Spotify Popularity Analysis: Multiple Regression and Classification

kite-luva

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Contents

```
# Global options for code chunks
knitr::opts_chunk$set(echo = TRUE,
                      eval = TRUE,
                      message = FALSE,
                      warning = FALSE,
                      fig.align = 'center',
                      out.width = '80%',
                      fig_caption = TRUE
                      )

##############################################################################################
### COMBINED SPOTIFY POPULARITY ANALYSIS: MULTIPLE REGRESSION MODELS THEN CLASSIFICATION ###
##############################################################################################

# Clear environment and set seed for reproducibility
# rm(list = ls())
set.seed(42)

# Load essential libraries
library(tidyverse)
```

```
## -- Attaching core tidyverse packages ------------------------ tidyverse 2.0.0 --
## v dplyr     1.1.4     v readr     2.1.5
## v forcats   1.0.0     v stringr   1.5.1
## v ggplot2   3.5.1     v tibble    3.2.1
## v lubridate 1.9.4     v tidyr     1.3.1
## v purrr     1.0.2
## -- Conflicts ---------------------------------------- tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
## i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become errors
```

```
library(caret)
```

```
## Loading required package: lattice
##
## Attaching package: 'caret'
##
```

```
## The following object is masked from 'package:purrr':
##
##     lift
```

```
library(corrplot)
```

```
## corrplot 0.95 loaded
```

```
library(skimr)
library(DataExplorer)
library(vip)
```

```
##
## Attaching package: 'vip'
##
## The following object is masked from 'package:utils':
##
##     vi
```

```
library(ranger)
library(xgboost)
```

```
##
## Attaching package: 'xgboost'
##
## The following object is masked from 'package:dplyr':
##
##     slice
```

```
library(e1071)
library(scales)
```

```
##
## Attaching package: 'scales'
##
## The following object is masked from 'package:purrr':
##
##     discard
##
## The following object is masked from 'package:readr':
##
##     col_factor
```

```
library(lubridate)
library(GGally)
```

```
## Registered S3 method overwritten by 'GGally':
##   method from
##   +.gg   ggplot2
```

```r
library(grid)
library(recipes)
```

```
##
## Attaching package: 'recipes'
##
## The following object is masked from 'package:stringr':
##
##     fixed
##
## The following object is masked from 'package:stats':
##
##     step
```

```r
library(pROC)
```

```
## Type 'citation("pROC")' for a citation.
##
## Attaching package: 'pROC'
##
## The following objects are masked from 'package:stats':
##
##     cov, smooth, var
```

```r
library(gridExtra)
```

```
##
## Attaching package: 'gridExtra'
##
## The following object is masked from 'package:dplyr':
##
##     combine
```

```r
library(ggpubr)
library(knitr)
library(MLmetrics)
```

```
##
## Attaching package: 'MLmetrics'
##
## The following objects are masked from 'package:caret':
##
##     MAE, RMSE
##
## The following object is masked from 'package:base':
##
##     Recall
```

```r
library(RColorBrewer)
library(flextable)
```

```
##
## Attaching package: 'flextable'
##
## The following objects are masked from 'package:ggpubr':
##
##     border, font, rotate
##
## The following object is masked from 'package:purrr':
##
##     compose
```

```
library(officer)
library(dplyr)
library(tidyr)
library(naniar)
```

```
##
## Attaching package: 'naniar'
##
## The following object is masked from 'package:skimr':
##
##     n_complete
```

```
# ==============================================================================
# Custom Dark Theme Function
# ==============================================================================
theme_dark_custom <- function(title_text = "") {
  theme_dark(base_size = 14) +
    theme(
      plot.background = element_rect(fill = "black"),
      panel.background = element_rect(fill = "gray20"),
      panel.grid.major = element_line(color = "gray40"),
      panel.grid.minor = element_blank(),
      plot.title = element_text(color = "white", size = 18, face = "bold", hjust = 0.5),
      plot.subtitle = element_text(color = "white", size = 14, hjust = 0.5),
      axis.text = element_text(color = "white", size = 12),
      axis.title = element_text(color = "white", size = 12),
      legend.background = element_rect(fill = "gray20"),
      legend.text = element_text(color = "white", size = 16),
      legend.title = element_text(color = "white", size = 16),
      strip.background = element_rect(fill = "gray40"),
      strip.text = element_text(color = "white", size = 14)
    )
}

# ==============================================================================
# 1. DATA LOADING AND INITIAL EXPLORATION (SHARED)
# ==============================================================================

# Load the csv file
spotify_charts <- read_csv("~/school docs/universal_top_spotify_songs.new.csv")
```

```
## Rows: 1750032 Columns: 25
```

```
## -- Column specification --------------------------------------------------------
## Delimiter: ","
## chr   (5): spotify_id, name, artists, country, album_name
## dbl  (17): daily_rank, daily_movement, weekly_movement, popularity, duration...
## lgl   (1): is_explicit
## date  (2): snapshot_date, album_release_date
##
## i Use `spec()` to retrieve the full column specification for this data.
## i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

```
# Initial data exploration (same as before)
# ... (rest of the initial exploration code) ...
cat("====================\n")
```

```
## ====================
```

```
cat("Initial Data Exploration\n")
```

```
## Initial Data Exploration
```

```
cat("====================\n")
```

```
## ====================
```

```
cat("\nSummary:\n")
```

```
##
## Summary:
```

```
print(summary(spotify_charts))
```

```
##   spotify_id            name              artists            daily_rank
##  Length:1750032     Length:1750032     Length:1750032     Min.   : 1.00
##  Class :character   Class :character   Class :character   1st Qu.:13.00
##  Mode  :character   Mode  :character   Mode  :character   Median :25.00
##                                                           Mean   :25.49
##                                                           3rd Qu.:38.00
##                                                           Max.   :50.00
##
##  daily_movement     weekly_movement     country           snapshot_date
##  Min.   :-49.0000   Min.   :-49.000   Length:1750032     Min.   :2023-10-18
##  1st Qu.: -1.0000   1st Qu.: -3.000   Class :character   1st Qu.:2024-02-15
##  Median :  0.0000   Median :  0.000   Mode  :character   Median :2024-06-17
##  Mean   :  0.9251   Mean   :  2.789                      Mean   :2024-06-17
##  3rd Qu.:  2.0000   3rd Qu.:  5.000                      3rd Qu.:2024-10-15
##  Max.   : 49.0000   Max.   : 49.000                      Max.   :2025-02-23
##
##    popularity     is_explicit      duration_ms       album_name
##  Min.   :  0.00   Mode :logical   Min.   :     0   Length:1750032
##  1st Qu.: 65.00   FALSE:1176171   1st Qu.:161655   Class :character
```

```
##  Median : 80.00   TRUE :573861    Median :185917   Mode  :character
##  Mean   : 76.06                   Mean   :193466
##  3rd Qu.: 88.00                   3rd Qu.:218423
##  Max.   :100.00                   Max.   :939666
##
##  album_release_date    danceability        energy              key
##  Min.   :1900-01-01   Min.   :0.0000   Min.   :2.01e-05   Min.   : 0.000
##  1st Qu.:2023-05-19   1st Qu.:0.5850   1st Qu.:5.51e-01   1st Qu.: 2.000
##  Median :2023-12-01   Median :0.7010   Median :6.68e-01   Median : 6.000
##  Mean   :2022-03-16   Mean   :0.6791   Mean   :6.49e-01   Mean   : 5.543
##  3rd Qu.:2024-05-23   3rd Qu.:0.7830   3rd Qu.:7.65e-01   3rd Qu.: 9.000
##  Max.   :2025-02-21   Max.   :0.9880   Max.   :9.98e-01   Max.   :11.000
##  NA's   :658
##     loudness            mode         speechiness       acousticness
##  Min.   :-54.341   Min.   :0.0000   Min.   :0.00000   Min.   :0.0000034
##  1st Qu.: -7.805   1st Qu.:0.0000   1st Qu.:0.03850   1st Qu.:0.0670000
##  Median : -6.025   Median :1.0000   Median :0.05780   Median :0.1890000
##  Mean   : -6.638   Mean   :0.5379   Mean   :0.09493   Mean   :0.2743197
##  3rd Qu.: -4.712   3rd Qu.:1.0000   3rd Qu.:0.11000   3rd Qu.:0.4370000
##  Max.   :  3.233   Max.   :1.0000   Max.   :0.93900   Max.   :0.9960000
##
##  instrumentalness       liveness         valence           tempo
##  Min.   :0.0000000   Min.   :0.0139   Min.   :0.0000   Min.   :  0.0
##  1st Qu.:0.0000000   1st Qu.:0.0961   1st Qu.:0.3710   1st Qu.:100.0
##  Median :0.0000013   Median :0.1210   Median :0.5520   Median :120.0
##  Mean   :0.0206821   Mean   :0.1708   Mean   :0.5493   Mean   :122.2
##  3rd Qu.:0.0000857   3rd Qu.:0.2050   3rd Qu.:0.7350   3rd Qu.:140.1
##  Max.   :0.9950000   Max.   :0.9780   Max.   :0.9920   Max.   :236.1
##
##  time_signature
##  Min.   :0.000
##  1st Qu.:4.000
##  Median :4.000
##  Mean   :3.901
##  3rd Qu.:4.000
##  Max.   :5.000
##
```

```
cat("\nSkim:\n")
```

```
##
## Skim:
```

```
print(skim(spotify_charts))
```

```
## -- Data Summary ------------------------
##                            Values
## Name                       spotify_charts
## Number of rows             1750032
## Number of columns          25
## _________________________
## Column type frequency:
##   character                5
```

```
##   Date                     2
##   logical                  1
##   numeric                  17
## ________________________
## Group variables            None
##
## -- Variable type: character ---------------------------------------------------------
##   skim_variable n_missing complete_rate min max empty n_unique whitespace
## 1 spotify_id            0         1      22  22     0    20796          0
## 2 name                 30         1.00    1 286     0    18316          0
## 3 artists              29         1.00    1 284     0    11756          0
## 4 country           23907         0.986   2   2     0       72          0
## 5 album_name          821         1.00    1 286     0    13853          0
##
## -- Variable type: Date --------------------------------------------------------------
##   skim_variable      n_missing complete_rate min        max        median
## 1 snapshot_date              0          1    2023-10-18 2025-02-23 2024-06-17
## 2 album_release_date       658          1.00 1900-01-01 2025-02-21 2023-12-01
##   n_unique
## 1      483
## 2     2630
##
## -- Variable type: logical -----------------------------------------------------------
##   skim_variable n_missing complete_rate  mean count
## 1 is_explicit           0             1 0.328 FAL: 1176171, TRU: 573861
##
## -- Variable type: numeric -----------------------------------------------------------
##    skim_variable    n_missing complete_rate        mean         sd           p0
##  1 daily_rank               0             1     25.5       14.4      1
##  2 daily_movement           0             1      0.925      7.00   -49
##  3 weekly_movement          0             1      2.79      12.1    -49
##  4 popularity               0             1     76.1       15.8      0
##  5 duration_ms              0             1 193466.     49650.       0
##  6 danceability             0             1      0.679      0.141    0
##  7 energy                   0             1      0.649      0.167    0.0000201
##  8 key                      0             1      5.54       3.58     0
##  9 loudness                 0             1     -6.64       3.40   -54.3
## 10 mode                     0             1      0.538      0.499    0
## 11 speechiness              0             1      0.0949     0.0909   0
## 12 acousticness             0             1      0.274      0.251    0.00000345
## 13 instrumentalness         0             1      0.0207     0.105    0
## 14 liveness                 0             1      0.171      0.125    0.0139
## 15 valence                  0             1      0.549      0.230    0
## 16 tempo                    0             1    122.        28.1      0
## 17 time_signature           0             1      3.90       0.405    0
##            p25      p50      p75       p100 hist
##  1     13       2.5 e+1  3.8 e+1     50
##  2     -1       0        2   e+0     49
##  3     -3       0        5   e+0     49
##  4     65       8   e+1  8.8 e+1    100
##  5 161655       1.86e+5  2.18e+5 939666
##  6      0.585   7.01e-1  7.83e-1      0.988
##  7      0.551   6.68e-1  7.65e-1      0.998
##  8      2       6   e+0  9   e+0     11
```

