:", max(components$csize), "\n")
```

```
## Size of largest component: 1433
```

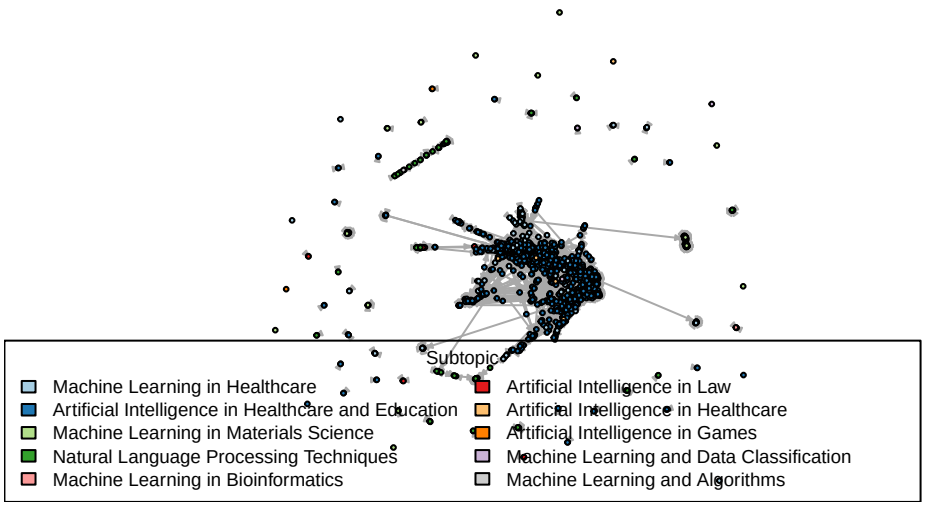
```r
cat("Proportion of nodes in largest component:",
    round(max(components$csize) / vcount(graph2) * 100, 2), "%\n\n")
```

```
## Proportion of nodes in largest component: 90.58 %
```

```r
top_subtopics <- names(sort(table(V(graph2)$subtopic),
                            decreasing = TRUE)[1:10])
V(graph2)$subtopic_group <- ifelse(V(graph2)$subtopic %in% top_subtopics,
                                   V(graph2)$subtopic, "Other")

# Create color palette
subtopic_groups <- unique(V(graph2)$subtopic_group)
n_groups <- length(subtopic_groups)
palette_sub <- c(brewer.pal(min(n_groups-1, 11), "Paired"), "gray80")
color_map_sub <- setNames(palette_sub[1:n_groups], subtopic_groups)
V(graph2)$color <- color_map_sub[V(graph2)$subtopic_group]

# Save plot to file
png("plots/citation_network_by_subtopic.png", width = 1400, height = 1000, res = 150)
plot(graph2, vertex.size=2, edge.arrow.size=0.2, vertex.color=V(graph2)$color,
     main="Citation Network (colored by subtopic)", vertex.label=NA)
legend("bottomleft", legend=names(color_map_sub), fill=color_map_sub,
       cex=0.6, title="Subtopic", ncol=2)
dev.off()
```

```
## pdf
##   2
```

```r
# Display plot in document
plot(graph2, vertex.size=2, edge.arrow.size=0.2, vertex.color=V(graph2)$color,
     main="Citation Network (colored by subtopic)", vertex.label=NA)
legend("bottomleft", legend=names(color_map_sub), fill=color_map_sub,
       cex=0.6, title="Subtopic", ncol=2)
```




```r
# Calculate all centrality metrics
V(graph2)$in_degree <- degree(graph2, mode="in")
V(graph2)$out_degree <- degree(graph2, mode="out")
V(graph2)$total_degree <- degree(graph2, mode="all")

# PageRank (influence - highly cited by other highly cited papers)
V(graph2)$pagerank <- page_rank(graph2, directed = TRUE)$vector

# Betweenness (bridging papers, potentially unifying ideas)
V(graph2)$betweenness <- betweenness(graph2, directed = TRUE, normalized = TRUE)

# Closeness (foundational papers)
V(graph2)$closeness_out <- closeness(graph2, mode = "out", normalized = TRUE)
V(graph2)$closeness_in <- closeness(graph2, mode = "in", normalized = TRUE)

# Eigenvector centrality (alternative influence measure)
V(graph2)$eigenvector <- eigen_centrality(graph2, directed = TRUE)$vector
```

Analyze the isolated nodes (Jinxi Hu)

```
# Load isolated nodes data
nodes_isolated <- read.csv("data/nodes_isolated.csv")

cat("=== ISOLATED NODES ANALYSIS ===\n")
```

```
## === ISOLATED NODES ANALYSIS ===
```

```
cat("Total isolated nodes:", nrow(nodes_isolated), "\n")
```

```
## Total isolated nodes: 1028
```

```
cat("Isolated nodes have no citations in or out\n\n")
```

```
## Isolated nodes have no citations in or out
```

```
# Basic statistics for isolated nodes
cat("Year range for isolated papers:", min(nodes_isolated$year, na.rm=TRUE), "-",
    max(nodes_isolated$year, na.rm=TRUE), "\n")
```

```
## Year range for isolated papers: 2015 - 2025
```

```
cat("Average citations for isolated papers:",
    round(mean(nodes_isolated$citations, na.rm=TRUE), 2), "\n")
```

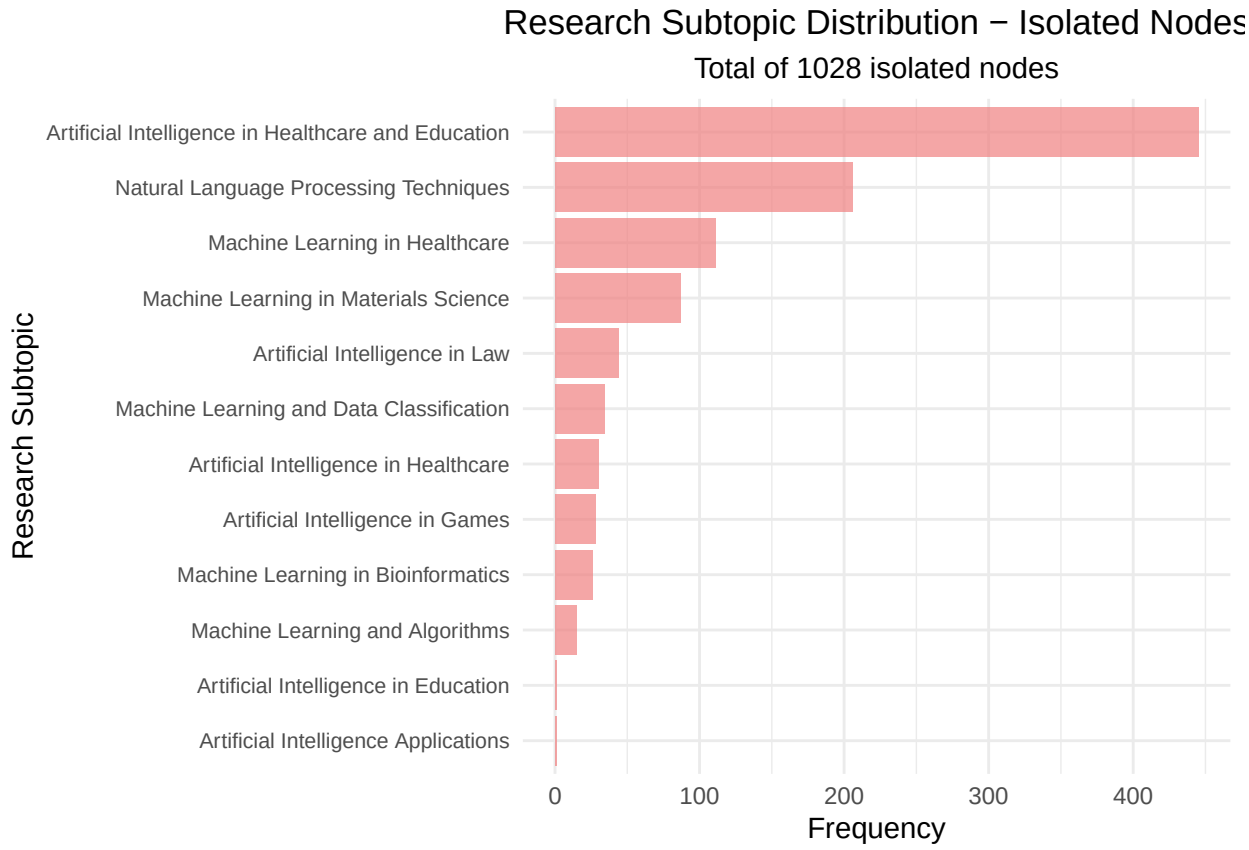
```
## Average citations for isolated papers: 9.97
```

```
cat("Average references for isolated papers:",
    round(mean(nodes_isolated$references, na.rm=TRUE), 2), "\n\n")
```

```
## Average references for isolated papers: 22.48
```

```
# Frequency analysis by research subtopic for isolated nodes

# Count frequency of subtopics in isolated nodes
subtopic_freq_isolated <- table(nodes_isolated$subtopic)
subtopic_df_isolated <- data.frame(
  subtopic = names(subtopic_freq_isolated),
  frequency = as.numeric(subtopic_freq_isolated)
)
subtopic_df_isolated <- subtopic_df_isolated[order(
  subtopic_df_isolated$frequency, decreasing = TRUE), ]

# Create histogram for subtopics (isolated nodes)
p1 <- ggplot(subtopic_df_isolated, aes(x = reorder(subtopic, frequency),
                                       y = frequency)) +
  geom_bar(stat = "identity", fill = "lightcoral", alpha = 0.7) +
```

```
  coord_flip() +
  labs(title = "Research Subtopic Distribution - Isolated Nodes",
       subtitle = paste("Total of", nrow(nodes_isolated), "isolated nodes"),
       x = "Research Subtopic",
       y = "Frequency") +
  theme_minimal() +
  theme(axis.text.y = element_text(size = 8),
        plot.title = element_text(hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5))

# Save plot
ggsave("plots/isolated_nodes_subtopic_distribution.png", plot = p1,
       width = 12, height = 8, dpi = 150)