```
##  9     -7.80   -6.03e+0 -4.71e+0      3.23
## 10      0       1   e+0  1   e+0      1
## 11      0.0385  5.78e-2  1.1 e-1      0.939
## 12      0.067   1.89e-1  4.37e-1      0.996
## 13      0       1.28e-6  8.57e-5      0.995
## 14      0.0961  1.21e-1  2.05e-1      0.978
## 15      0.371   5.52e-1  7.35e-1      0.992
## 16    100.      1.20e+2  1.40e+2    236.
## 17      4       4   e+0  4   e+0      5
```

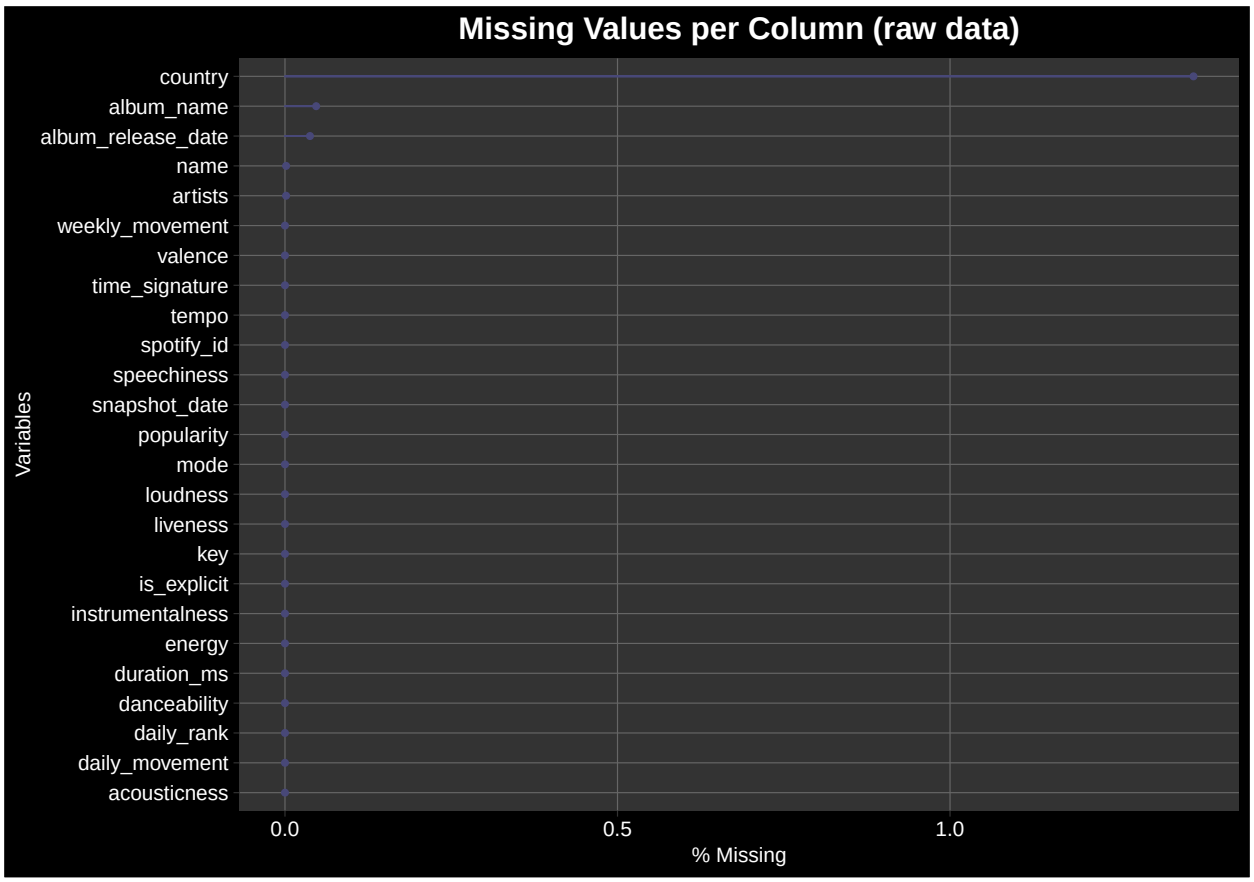
```r
# Check for missing values
missing_values <- colSums(is.na(spotify_charts))
cat("\nMissing values per column:\n")
```

```
##
## Missing values per column:
```

```r
print(missing_values[missing_values > 0])
```

```
##                name             artists             country          album_name
##                  30                  29                23907                 821
## album_release_date
##                 658
```

```r
# Create a dark-themed missingness plot manually
missing_heatmap_1 <- gg_miss_var(spotify_charts, show_pct = TRUE) +
  labs(title = "Missing Values per Column (raw data)") +
  theme_dark_custom()

print(missing_heatmap_1)
```




```r
# ============================================================================
# 2. DATA CLEANING AND FEATURE ENGINEERING (SHARED)
# ============================================================================

# combining all the codes
spotify_charts <- spotify_charts %>%
  group_by(spotify_id) %>%
  mutate(
    market_count = n_distinct(country, na.rm = TRUE),
    other_charted_countries = paste(country[!duplicated(country)], collapse = ", ")
  ) %>%
  slice_max(order_by = popularity, n = 1, with_ties = FALSE) %>%
  ungroup() %>%
  mutate(
    artist_count = sapply(strsplit(artists, ","), length),
    snapshot_date = ymd(snapshot_date),
    album_release_date = ymd(album_release_date),
    days_out = as.numeric(snapshot_date - album_release_date),
    is_explicit = as.integer(is_explicit),
    duration_min = duration_ms / 60000
  ) %>%
  select(-duration_ms) # Remove the original duration_ms column

# Verify the column name change (optional)
colnames(spotify_charts)[colnames(spotify_charts) == "duration_min"] <- "duration_min"
```

```r
view(spotify_charts)
cat("\n====================\n")
```

```
##
## ====================
```

```r
cat("Cleaned and Engineered Data (First few rows):\n")
```

```
## Cleaned and Engineered Data (First few rows):
```

```r
cat("====================\n")
```

```
## ====================
```

```r
print(head(spotify_charts))
```

```
## # A tibble: 6 x 29
##   spotify_id     name  artists daily_rank daily_movement weekly_movement country
##   <chr>          <chr> <chr>        <dbl>          <dbl>           <dbl> <chr>
## 1 000n6Lx4yqUAs~ béke  Azahri~         20             -2              -5 HU
## 2 001TLpmtuQMWJ~ All ~ Olexes~         23             27              27 DE
## 3 003vvx7Niy0yv~ Mr. ~ The Ki~         41              5               7 IE
## 4 005L1nFVHdbcd~ Obě ~ Nik Te~         43             -3               7 CZ
## 5 005cocyIL36CV~ En S~ Postgi~         50             -6             -16 NO
## 6 006oGnrSZevqZ~ Diva~ Melike~         38              2              -3 TR
## # i 22 more variables: snapshot_date <date>, popularity <dbl>,
## #   is_explicit <int>, album_name <chr>, album_release_date <date>,
## #   danceability <dbl>, energy <dbl>, key <dbl>, loudness <dbl>, mode <dbl>,
## #   speechiness <dbl>, acousticness <dbl>, instrumentalness <dbl>,
## #   liveness <dbl>, valence <dbl>, tempo <dbl>, time_signature <dbl>,
## #   market_count <int>, other_charted_countries <chr>, artist_count <int>,
## #   days_out <dbl>, duration_min <dbl>
```

```r
# Prepare dataset for regression modeling
regression_data <- spotify_charts %>%
  select(-country, -other_charted_countries, -snapshot_date, -name, -artists,
         -album_name, -album_release_date, -spotify_id) %>%
  mutate(across(where(is.character), as.factor)) %>%
  mutate(across(where(is.numeric), ~if_else(is.na(.), median(., na.rm = TRUE), .))) %>%
  filter(popularity != 0)
# arrange columns
regression_data <- regression_data %>%
  select(popularity, market_count, daily_rank, days_out, artist_count, daily_movement, weekly_movement,
         duration_min, is_explicit, mode, danceability, energy, loudness, speechiness,
         acousticness, instrumentalness, time_signature, liveness, valence, key, tempo)