# Display plot
print(p1)
```



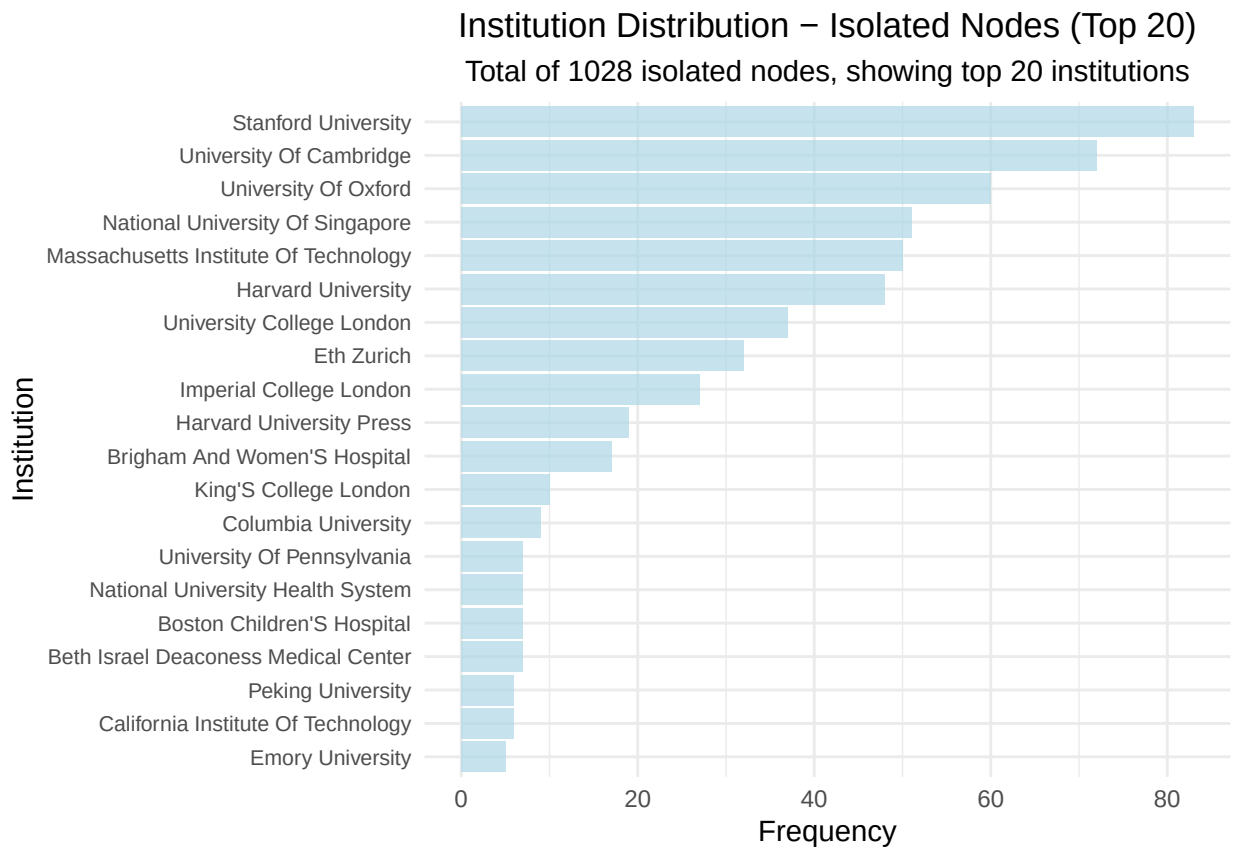

```
# Print top subtopics for isolated nodes
cat("Top 10 research subtopics in isolated nodes:\n")
```

```
## Top 10 research subtopics in isolated nodes:
```

```
print(head(subtopic_df_isolated, 10))
```

```
##                                              subtopic frequency
## 5  Artificial Intelligence in Healthcare and Education       445
## 12              Natural Language Processing Techniques       206
## 10                      Machine Learning in Healthcare       111
## 11               Machine Learning in Materials Science        87
## 6                       Artificial Intelligence in Law        44
## 8             Machine Learning and Data Classification        34
## 4                Artificial Intelligence in Healthcare        30
## 3                     Artificial Intelligence in Games        28
## 9                   Machine Learning in Bioinformatics        26
## 7                      Machine Learning and Algorithms        15
```

```r
# Frequency analysis by institution for isolated nodes

# Count frequency of institutions in isolated nodes
institution_freq_isolated <- table(nodes_isolated$institution)
institution_df_isolated <- data.frame(
  institution = names(institution_freq_isolated),
  frequency = as.numeric(institution_freq_isolated)
)
institution_df_isolated <- institution_df_isolated[order(
  institution_df_isolated$frequency, decreasing = TRUE), ]

# Show only top 20 institutions for better visualization
top_institutions_isolated <- head(institution_df_isolated, 20)

# Create histogram for institutions (isolated nodes)
p2 <- ggplot(top_institutions_isolated, aes(x = reorder(institution, frequency),
                                            y = frequency)) +
  geom_bar(stat = "identity", fill = "lightblue", alpha = 0.7) +
  coord_flip() +
  labs(title = "Institution Distribution - Isolated Nodes (Top 20)",
       subtitle = paste("Total of", nrow(nodes_isolated),
        "isolated nodes, showing top 20 institutions"),
        x = "Institution",
        y = "Frequency") +
  theme_minimal() +
  theme(axis.text.y = element_text(size = 8),
        plot.title = element_text(hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5))

# Save plot
ggsave("plots/isolated_nodes_institution_distribution.png", plot = p2,
       width = 12, height = 8, dpi = 150)

# Display plot
print(p2)
```




```
# Print top institutions for isolated nodes
cat("\nTop 15 institutions with isolated nodes:\n")
```

```
##
## Top 15 institutions with isolated nodes:
```

```
print(head(institution_df_isolated, 15))
```

```
##                              institution frequency
## 258                  Stanford University        83
## 308               University Of Cambridge        72
## 332                  University Of Oxford        60
## 206      National University Of Singapore        51
## 173 Massachusetts Institute Of Technology        50
## 104                   Harvard University        48
## 291             University College London        37
## 80                              Eth Zurich        32
## 120               Imperial College London        27
## 105              Harvard University Press        19
## 33           Brigham And Women'S Hospital        17
## 146                 King'S College London        10
## 63                   Columbia University         9
## 26   Beth Israel Deaconess Medical Center         7
## 29             Boston Children'S Hospital         7
```

```r
# Compare isolated vs connected nodes

# For connected nodes
subtopic_freq_connected <- table(V(graph2)$subtopic)
institution_freq_connected <- table(V(graph2)$institution)

# Create comparison data frame for subtopics
subtopic_comparison <- data.frame(
  subtopic = unique(c(names(subtopic_freq_isolated),
                      names(subtopic_freq_connected))),
  isolated = 0,
  connected = 0
)