cat("\n====================\n")
```

```
##
## ====================
```

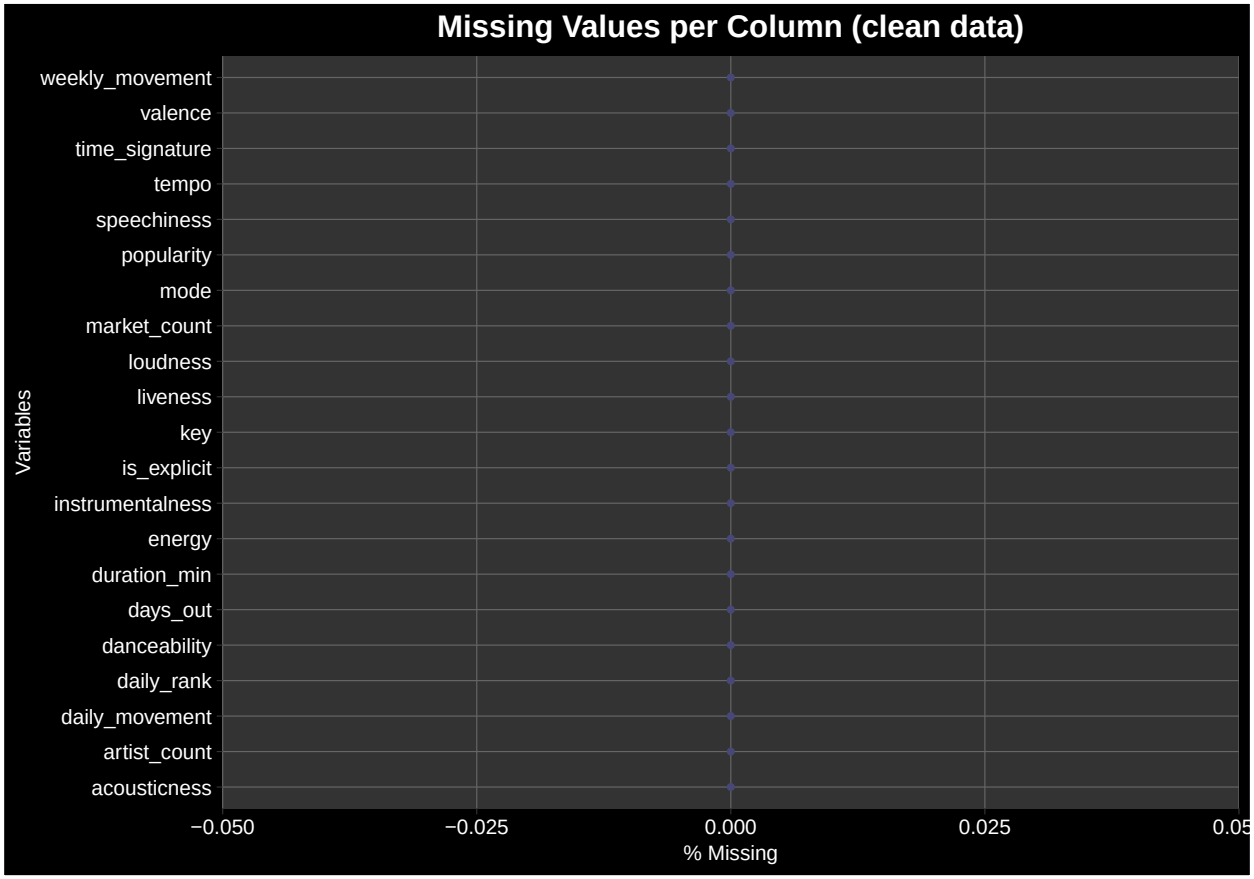
```r
cat("Regression Modeling Data (Summary):\n")
```

```
## Regression Modeling Data (Summary):
```

```r
cat("====================\n")
```

```
## ====================
```

```r
view(regression_data)

missing_regression <- gg_miss_var(regression_data, show_pct = TRUE) +
  labs(title = "Missing Values per Column (clean data)") +
  theme_dark_custom()

print(missing_regression)
```




```r
#=====================================================================
## DESCRIPTIVE STATISTICS, SCATTER AND CORRELATION PLOTS
#=====================================================================

# Function to compute basic statistics
spotify_stats <- function(column) {
  stats <- c(
```

```
    Mean = mean(column, na.rm = TRUE),
    Median = median(column, na.rm = TRUE),
    SD = sd(column, na.rm = TRUE),
    Variance = var(column, na.rm = TRUE),
    IQR = IQR(column, na.rm = TRUE)
  )
  return(stats)
}

# Loop through columns and compute statistics
stats_results <- lapply(regression_data, spotify_stats)
names(stats_results) <- colnames(regression_data)

# Convert the list of statistics to a data frame for better printing
stats_table <- as.data.frame(stats_results)
print(stats_table)
```

```
##          popularity market_count daily_rank     days_out artist_count
## Mean       58.21686     2.201072   35.10250     947.7601     1.631360
## Median     60.00000     1.000000   40.00000      46.0000     1.000000
## SD         17.93296     4.725443   14.35924    2719.6485     1.000970
## Variance  321.59096    22.329815  206.18770 7396488.2233     1.001941
## IQR        23.00000     0.000000   21.00000     233.0000     1.000000
##          daily_movement weekly_movement duration_min is_explicit      mode
## Mean           2.316623        3.296669    3.1840513   0.3280389 0.5115898
## Median         0.000000        1.000000    3.0280833   0.0000000 1.0000000
## SD            12.077978       14.798967    0.9853391   0.4695107 0.4998781
## Variance     145.877557      219.009422    0.9708932   0.2204403 0.2498781
## IQR            7.000000       13.000000    0.9951083   1.0000000 1.0000000
##          danceability     energy  loudness speechiness acousticness
## Mean       0.67312286 0.65018782 -7.076078  0.12091624   0.27773925
## Median     0.69100000 0.66800000 -6.582000  0.06950000   0.20100000
## SD         0.14019752 0.17081241  3.195613  0.11258703   0.25132402
## Variance   0.01965534 0.02917688 10.211945  0.01267584   0.06316376
## IQR        0.19100000 0.23100000  3.206000  0.12260000   0.37435000
##          instrumentalness time_signature   liveness    valence       key
## Mean           0.02733874      3.9455998 0.18292358 0.53476607  5.371619
## Median         0.00000102      4.0000000 0.12700000 0.53400000  6.000000
## SD             0.12895952      0.3490409 0.13937591 0.22941330  3.600955
## Variance       0.01663056      0.1218295 0.01942564 0.05263046 12.966876
## IQR            0.00013700      0.0000000 0.12660000 0.35600000  7.000000
##              tempo
## Mean     122.33293
## Median   121.03000
## SD        27.86529
## Variance 776.47437
## IQR       40.05050
```

```
#-------------------------------------------------------------------------------
# Generate the scatter plot matrices
#-------------------------------------------------------------------------------

# plot1_dark <- ggpairs(
```

```
#   regression_data,
#   columns = 1:21,
#   upper = list(continuous = wrap("cor", alpha = 0.7, color = "white")),
#   lower = list(continuous = wrap("points", alpha = 0.5, color = "skyblue")),
#   diag = list(continuous = wrap("densityDiag", fill = "skyblue", alpha = 0.6))
# ) +
#   theme_dark_custom() +
#   labs(title = "Scatter Plot Matrix of Numerical Features")
# print(plot1_dark)
#-------------------------------------------------------------------------------
# DESCRIPTIVE STATISTICS
#-------------------------------------------------------------------------------

cat("\n====================\n")
```

```
##
## ====================
```

```
cat("Descriptive Statistics for Key Audio Features (Flextable)\n")
```

```
## Descriptive Statistics for Key Audio Features (Flextable)
```

```
cat("====================\n")
```

```
## ====================
```

```
numeric_cols_desc <- regression_data %>%
  select(popularity,danceability, energy, loudness, speechiness,
         acousticness, instrumentalness, liveness, valence, key, tempo)

descriptive_stats <- numeric_cols_desc %>%
  summarise(across(everything(), list(
    Mean = ~round(mean(.), 2),
    SE = ~round(sd(.) / sqrt(n()), 2),
    Median = ~round(median(.), 2),
    SD = ~round(sd(.), 2),
    Min = ~round(min(.), 2),
    Max = ~round(max(.), 2),
    N = ~n()
  ))) %>%
  pivot_longer(cols = everything(),
               names_to = c("Attribute", ".value"),
               names_sep = "_")

if (nrow(descriptive_stats) > 0) {
  table_flex <- flextable(descriptive_stats) %>%
    autofit() %>%
    set_caption(caption = "Descriptive Statistics for Numeric Features") %>%
    fontsize(size = 10, part = "all") %>%
    theme_box() %>%
    bg(bg = "grey20", part = "header") %>%
```

```
    color(color = "white", part = "header") %>%
    bg(bg = "grey15", part = "body") %>%
    color(color = "grey85", part = "body") %>%
    border_outer(part = "all", border = fp_border(color = "grey50")) %>%
    border_inner_h(part = "all", border = fp_border(color = "grey40")) %>%
    border_inner_v(part = "all", border = fp_border(color = "grey40"))

  print(table_flex)
} else {
  cat("No numeric columns found for descriptive statistics table.\n")
}
```

```
## a flextable object.
## col_keys: `Attribute`, `Mean`, `SE`, `Median`, `SD`, `Min`, `Max`, `N`
## header has 1 row(s)
## body has 11 row(s)
## original dataset sample:
##      Attribute  Mean   SE Median    SD    Min    Max     N
## 1   popularity 58.22 0.13  60.00 17.93   1.00 100.00 20147
## 2 danceability  0.67 0.00   0.69  0.14   0.00   0.99 20147
## 3       energy  0.65 0.00   0.67  0.17   0.00   1.00 20147
## 4     loudness -7.08 0.02  -6.58  3.20 -54.34   3.23 20147
## 5  speechiness  0.12 0.00   0.07  0.11   0.00   0.94 20147
```

```
# density plots for the features

cat("\n====================\n")
```

```
##
## ====================
```

```
cat("Density Distributions for Numerical Features\n")
```

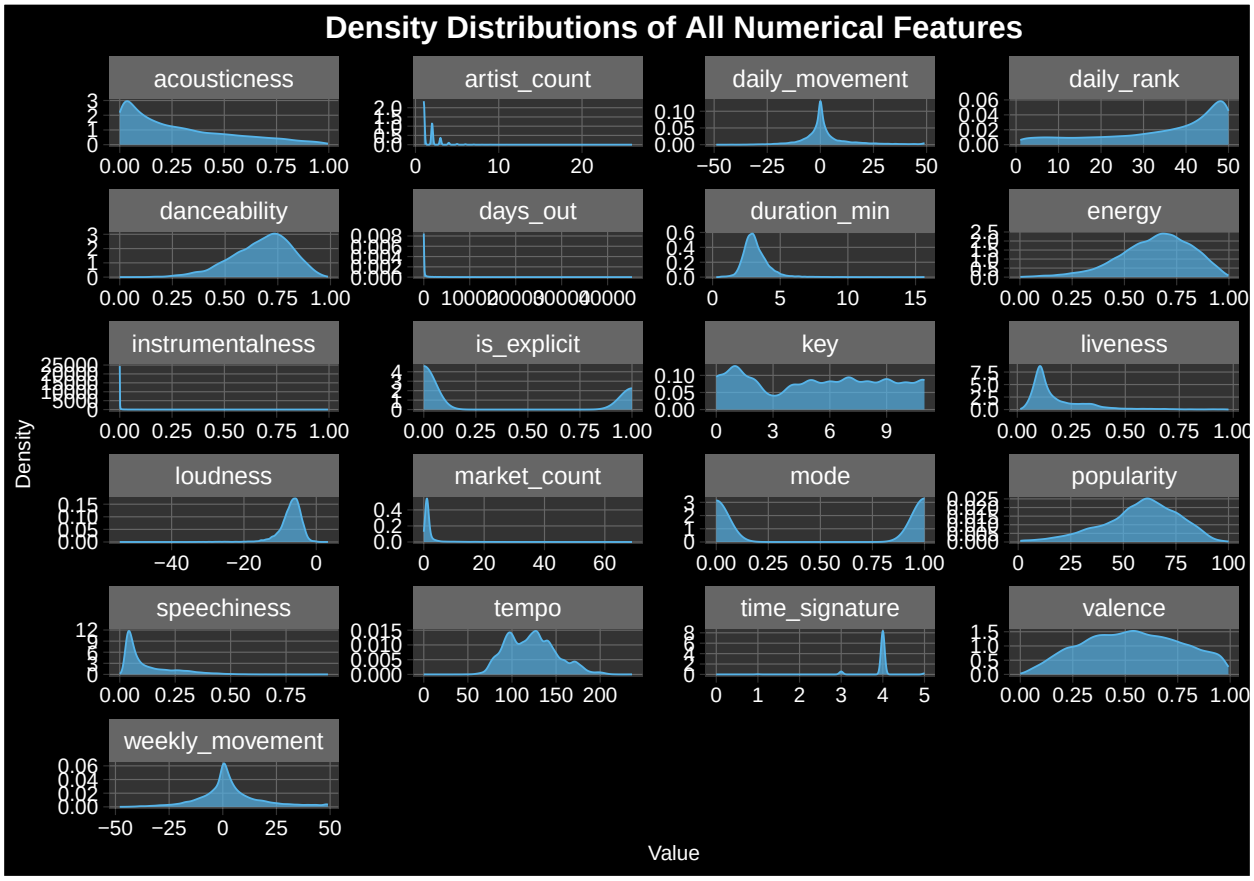
```
## Density Distributions for Numerical Features
```