# Fill in frequencies
for(i in 1:nrow(subtopic_comparison)) {
  topic <- subtopic_comparison$subtopic[i]
  subtopic_comparison$isolated[i] <- ifelse(
    topic %in% names(subtopic_freq_isolated),
    subtopic_freq_isolated[topic], 0)
  subtopic_comparison$connected[i] <- ifelse(
    topic %in% names(subtopic_freq_connected),
    subtopic_freq_connected[topic], 0)
}

# Calculate proportions
subtopic_comparison$total <- subtopic_comparison$isolated + subtopic_comparison$connected
subtopic_comparison$isolated_prop <- subtopic_comparison$
  isolated / subtopic_comparison$total
subtopic_comparison <- subtopic_comparison[order(
  subtopic_comparison$isolated_prop, decreasing = TRUE), ]

cat("\n=== COMPARISON: ISOLATED vs CONNECTED NODES ===\n")
```

```
##
## === COMPARISON: ISOLATED vs CONNECTED NODES ===
```

```r
cat("Research subtopics with highest isolation rates:\n")
```

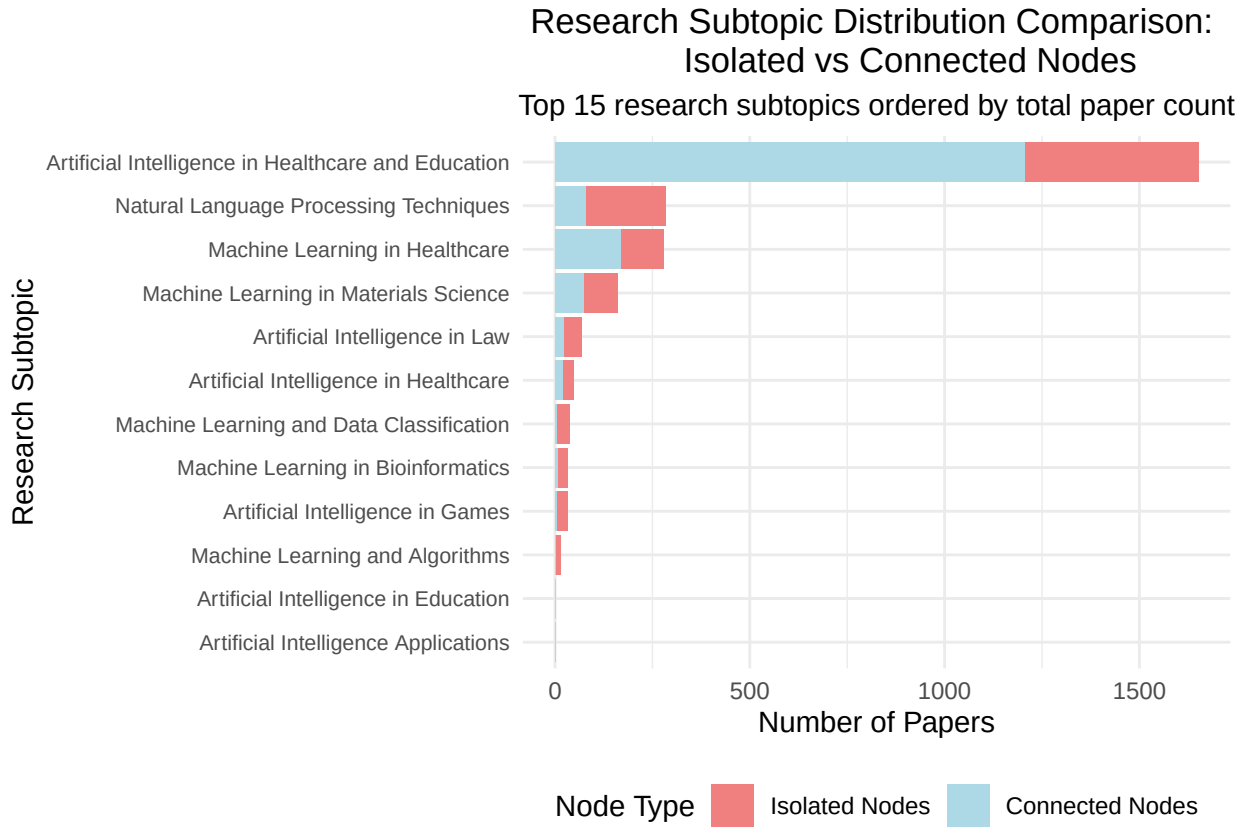
```
## Research subtopics with highest isolation rates:
```

```r
print(head(subtopic_comparison[subtopic_comparison$total >= 5,
                               c("subtopic", "isolated", "connected",
                                 "isolated_prop")], 10))
```

```
##                                          subtopic isolated connected
## 7                     Machine Learning and Algorithms       15         1
## 8            Machine Learning and Data Classification       34         4
## 3                    Artificial Intelligence in Games       28         4
## 9                  Machine Learning in Bioinformatics       26         7
## 12             Natural Language Processing Techniques      206        78
## 6                      Artificial Intelligence in Law       44        23
```

```
## 4                Artificial Intelligence in Healthcare       30        18
## 11               Machine Learning in Materials Science       87        74
## 10                     Machine Learning in Healthcare      111       167
## 5  Artificial Intelligence in Healthcare and Education      445      1206
##    isolated_prop
## 7      0.9375000
## 8      0.8947368
## 3      0.8750000
## 9      0.7878788
## 12     0.7253521
## 6      0.6567164
## 4      0.6250000
## 11     0.5403727
## 10     0.3992806
## 5      0.2695336
```

```r
# Visualize comparison of isolated vs connected by subtopic

# Prepare data for comparison plot (top 15 subtopics by total count)
top_subtopics_total <- head(subtopic_comparison[order(subtopic_comparison$total,
                                                      decreasing = TRUE), ], 15)
comparison_melted <- melt(top_subtopics_total[,
                          c("subtopic", "isolated", "connected")],
                          id.vars = "subtopic",
                          variable.name = "type",
                          value.name = "count")