```
cat("====================\n")
```

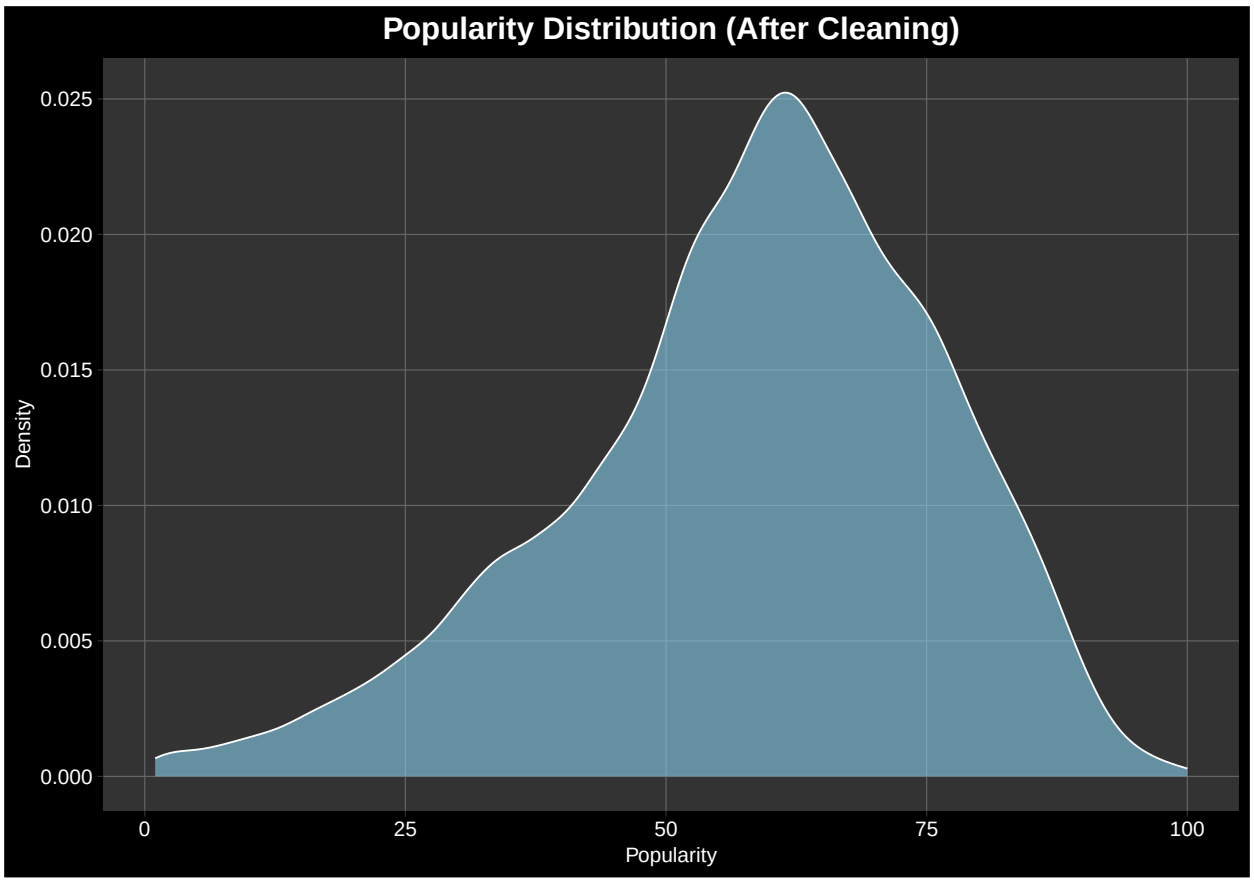
```
## ====================
```

```
numeric_features_for_density <- regression_data %>%
  select(where(is.numeric))

if (ncol(numeric_features_for_density) > 0) {
  data_long_features <- numeric_features_for_density %>%
    pivot_longer(cols = everything(), names_to = "Feature", values_to = "Value")

  all_features_density_plot <- ggplot(data = data_long_features, aes(x = Value)) +
    geom_density(fill = "#56B4E9", alpha = 0.7, color = "#56B4E9") +
    facet_wrap(~ Feature, scales = "free", ncol = 4) +
    labs(title = "Density Distributions of All Numerical Features",
         x = "Value", y = "Density") +
```

```
    theme_dark_custom()

  print(all_features_density_plot)
} else {
  cat("No numeric features to plot densities.\n")
}
```

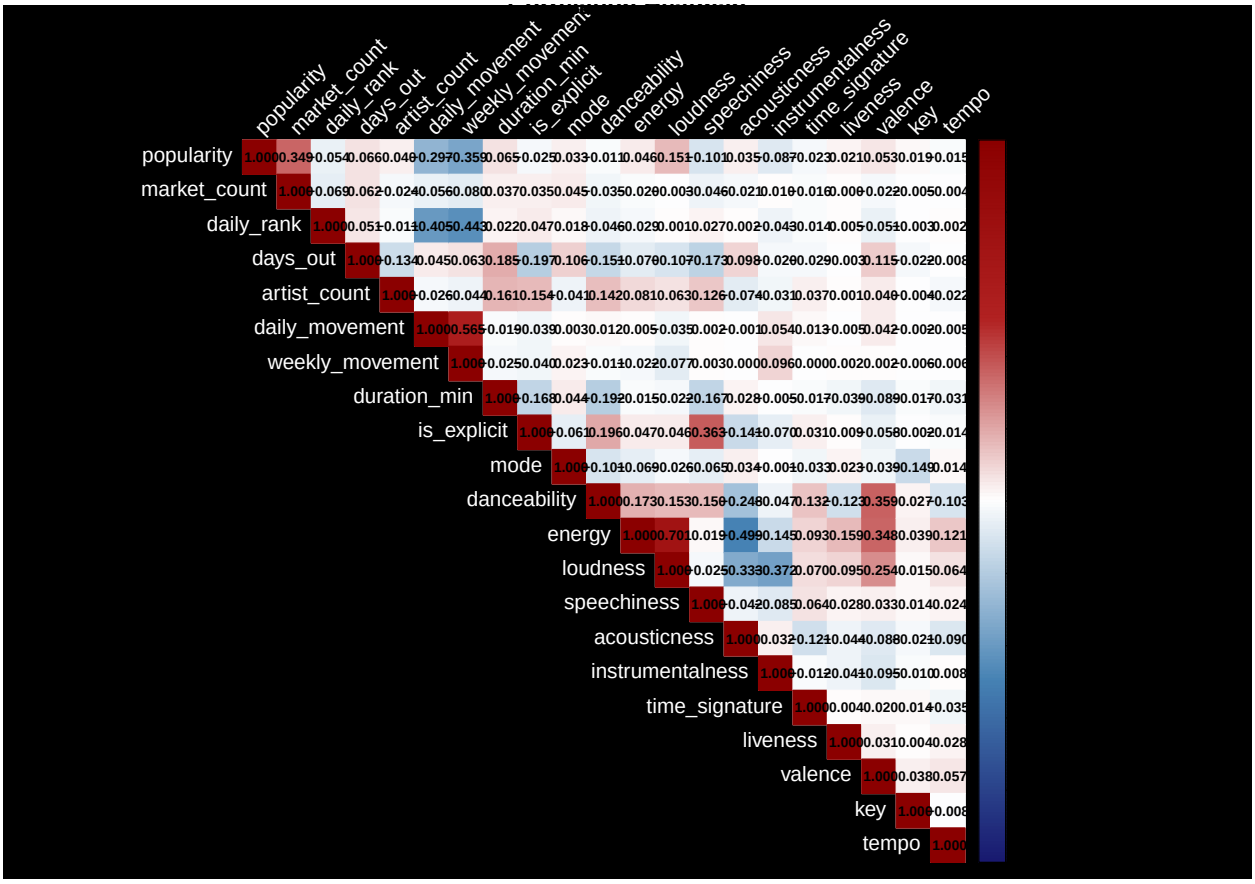



```
# Popularity distribution density plot
popularity_dist_density_plot <- ggplot(data = regression_data, aes(x = popularity)) +
  geom_density(fill = "skyblue", alpha = 0.6, color = "white") +
  labs(title = "Popularity Distribution (After Cleaning)",
       x = "Popularity",
       y = "Density") +
  theme_dark_custom()
print(popularity_dist_density_plot)
```




```
# Compute correlation matrix
correlation_matrix <- cor(regression_data, use = "complete.obs")

# Create the correlation plot with a dark background
par(bg = "black", mar = c(0, 0, 2, 0)) # Set plotting area background to black
corrplot(
  correlation_matrix,
  method = "color",
  col = colorRampPalette(c("midnightblue", "steelblue", "white", "firebrick", "darkred"))(200),
  tl.col = "white",
  tl.srt = 45,
  type = "upper",
  addCoef.col = "black",
  number.cex = 0.7,
  number.digits = 3,
  main = "Correlation Heatmap"
)
```

```
## Warning in ind1:ind2: numerical expression has 2 elements: only the first used
```




```r
par(bg = "transparent") # Reset plotting area background to transparent for subsequent ggplot2 plots


# Extract the correlations with 'popularity'
popularity_correlations <- correlation_matrix["popularity", ]

# Print the correlations of popularity with each variable
print(popularity_correlations)
```

```
##       popularity     market_count       daily_rank         days_out
##       1.00000000       0.34944530      -0.05355698       0.06588692
##     artist_count   daily_movement  weekly_movement     duration_min
##       0.03992112      -0.29728253      -0.35904008       0.06474324
##      is_explicit             mode     danceability           energy
##      -0.02513331       0.03287952      -0.01125413       0.04624822
##         loudness      speechiness     acousticness instrumentalness
##       0.15149381      -0.10112939       0.03516400      -0.08702787
##   time_signature         liveness          valence              key
##      -0.02273048       0.02055590       0.05344534       0.01900805
##            tempo
##      -0.01456841
```