# Create stacked bar chart
p3 <- ggplot(comparison_melted, aes(x = reorder(subtopic, count), y = count,
                                    fill = type)) +
  geom_bar(stat = "identity") +
  coord_flip() +
  scale_fill_manual(values = c("isolated" = "lightcoral",
                               "connected" = "lightblue"),
                    labels = c("Isolated Nodes", "Connected Nodes")) +
  labs(title = "Research Subtopic Distribution Comparison:
       Isolated vs Connected Nodes",
       subtitle = "Top 15 research subtopics ordered by total paper count",
       x = "Research Subtopic",
       y = "Number of Papers",
       fill = "Node Type") +
  theme_minimal() +
  theme(axis.text.y = element_text(size = 8),
        plot.title = element_text(hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        legend.position = "bottom")

# Save plot
ggsave("plots/subtopic_comparison_isolated_vs_connected.png", plot = p3,
       width = 14, height = 10, dpi = 150)

# Display plot
print(p3)
```



Analyze the connected nodes (Jinxi Hu)

```
# Analyze connected nodes (non-isolated nodes)
cat("=== CONNECTED NODES ANALYSIS ===\n")
```

```
## === CONNECTED NODES ANALYSIS ===
```

```
cat("Total connected nodes:", nrow(nodes2), "\n")
```

```
## Total connected nodes: 1582
```

```
cat("Connected nodes have at least one citation in or out\n\n")
```

```
## Connected nodes have at least one citation in or out
```

```
# Basic statistics for connected nodes
cat("Year range for connected papers:", min(nodes2$year, na.rm=TRUE), "-",
    max(nodes2$year, na.rm=TRUE), "\n")
```

```
## Year range for connected papers: 2015 - 2025
```

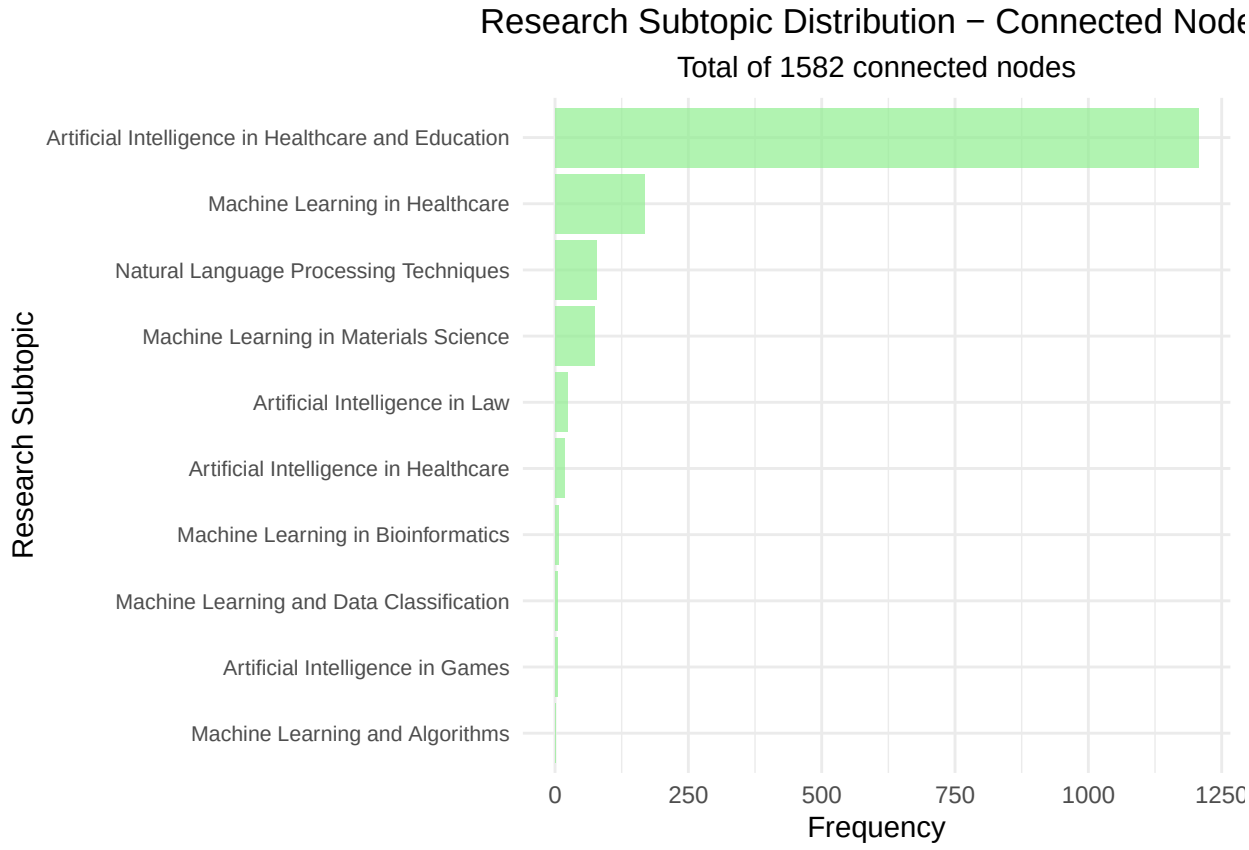
```r
cat("Average citations for connected papers:",
    round(mean(nodes2$citations, na.rm=TRUE), 2), "\n")
```

```
## Average citations for connected papers: 50.88
```

```r
cat("Average references for connected papers:",
    round(mean(nodes2$references, na.rm=TRUE), 2), "\n\n")
```