```r
# ============================================================================
# 3. MULTIPLE REGRESSION MODEL TRAINING AND EVALUATION
# ============================================================================
```

```r
cat("\n====================\n")
```

```
##
## ====================
```

```r
cat("Multiple Regression Model Training and Evaluation\n")
```

```
## Multiple Regression Model Training and Evaluation
```

```r
cat("====================\n")
```

```
## ====================
```

```r
# Split data for regression
set.seed(42) # Reset seed for consistent split
train_index_reg <- createDataPartition(regression_data$popularity, p = 0.8, list = FALSE)
train_data_reg <- regression_data[train_index_reg, ]
test_data_reg <- regression_data[-train_index_reg, ]

# Create preprocessing recipe for regression
preprocess_recipe_reg <- recipe(popularity ~ ., data = train_data_reg) %>%
  step_center(all_numeric(), -all_outcomes()) %>%
  step_scale(all_numeric(), -all_outcomes()) %>%
  step_dummy(all_nominal(), -all_outcomes())

prep_recipe_reg <- prep(preprocess_recipe_reg, training = train_data_reg)
train_processed_reg <- bake(prep_recipe_reg, new_data = train_data_reg)
test_processed_reg <- bake(prep_recipe_reg, new_data = test_data_reg)

# Define resampling strategy
ctrl_reg <- trainControl(method = "cv", number = 5, verboseIter = FALSE, savePredictions = "final")

# Initialize a list to store regression models
regression_models <- list()

# 1. Random Forest
cat("\nTraining Random Forest (Regression)...\n")
```

```
##
## Training Random Forest (Regression)...
```

```r
regression_models$R.F <- train(
  popularity ~ .,
  data = train_processed_reg,
  method = "ranger",
  trControl = ctrl_reg,
  tuneGrid = expand.grid(mtry = c(5, 7, 9), splitrule = "variance", min.node.size = c(1, 3)),
  importance = 'impurity',
  num.tree = 250
)
```

```
## Growing trees.. Progress: 93%. Estimated remaining time: 2 seconds.
## Growing trees.. Progress: 73%. Estimated remaining time: 11 seconds.
## Growing trees.. Progress: 95%. Estimated remaining time: 1 seconds.
## Growing trees.. Progress: 86%. Estimated remaining time: 5 seconds.
## Growing trees.. Progress: 97%. Estimated remaining time: 1 seconds.
## Growing trees.. Progress: 86%. Estimated remaining time: 4 seconds.
```

```
cat("Random Forest (Regression) trained.\n")
```

```
## Random Forest (Regression) trained.
```

```
print(regression_models$R.F)
```

```
## Random Forest
##
## 16119 samples
##    20 predictor
##
## No pre-processing
## Resampling: Cross-Validated (5 fold)
## Summary of sample sizes: 12896, 12897, 12895, 12894, 12894
## Resampling results across tuning parameters:
##
##   mtry  min.node.size  RMSE      Rsquared   MAE
##   5     1              11.24631  0.6108729  8.569824
##   5     3              11.24312  0.6111175  8.569425
##   7     1              11.22550  0.6108413  8.522683
##   7     3              11.23258  0.6103453  8.525309
##   9     1              11.24379  0.6091211  8.522339
##   9     3              11.23409  0.6097991  8.514749
##
## Tuning parameter 'splitrule' was held constant at a value of variance
## RMSE was used to select the optimal model using the smallest value.
## The final values used for the model were mtry = 7, splitrule = variance
##  and min.node.size = 1.
```

```
saveRDS(regression_models$R.F, "RF_model.rds")
# 2. Gradient Boosting
cat("\nTraining Gradient Boosting (Regression)...\n")
```

```
##
## Training Gradient Boosting (Regression)...
```

```
regression_models$GBM <- train(
  popularity ~ .,
  data = train_processed_reg,
  method = "gbm",
  trControl = ctrl_reg,
  tuneGrid = expand.grid(n.trees = c(150, 250), interaction.depth = c(3, 5), shrinkage = c(0.1, 0.5), n
  verbose = FALSE
)
cat("Gradient Boosting (Regression) trained.\n")
```

```
## Gradient Boosting (Regression) trained.
```

```
print(regression_models$GBM)
```

```
## Stochastic Gradient Boosting
##
## 16119 samples
##    20 predictor
##
## No pre-processing
## Resampling: Cross-Validated (5 fold)
## Summary of sample sizes: 12894, 12897, 12895, 12894, 12896
## Resampling results across tuning parameters:
##
##   shrinkage  interaction.depth  n.trees  RMSE      Rsquared   MAE
##   0.1        3                  150      11.45392  0.5936771  8.749513
##   0.1        3                  250      11.41780  0.5961667  8.716215
##   0.1        5                  150      11.37813  0.5989436  8.674404
##   0.1        5                  250      11.36233  0.6001090  8.655629
##   0.5        3                  150      11.79482  0.5719116  9.020331
##   0.5        3                  250      11.98528  0.5608290  9.140216
##   0.5        5                  150      12.08133  0.5545316  9.210313
##   0.5        5                  250      12.40276  0.5364842  9.455211
##
## Tuning parameter 'n.minobsinnode' was held constant at a value of 10
## RMSE was used to select the optimal model using the smallest value.
## The final values used for the model were n.trees = 250, interaction.depth =
##  5, shrinkage = 0.1 and n.minobsinnode = 10.
```

```
saveRDS(regression_models$GBM, "GBM_model.rds")
# 3. XGBoost
cat("\nTraining XGBoost (Regression)...\n")
```

```
##
## Training XGBoost (Regression)...
```

```
regression_models$XGB <- train(
  popularity ~ .,
  data = train_processed_reg,
  method = "xgbTree",
  trControl = ctrl_reg,
  tuneGrid = expand.grid(nrounds = c(150, 250), max_depth = c(3, 6), eta = c(0.1, 0.5), gamma = 0,
                         colsample_bytree = c(0.5, 0.75), min_child_weight = c(1, 3), subsample = 0.75),
  verbose = FALSE
)
```

```
## [19:54:05] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:54:07] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:54:10] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:54:13] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:54:16] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:54:20] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
```

```
## [19:54:30] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:54:35] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:54:37] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:54:39] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:54:41] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:54:43] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:54:47] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:54:52] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:54:59] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:55:11] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:55:15] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:55:18] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:55:21] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:55:23] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:55:27] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:55:30] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:55:35] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:55:42] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:55:45] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:55:47] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:55:53] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:55:56] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:56:01] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:56:10] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:56:15] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:56:19] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:56:21] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:56:24] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:56:27] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:56:29] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:56:33] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:56:36] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:56:41] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:56:45] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:56:48] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:56:51] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:56:54] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:56:57] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:57:01] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:57:08] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:57:13] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:57:19] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:57:21] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:57:23] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:57:25] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:57:27] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:57:31] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:57:35] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:57:40] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:57:44] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:57:46] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:57:47] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:57:50] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:57:52] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
```

```
## [19:57:58] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:58:06] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:58:11] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:58:16] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:58:19] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:58:21] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:58:23] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:58:27] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:58:32] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:58:38] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:58:45] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:58:57] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:59:00] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:59:06] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:59:08] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:59:10] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:59:14] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:59:17] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:59:22] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [19:59:27] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
```

```
cat("XGBoost (Regression) trained.\n")
```

```
## XGBoost (Regression) trained.
```

```
print(regression_models$XGB)
```

```
## eXtreme Gradient Boosting
##
## 16119 samples
##    20 predictor
##
## No pre-processing
## Resampling: Cross-Validated (5 fold)
## Summary of sample sizes: 12896, 12895, 12895, 12895, 12895
## Resampling results across tuning parameters:
##
##   eta  max_depth  colsample_bytree  min_child_weight  nrounds  RMSE
##   0.1  3          0.50              1                 150      11.32682
##   0.1  3          0.50              1                 250      11.30378
##   0.1  3          0.50              3                 150      11.32583
##   0.1  3          0.50              3                 250      11.29607
##   0.1  3          0.75              1                 150      11.29885
##   0.1  3          0.75              1                 250      11.27969
##   0.1  3          0.75              3                 150      11.32140
##   0.1  3          0.75              3                 250      11.30361
##   0.1  6          0.50              1                 150      11.30595
##   0.1  6          0.50              1                 250      11.36762
##   0.1  6          0.50              3                 150      11.26940
##   0.1  6          0.50              3                 250      11.33193
##   0.1  6          0.75              1                 150      11.29206
##   0.1  6          0.75              1                 250      11.35299
##   0.1  6          0.75              3                 150      11.29189
```

```
##   0.1  6          0.75              3                250      11.33287
##   0.5  3          0.50              1                150      11.75239
##   0.5  3          0.50              1                250      11.97113
##   0.5  3          0.50              3                150      11.76705
##   0.5  3          0.50              3                250      11.96198
##   0.5  3          0.75              1                150      11.82008
##   0.5  3          0.75              1                250      11.99316
##   0.5  3          0.75              3                150      11.84043
##   0.5  3          0.75              3                250      12.01539
##   0.5  6          0.50              1                150      13.01533
##   0.5  6          0.50              1                250      13.27783
##   0.5  6          0.50              3                150      12.88003
##   0.5  6          0.50              3                250      13.12636
##   0.5  6          0.75              1                150      13.06195
##   0.5  6          0.75              1                250      13.28331
##   0.5  6          0.75              3                150      12.98027
##   0.5  6          0.75              3                250      13.24722
##   Rsquared   MAE
##   0.6028896   8.635574
##   0.6043995   8.600772
##   0.6029355   8.628609
##   0.6049856   8.594719
##   0.6048136   8.603973
##   0.6060852   8.577506
##   0.6032420   8.616366
##   0.6044849   8.589057
##   0.6043553   8.581430
##   0.6002210   8.623910
##   0.6068327   8.575797
##   0.6025787   8.614112
##   0.6053945   8.563515
##   0.6015056   8.614357
##   0.6053739   8.566714
##   0.6028188   8.592183
##   0.5754863   8.957124
##   0.5630110   9.120007
##   0.5742985   8.966772
##   0.5630305   9.123982
##   0.5713747   8.983435
##   0.5616867   9.130902
##   0.5699708   9.023214
##   0.5602563   9.147112
##   0.5037725   9.936519
##   0.4913286  10.134106
##   0.5114457   9.885784
##   0.4996441  10.078808
##   0.5019839   9.987629
##   0.4907193  10.180429
##   0.5069205   9.883368
##   0.4943729  10.098038
##
## Tuning parameter 'gamma' was held constant at a value of 0
## Tuning
##  parameter 'subsample' was held constant at a value of 0.75
```