```
## Average references for connected papers: 45.12
```

```r
# Frequency analysis by research subtopic for connected nodes

# Count frequency of subtopics in connected nodes
subtopic_freq_connected_detailed <- table(nodes2$subtopic)
subtopic_df_connected <- data.frame(
  subtopic = names(subtopic_freq_connected_detailed),
  frequency = as.numeric(subtopic_freq_connected_detailed)
)
subtopic_df_connected <- subtopic_df_connected[order(
  subtopic_df_connected$frequency, decreasing = TRUE), ]

# Create histogram for subtopics (connected nodes)
p4 <- ggplot(subtopic_df_connected, aes(x = reorder(subtopic, frequency),
                                        y = frequency)) +
  geom_bar(stat = "identity", fill = "lightgreen", alpha = 0.7) +
  coord_flip() +
  labs(title = "Research Subtopic Distribution - Connected Nodes",
       subtitle = paste("Total of", nrow(nodes2), "connected nodes"),
       x = "Research Subtopic",
       y = "Frequency") +
  theme_minimal() +
  theme(axis.text.y = element_text(size = 8),
        plot.title = element_text(hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5))

# Save plot
ggsave("plots/connected_nodes_subtopic_distribution.png", plot = p4,
       width = 12, height = 8, dpi = 150)

# Display plot
print(p4)
```




```
# Print top subtopics for connected nodes
cat("Top 10 research subtopics in connected nodes:\n")
```

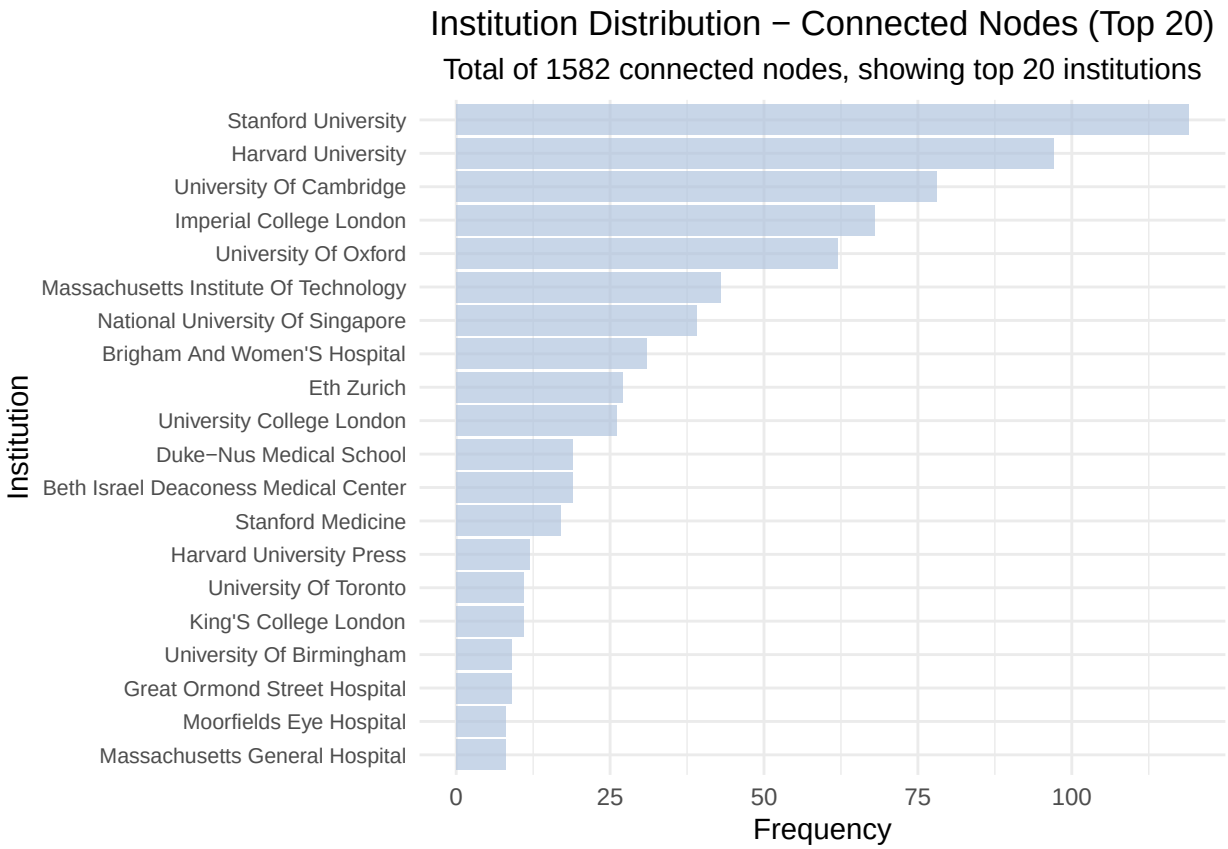
```
## Top 10 research subtopics in connected nodes:
```

```
print(head(subtopic_df_connected, 10))
```

```
##                                              subtopic frequency
## 3  Artificial Intelligence in Healthcare and Education      1206
## 8                       Machine Learning in Healthcare       167
## 10              Natural Language Processing Techniques        78
## 9                Machine Learning in Materials Science        74
## 4                       Artificial Intelligence in Law        23
## 2                Artificial Intelligence in Healthcare        18
## 7                   Machine Learning in Bioinformatics         7
## 1                     Artificial Intelligence in Games         4
## 6             Machine Learning and Data Classification         4
## 5                      Machine Learning and Algorithms         1
```

```
# Frequency analysis by institution for connected nodes

# Count frequency of institutions in connected nodes
institution_freq_connected_detailed <- table(nodes2$institution)
institution_df_connected <- data.frame(
```