```
## RMSE was used to select the optimal model using the smallest value.
## The final values used for the model were nrounds = 150, max_depth = 6, eta
##  = 0.1, gamma = 0, colsample_bytree = 0.5, min_child_weight = 3 and subsample
##  = 0.75.
```

```
saveRDS(regression_models$XGB, "XGB_model.rds")
# Evaluate all regression models on the test set
regression_evaluation_results <- lapply(names(regression_models), function(model_name) {
  predictions <- predict(regression_models[[model_name]], newdata = test_processed_reg)
  performance <- postResample(pred = predictions, obs = test_processed_reg$popularity)
  cat(paste0("\nPerformance of ", model_name, " (Regression) on Test Set:\n"))
  print(performance)

  # Return both performance metrics and predictions as a list
  return(list(performance = performance, predictions = predictions))
})
```

```
##
## Performance of R.F (Regression) on Test Set:
##       RMSE   Rsquared        MAE
## 11.1563965  0.6070226  8.4484207
##
## Performance of GBM (Regression) on Test Set:
##       RMSE   Rsquared        MAE
## 11.2630803  0.5989427  8.6072880
##
## Performance of XGB (Regression) on Test Set:
##       RMSE   Rsquared        MAE
## 11.1120101  0.6096056  8.4676503
```

```
names(regression_evaluation_results) <- names(regression_models)

# Compile performance metrics for comparison
regression_results_df <- data.frame(
  Model = names(regression_models),
  RMSE = sapply(regression_evaluation_results, function(x) x$performance["RMSE"]),
  Rsquared = sapply(regression_evaluation_results, function(x) x$performance["Rsquared"]),
  MAE = sapply(regression_evaluation_results, function(x) x$performance["MAE"])
)

# Transpose the dataframe for the desired output
regression_results_df <- as.data.frame(t(regression_results_df[,-1]))
colnames(regression_results_df) <- names(regression_models)
rownames(regression_results_df) <- c("RMSE", "Rsquared", "MAE")


print("\nRegression Model Performance Comparison:")
```

```
## [1] "\nRegression Model Performance Comparison:"
```

```
print(regression_results_df)
```

```
##                 R.F        GBM        XGB
## RMSE     11.1563965 11.2630803 11.1120101
## Rsquared  0.6070226  0.5989427  0.6096056
## MAE       8.4484207  8.6072880  8.4676503
```

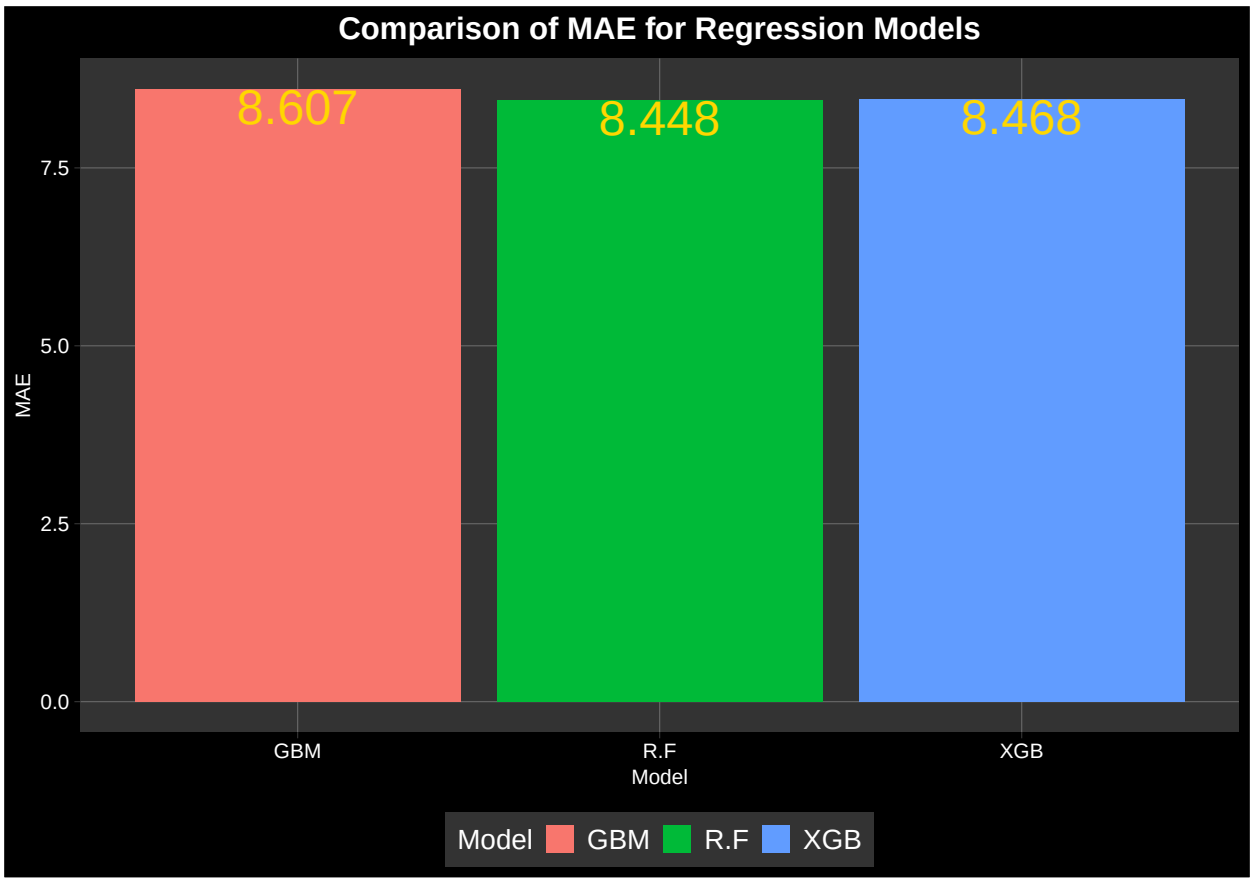
```r
# Determine the best performing regression model based on Rsquared
best_reg_model_name <- names(which.max(regression_results_df["Rsquared",]))
best_reg_model <- regression_models[[best_reg_model_name]]

cat(paste("\nBest performing regression model (based on Rsquared):", best_reg_model_name, "\n"))
```

```
##
## Best performing regression model (based on Rsquared): XGB
```

```r
# Get predictions from the best regression model
predictions_best_reg <- predict(best_reg_model, newdata = test_processed_reg)

# ------------------------------------------------------------------------------------------------------------
# Visualization of Regression Model Performance
# ------------------------------------------------------------------------------------------------------------

# Create a data frame for plotting performance metrics
performance_plot_data <- gather(regression_results_df, key = "Model", value = "Value") %>%
  mutate(Metric = rep(rownames(regression_results_df), times = length(regression_models)))

# Plotting RMSE with numeric values
rmse_plot <- ggplot(performance_plot_data %>% filter(Metric == "RMSE"), aes(x = Model, y = Value, fill =
  geom_bar(stat = "identity") +
  geom_text(aes(label = round(Value, 3), vjust = -0.5), size = 10, col = "gold") + # Add numeric labels
  labs(title = "Comparison of RMSE for Regression Models", y = "RMSE") +
  theme_dark_custom() +
  theme(legend.position = "bottom")
print(rmse_plot)
```

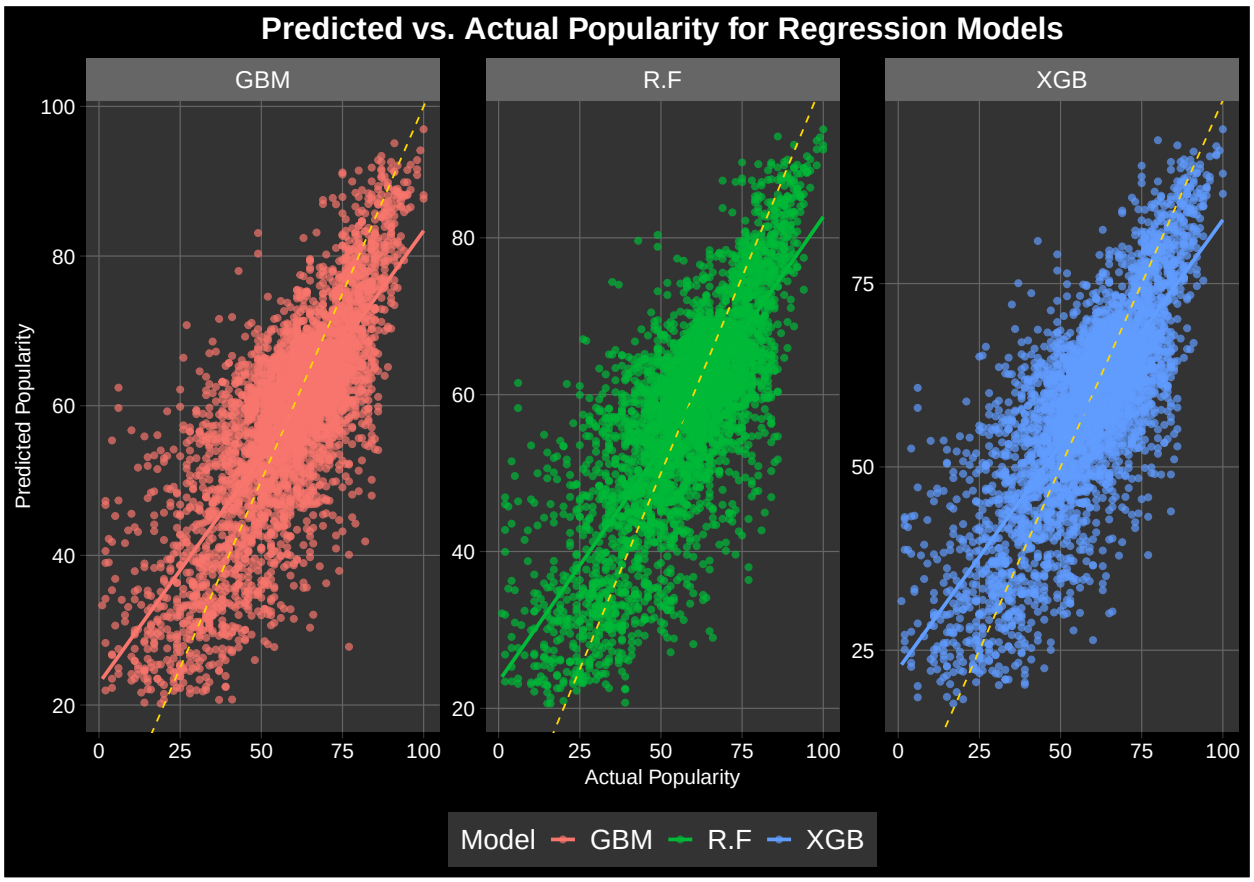

```
# Plotting Rsquared with numeric values
rsquared_plot <- ggplot(performance_plot_data %>% filter(Metric == "Rsquared"), aes(x = Model, y = Valu
  geom_bar(stat = "identity") +
  geom_text(aes(label = round(Value, 3), vjust = 1), size = 10, col = "gold") + # Add numeric labels
  labs(title = "Comparison of Rsquared for Regression Models", y = "R-squared") +
  theme_dark_custom() +
  theme(legend.position = "bottom")
print(rsquared_plot)
```