```r
  institution = names(institution_freq_connected_detailed),
  frequency = as.numeric(institution_freq_connected_detailed)
)
institution_df_connected <- institution_df_connected[order(
  institution_df_connected$frequency, decreasing = TRUE), ]

# Show only top 20 institutions for better visualization
top_institutions_connected <- head(institution_df_connected, 20)

# Create histogram for institutions (connected nodes)
p5 <- ggplot(top_institutions_connected, aes(x = reorder(institution, frequency),
                                             y = frequency)) +
  geom_bar(stat = "identity", fill = "lightsteelblue", alpha = 0.7) +
  coord_flip() +
  labs(title = "Institution Distribution - Connected Nodes (Top 20)",
       subtitle = paste("Total of", nrow(nodes2),
                        "connected nodes, showing top 20 institutions"),
       x = "Institution",
       y = "Frequency") +
  theme_minimal() +
  theme(axis.text.y = element_text(size = 8),
        plot.title = element_text(hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5))

# Save plot
ggsave("plots/connected_nodes_institution_distribution.png", plot = p5,
       width = 12, height = 8, dpi = 150)

# Display plot
print(p5)
```




```
# Print top institutions for connected nodes
cat("\nTop 15 institutions with connected nodes:\n")
```

```
##
## Top 15 institutions with connected nodes:
```

```
print(head(institution_df_connected, 15))
```

```
##                              institution frequency
## 394                  Stanford University       119
## 178                   Harvard University        97
## 464               University Of Cambridge        78
## 208               Imperial College London        68
## 500                  University Of Oxford        62
## 269 Massachusetts Institute Of Technology        43
## 309      National University Of Singapore        39
## 61           Brigham And Women'S Hospital        31
## 138                            Eth Zurich        27
## 431             University College London        26
## 53   Beth Israel Deaconess Medical Center        19
## 124               Duke-Nus Medical School        19
## 393                    Stanford Medicine        17
## 179             Harvard University Press        12
## 234                King'S College London        11
```

```r
# Detailed comparison between isolated and connected nodes

cat("\n=== DETAILED COMPARISON ANALYSIS ===\n")
```

```
##
## === DETAILED COMPARISON ANALYSIS ===
```

```r
# Compare basic statistics
cat("BASIC STATISTICS COMPARISON:\n")
```

```
## BASIC STATISTICS COMPARISON:
```

```r
cat("Isolated nodes - Average citations:",
    round(mean(nodes_isolated$citations, na.rm=TRUE), 2), "\n")
```

```
## Isolated nodes - Average citations: 9.97
```

```r
cat("Connected nodes - Average citations:",
    round(mean(nodes2$citations, na.rm=TRUE), 2), "\n")
```

```
## Connected nodes - Average citations: 50.88
```

```r
cat("Isolated nodes - Average references:",
    round(mean(nodes_isolated$references, na.rm=TRUE), 2), "\n")
```

```
## Isolated nodes - Average references: 22.48
```

```r
cat("Connected nodes - Average references:",
    round(mean(nodes2$references, na.rm=TRUE), 2), "\n\n")
```

```
## Connected nodes - Average references: 45.12
```

```r
# Top institutions comparison
cat("TOP INSTITUTIONS COMPARISON:\n")
```

```
## TOP INSTITUTIONS COMPARISON:
```

```r
cat("Top 5 institutions in isolated nodes:\n")
```

```
## Top 5 institutions in isolated nodes:
```

```r
print(head(institution_df_isolated, 5))
```

```
##                                institution frequency
## 258                    Stanford University        83
## 308                University Of Cambridge        72
## 332                   University Of Oxford        60
## 206      National University Of Singapore        51
## 173 Massachusetts Institute Of Technology        50
```

```r
cat("\nTop 5 institutions in connected nodes:\n")
```

```
##
## Top 5 institutions in connected nodes:
```

```r
print(head(institution_df_connected, 5))
```

```
##                 institution frequency
## 394     Stanford University       119
## 178      Harvard University        97
## 464 University Of Cambridge        78
## 208 Imperial College London        68
## 500    University Of Oxford        62
```