```r
# Plotting MAE with numeric values
mae_plot <- ggplot(performance_plot_data %>% filter(Metric == "MAE"), aes(x = Model, y = Value, fill = M
  geom_bar(stat = "identity") +
  geom_text(aes(label = round(Value, 3), vjust = 1), size = 10, col = "gold") + # Add numeric labels
  labs(title = "Comparison of MAE for Regression Models", y = "MAE") +
  theme_dark_custom() +
  theme(legend.position = "bottom")
print(mae_plot)
```

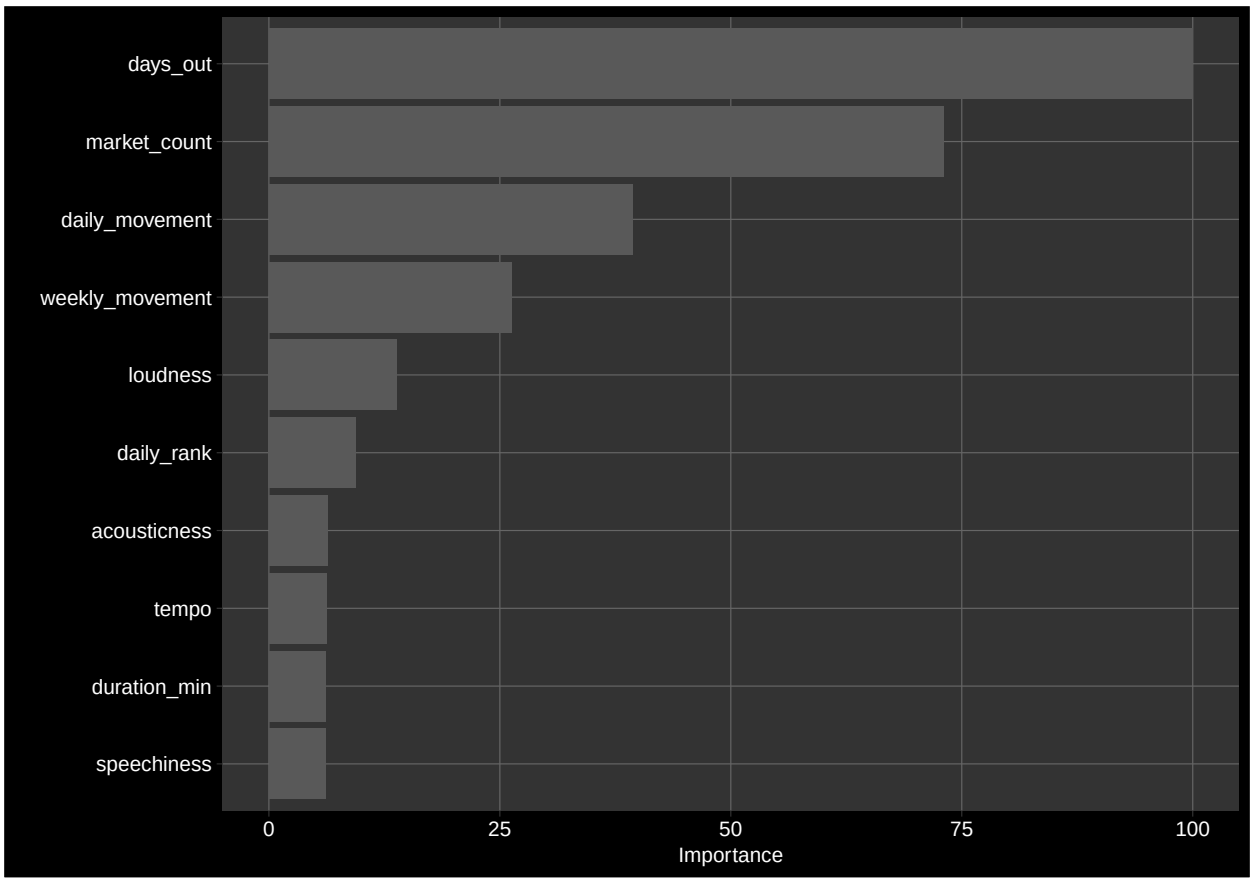



```r
# Create a data frame for plotting predicted vs actual values
plot_data_reg <- data.frame(
  Model = rep(names(regression_models), each = nrow(test_processed_reg)),
  Predicted = unlist(lapply(regression_evaluation_results, function(x) x$predictions)),
  Actual = rep(test_processed_reg$popularity, times = length(regression_models))
)

# Scatter plot of predicted vs actual values for each model
regression_scatter_plot <- ggplot(plot_data_reg, aes(x = Actual, y = Predicted, color = Model)) +
  geom_point(alpha = 0.7) +
  geom_abline(intercept = 0, slope = 1, color = "gold", linetype = "dashed") +
  geom_smooth(aes(group = Model), method = "lm", se = FALSE) +
  facet_wrap(~Model, scales = "free") +
  labs(title = "Predicted vs. Actual Popularity for Regression Models",
       x = "Actual Popularity",
       y = "Predicted Popularity") +
  theme_dark_custom() +
  theme(legend.position = "bottom")
print(regression_scatter_plot)
```

```
## `geom_smooth()` using formula = 'y ~ x'
```




```
# ------------------------------------------------------------------------------------------------------------
# Feature Importance Plot (Best Regression Model)
# ------------------------------------------------------------------------------------------------------------

# Plot feature importance for the best regression model
vip_plot_reg <- vip(
  best_reg_model,
  main = paste("Feature Importance in", best_reg_model_name, "(Regression)")) +
  theme_dark_custom()

print(vip_plot_reg)
```




```
# ================================================================================
# 4. PREPARE DATA FOR CLASSIFICATION (FROM BEST REGRESSION OUTPUT)
# ================================================================================

cat("\n====================\n")
```

```
##
## ====================
```

```
cat("Classification Based on Best Regression Model Predictions\n")
```

```
## Classification Based on Best Regression Model Predictions
```

```
cat("====================\n")
```

```
## ====================
```

```
# Define popularity thresholds
very_high_threshold <- 75
high_threshold <- 50
very_low_threshold <- 25

# Categorize the predicted popularity from the best regression model
```

```r
predicted_popularity_level <- case_when(
  predictions_best_reg >= very_high_threshold ~ "very_high",
  predictions_best_reg < very_low_threshold ~ "very_low",
  predictions_best_reg >= high_threshold ~ "high",
  predictions_best_reg < high_threshold ~ "low"
)
predicted_popularity_level <- factor(predicted_popularity_level, levels = c("very_low", "low", "high", 

# Create the actual popularity levels from the test set
actual_popularity_level <- case_when(
  test_data_reg$popularity >= very_high_threshold ~ "very_high",
  test_data_reg$popularity < very_low_threshold ~ "very_low",
  test_data_reg$popularity >= high_threshold ~ "high",
  test_data_reg$popularity < high_threshold ~ "low"
)
actual_popularity_level <- factor(actual_popularity_level, levels = c("very_low", "low", "high", "very_l

# Prepare data for classification model training
classification_data <- data.frame(
  popularity_level = actual_popularity_level,  # Use the actual levels from the test set
  test_processed_reg
)
# Remove the original 'popularity' column to avoid redundancy/potential issues
classification_data <- classification_data %>% select(-popularity)

# Split data for classification
set.seed(42)
train_index_class <- createDataPartition(classification_data$popularity_level, p = 0.8, list = FALSE)
train_data_class <- classification_data[train_index_class, ]
test_data_class <- classification_data[-train_index_class, ]

# ============================================================================
# 5. CLASSIFICATION MODEL TRAINING AND EVALUATION
# ============================================================================
cat("\n====================\n")
```

```
##
## ====================
```

```r
cat("Classification Model Training and Evaluation\n")
```

```
## Classification Model Training and Evaluation
```

```r
cat("====================\n")
```

```
## ====================
```

```r
# Custom summary function for multi-class ROC
multiClassSummary <- function (data, lev = NULL, model = NULL) {
  if (length(lev) > 2) {
    rocs <- pROC::multiclass.roc(data$obs, data[, lev])
```

```
    auc <- pROC::auc(rocs)
    names(auc) <- "AUC"
    accuracy <- mean(data$obs == data$pred)
    names(accuracy) <- "Accuracy"
    return(c(AUC = auc, Accuracy = accuracy))
  } else {
    return(defaultSummary(data, lev, model))
  }
}

# Define resampling strategy for classification
trainControl_roc <- trainControl(method = "cv",
                                 number = 5,
                                 allowParallel = TRUE,
                                 summaryFunction = multiClassSummary,
                                 classProbs = TRUE,
                                 savePredictions = TRUE)

# Initialize a list to store classification models
classification_models <- list()

# Train a classification model (Random Forest, for example)
cat("\nTraining Classification Model (Random Forest)...\n")
```

```
##
## Training Classification Model (Random Forest)...
```

```
classification_models$R.F <- train(
  popularity_level ~ .,
  data = train_data_class,
  method = "ranger",
  trControl = trainControl_roc,
  tuneGrid = expand.grid(mtry = c(5, 7, 9),
                         min.node.size = c(1, 3, 5),
                         splitrule = "gini"),
  num.trees = 250,
  metric = "AUC"
)
```

```
## Warning in train.default(x, y, weights = w, ...): The metric "AUC" was not in
## the result set. AUC.AUC will be used instead.
```

```
cat("Random Forest Classification trained.\n")
```

```
## Random Forest Classification trained.
```

```
print(classification_models$R.F)
```

```
## Random Forest
##
## 3223 samples
```

```
##   20 predictor
##    4 classes: 'very_low', 'low', 'high', 'very_high'
##
## No pre-processing
## Resampling: Cross-Validated (5 fold)
## Summary of sample sizes: 2578, 2580, 2578, 2577, 2579
## Resampling results across tuning parameters:
##
##   mtry  min.node.size  AUC.AUC    Accuracy.Accuracy
##   5     1              0.8478300  0.6940940
##   5     3              0.8451799  0.6894385
##   5     5              0.8446820  0.6906841
##   7     1              0.8478490  0.6916085
##   7     3              0.8467087  0.6944007
##   7     5              0.8463405  0.6906865
##   9     1              0.8445634  0.6888212
##   9     3              0.8452649  0.6928537
##   9     5              0.8455274  0.6903740
##
## Tuning parameter 'splitrule' was held constant at a value of gini
## AUC.AUC was used to select the optimal model using the largest value.
## The final values used for the model were mtry = 7, splitrule = gini
##  and min.node.size = 1.
```