```r
# Top subtopics comparison
cat("\nTOP SUBTOPICS COMPARISON:\n")
```

```
##
## TOP SUBTOPICS COMPARISON:
```

```r
cat("Top 5 subtopics in isolated nodes:\n")
```

```
## Top 5 subtopics in isolated nodes:
```

```r
print(head(subtopic_df_isolated, 5))
```

```
##                                           subtopic frequency
## 5  Artificial Intelligence in Healthcare and Education       445
## 12              Natural Language Processing Techniques       206
## 10                      Machine Learning in Healthcare       111
## 11               Machine Learning in Materials Science        87
## 6                       Artificial Intelligence in Law        44
```

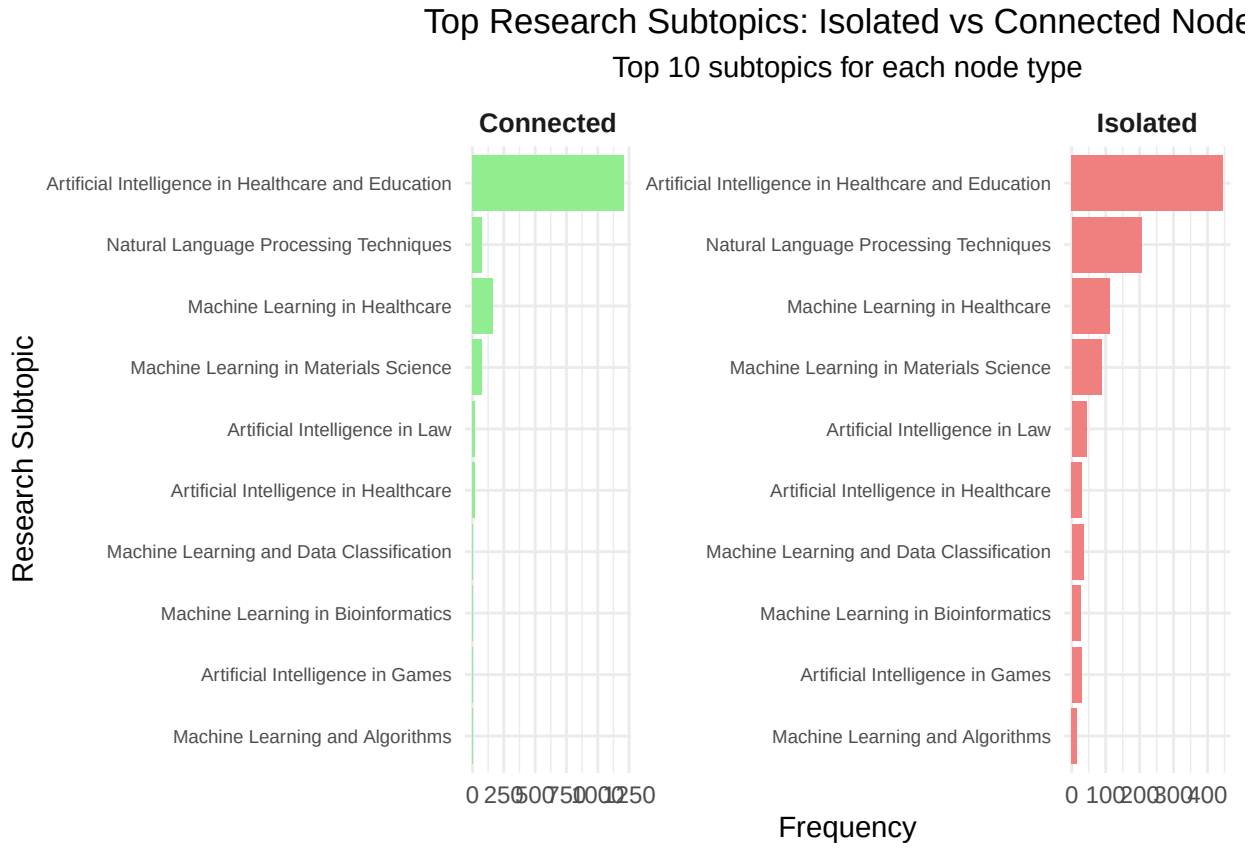
```r
cat("\nTop 5 subtopics in connected nodes:\n")
```

```
##
## Top 5 subtopics in connected nodes:
```

```r
print(head(subtopic_df_connected, 5))
```

```
##                                           subtopic frequency
## 3  Artificial Intelligence in Healthcare and Education      1206
## 8                       Machine Learning in Healthcare       167
## 10              Natural Language Processing Techniques        78
## 9                Machine Learning in Materials Science        74
## 4                       Artificial Intelligence in Law        23
```

```r
# Create side-by-side comparison plots

# Prepare data for subtopic comparison (top 10 from each)
top_isolated_subtopics <- head(subtopic_df_isolated, 10)
top_connected_subtopics <- head(subtopic_df_connected, 10)

# Combine and label data
top_isolated_subtopics$type <- "Isolated"
top_connected_subtopics$type <- "Connected"

combined_subtopics <- rbind(
  top_isolated_subtopics[, c("subtopic", "frequency", "type")],
  top_connected_subtopics[, c("subtopic", "frequency", "type")]
)

# Create faceted plot for subtopic comparison
p6 <- ggplot(combined_subtopics, aes(x = reorder(subtopic, frequency),
                                     y = frequency, fill = type)) +
  geom_bar(stat = "identity") +
  coord_flip() +
  facet_wrap(~type, scales = "free") +
  scale_fill_manual(values = c("Isolated" = "lightcoral",
                               "Connected" = "lightgreen")) +
  labs(title = "Top Research Subtopics: Isolated vs Connected Nodes",
       subtitle = "Top 10 subtopics for each node type",
       x = "Research Subtopic",
       y = "Frequency") +
  theme_minimal() +
  theme(axis.text.y = element_text(size = 7),
        plot.title = element_text(hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        legend.position = "none",
        strip.text = element_text(size = 10, face = "bold"))

# Save plot
ggsave("plots/subtopic_faceted_comparison.png", plot = p6,
       width = 16, height = 10, dpi = 150)

# Display plot
print(p6)
```




```r
# Institution comparison plot
top_isolated_institutions <- head(institution_df_isolated, 10)
top_connected_institutions <- head(institution_df_connected, 10)

# Combine and label data
top_isolated_institutions$type <- "Isolated"
top_connected_institutions$type <- "Connected"

combined_institutions <- rbind(
  top_isolated_institutions[, c("institution", "frequency", "type")],
  top_connected_institutions[, c("institution", "frequency", "type")]
)

# Create faceted plot for institution comparison
p7 <- ggplot(combined_institutions, aes(x = reorder(institution, frequency),
                                        y = frequency, fill = type)) +
  geom_bar(stat = "identity") +
  coord_flip() +
  facet_wrap(~type, scales = "free") +
  scale_fill_manual(values = c("Isolated" = "lightblue",
                               "Connected" = "lightsteelblue")) +
  labs(title = "Top Institutions: Isolated vs Connected Nodes",
       subtitle = "Top 10 institutions for each node type",
       x = "Institution",
       y = "Frequency") +
  theme_minimal() +
```

```r
  theme(axis.text.y = element_text(size = 7),
        plot.title = element_text(hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        legend.position = "none",
        strip.text = element_text(size = 10, face = "bold"))

# Save plot
ggsave("plots/institution_faceted_comparison.png", plot = p7,
       width = 16, height = 10, dpi = 150)

# Display plot
print(p7)
```