```
print(classification_models$R.F$results)
```

```
##   mtry min.node.size splitrule   AUC.AUC Accuracy.Accuracy  AUC.AUCSD
## 1    5             1      gini 0.8478300         0.6940940 0.01548483
## 2    5             3      gini 0.8451799         0.6894385 0.01302378
## 3    5             5      gini 0.8446820         0.6906841 0.01238808
## 4    7             1      gini 0.8478490         0.6916085 0.01319797
## 5    7             3      gini 0.8467087         0.6944007 0.01282207
## 6    7             5      gini 0.8463405         0.6906865 0.01231607
## 7    9             1      gini 0.8445634         0.6888212 0.01234270
## 8    9             3      gini 0.8452649         0.6928537 0.01317911
## 9    9             5      gini 0.8455274         0.6903740 0.01402722
##   Accuracy.AccuracySD
## 1          0.02222283
## 2          0.01679219
## 3          0.02120189
## 4          0.01770734
## 5          0.02038249
## 6          0.02696380
## 7          0.02366248
## 8          0.02424969
## 9          0.02346741
```

```
# Train XGBoost
cat("\nTraining Classification Model (XGBoost)...\n")
```

```
##
## Training Classification Model (XGBoost)...
```

```r
classification_models$XGB <- train(
  popularity_level ~ .,
  data = train_data_class,
  method = "xgbTree",
  trControl = trainControl_roc,
  tuneGrid = expand.grid(nrounds = c(150, 250),
                         max_depth = c(3, 6),
                         eta = c(0.1, 0.5),
                         gamma = 0,
                         colsample_bytree = c(0.5, 0.75),
                         min_child_weight = c(1, 3),
                         subsample = 0.75),
  metric = "AUC",
  verbose = FALSE
)
```

```
## Warning in train.default(x, y, weights = w, ...): The metric "AUC" was not in
## the result set. AUC.AUC will be used instead.
```

```
## [20:01:20] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:20] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:22] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:22] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:25] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:25] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:27] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:27] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:32] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:32] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:37] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:37] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:42] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:42] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:47] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:47] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:49] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:49] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:52] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:52] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:54] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:54] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:57] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:01:57] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:01] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:01] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:07] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:07] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:11] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:11] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:15] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:15] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:17] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:17] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
```

```
## [20:02:20] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:20] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:22] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:22] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:25] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:25] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:29] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:29] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:34] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:34] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:39] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:39] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:44] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:44] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:46] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:46] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:48] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:48] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:51] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:51] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:53] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:53] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:58] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:02:58] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:01] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:01] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:07] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:07] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:11] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:11] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:13] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:13] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:15] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:16] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:18] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:18] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:21] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:21] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:25] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:25] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:30] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:30] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:35] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:35] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:40] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:40] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:42] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:42] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:45] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:45] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:47] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:47] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:49] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:50] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
```

```
## [20:03:54] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:54] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:57] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:03:57] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:04:06] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:04:06] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:04:13] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:04:13] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:04:16] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:04:16] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:04:20] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:04:20] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:04:25] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:04:25] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:04:29] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:04:29] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:04:37] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:04:37] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:04:45] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:04:45] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:04:55] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:04:55] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:06] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:06] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:10] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:10] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:13] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:13] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:18] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:18] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:22] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:22] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:30] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:30] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:36] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:36] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:43] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:43] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:49] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:49] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:53] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:53] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:57] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:05:57] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:06:03] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:06:03] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:06:08] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:06:08] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:06:16] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:06:16] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:06:24] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:06:24] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:06:33] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:06:33] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
```

```
## [20:06:42] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:06:42] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:06:45] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
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## [20:06:49] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:06:49] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:06:54] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:06:54] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:06:58] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:06:58] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:07:07] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:07:07] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:07:12] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:07:12] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:07:20] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:07:20] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:07:27] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
## [20:07:27] WARNING: src/c_api/c_api.cc:935: `ntree_limit` is deprecated, use `iteration_range` instea
```

```
cat("XGBoost Classification trained.\n")
```

```
## XGBoost Classification trained.
```

```
print(classification_models$XGB)
```

```
## eXtreme Gradient Boosting
##
## 3223 samples
##   20 predictor
##    4 classes: 'very_low', 'low', 'high', 'very_high'
##
## No pre-processing
## Resampling: Cross-Validated (5 fold)
## Summary of sample sizes: 2578, 2578, 2577, 2579, 2580
## Resampling results across tuning parameters:
##
##   eta  max_depth  colsample_bytree  min_child_weight  nrounds  AUC.AUC
##   0.1  3          0.50              1                 150      0.8471965
##   0.1  3          0.50              1                 250      0.8441051
##   0.1  3          0.50              3                 150      0.8471562
##   0.1  3          0.50              3                 250      0.8448742
##   0.1  3          0.75              1                 150      0.8470788
##   0.1  3          0.75              1                 250      0.8439682
##   0.1  3          0.75              3                 150      0.8468363
##   0.1  3          0.75              3                 250      0.8431086
##   0.1  6          0.50              1                 150      0.8381922
##   0.1  6          0.50              1                 250      0.8345700
##   0.1  6          0.50              3                 150      0.8408294
##   0.1  6          0.50              3                 250      0.8370225
##   0.1  6          0.75              1                 150      0.8393807
##   0.1  6          0.75              1                 250      0.8360153
##   0.1  6          0.75              3                 150      0.8417988
##   0.1  6          0.75              3                 250      0.8367599
```

```
##   0.5  3          0.50             1                150      0.8217919
##   0.5  3          0.50             1                250      0.8195591
##   0.5  3          0.50             3                150      0.8250680
##   0.5  3          0.50             3                250      0.8197260
##   0.5  3          0.75             1                150      0.8262211
##   0.5  3          0.75             1                250      0.8205599
##   0.5  3          0.75             3                150      0.8252410
##   0.5  3          0.75             3                250      0.8219665
##   0.5  6          0.50             1                150      0.8188519
##   0.5  6          0.50             1                250      0.8176220
##   0.5  6          0.50             3                150      0.8186569
##   0.5  6          0.50             3                250      0.8172406
##   0.5  6          0.75             1                150      0.8236683
##   0.5  6          0.75             1                250      0.8224824
##   0.5  6          0.75             3                150      0.8222595
##   0.5  6          0.75             3                250      0.8208097
##   Accuracy.Accuracy
##   0.6912985
##   0.6847796
##   0.6894336
##   0.6822932
##   0.6897336
##   0.6838339
##   0.6906768
##   0.6757671
##   0.6798121
##   0.6748388
##   0.6844541
##   0.6835181
##   0.6822850
##   0.6813548
##   0.6816735
##   0.6723572
##   0.6608824
##   0.6512598
##   0.6577878
##   0.6506431
##   0.6624390
##   0.6565451
##   0.6500224
##   0.6528016
##   0.6692530
##   0.6658393
##   0.6534309
##   0.6534285
##   0.6676983
##   0.6661431
##   0.6608906
##   0.6574677
##
## Tuning parameter 'gamma' was held constant at a value of 0
## Tuning
##  parameter 'subsample' was held constant at a value of 0.75
## AUC.AUC was used to select the optimal model using the largest value.
```

```
## The final values used for the model were nrounds = 150, max_depth = 3, eta
##  = 0.1, gamma = 0, colsample_bytree = 0.5, min_child_weight = 1 and subsample
##  = 0.75.
```

```
print(classification_models$XGB$results)
```

```
##    eta max_depth gamma colsample_bytree min_child_weight subsample nrounds
## 1  0.1         3     0              0.50                1      0.75     150
## 3  0.1         3     0              0.50                3      0.75     150
## 5  0.1         3     0              0.75                1      0.75     150
## 7  0.1         3     0              0.75                3      0.75     150
## 17 0.5         3     0              0.50                1      0.75     150
## 19 0.5         3     0              0.50                3      0.75     150
## 21 0.5         3     0              0.75                1      0.75     150
## 23 0.5         3     0              0.75                3      0.75     150
## 9  0.1         6     0              0.50                1      0.75     150
## 11 0.1         6     0              0.50                3      0.75     150
## 13 0.1         6     0              0.75                1      0.75     150
## 15 0.1         6     0              0.75                3      0.75     150
## 25 0.5         6     0              0.50                1      0.75     150
## 27 0.5         6     0              0.50                3      0.75     150
## 29 0.5         6     0              0.75                1      0.75     150
## 31 0.5         6     0              0.75                3      0.75     150
## 2  0.1         3     0              0.50                1      0.75     250
## 4  0.1         3     0              0.50                3      0.75     250
## 6  0.1         3     0              0.75                1      0.75     250
## 8  0.1         3     0              0.75                3      0.75     250
## 18 0.5         3     0              0.50                1      0.75     250
## 20 0.5         3     0              0.50                3      0.75     250
## 22 0.5         3     0              0.75                1      0.75     250
## 24 0.5         3     0              0.75                3      0.75     250
## 10 0.1         6     0              0.50                1      0.75     250
## 12 0.1         6     0              0.50                3      0.75     250
## 14 0.1         6     0              0.75                1      0.75     250
## 16 0.1         6     0              0.75                3      0.75     250
## 26 0.5         6     0              0.50                1      0.75     250
## 28 0.5         6     0              0.50                3      0.75     250
## 30 0.5         6     0              0.75                1      0.75     250
## 32 0.5         6     0              0.75                3      0.75     250
##      AUC.AUC Accuracy.Accuracy   AUC.AUCSD Accuracy.AccuracySD
## 1  0.8471965         0.6912985 0.004780348         0.019791458
## 3  0.8471562         0.6894336 0.005052652         0.015809634
## 5  0.8470788         0.6897336 0.005852254         0.012029837
## 7  0.8468363         0.6906768 0.006042619         0.015507421
## 17 0.8217919         0.6608824 0.014804834         0.015264801
## 19 0.8250680         0.6577878 0.008582047         0.017597665
## 21 0.8262211         0.6624390 0.014152165         0.012459426
## 23 0.8252410         0.6500224 0.012517161         0.015621568
## 9  0.8381922         0.6798121 0.006419690         0.012455717
## 11 0.8408294         0.6844541 0.006276105         0.015325563
## 13 0.8393807         0.6822850 0.005796057         0.010174891
## 15 0.8417988         0.6816735 0.008982473         0.010745674
## 25 0.8188519         0.6692530 0.015635727         0.012522169
## 27 0.8186569         0.6534309 0.010288992         0.013364202
```

```
## 29 0.8236683         0.6676983 0.011311210         0.010047824
## 31 0.8222595         0.6608906 0.011824892         0.018504329
## 2  0.8441051         0.6847796 0.005979236         0.013288417
## 4  0.8448742         0.6822932 0.005928244         0.015165941
## 6  0.8439682         0.6838339 0.007620035         0.010445429
## 8  0.8431086         0.6757671 0.006116087         0.011563283
## 18 0.8195591         0.6512598 0.014337442         0.018293686
## 20 0.8197260         0.6506431 0.010386932         0.009231630
## 22 0.8205599         0.6565451 0.013958231         0.016378643
## 24 0.8219665         0.6528016 0.012410840         0.015498555
## 10 0.8345700         0.6748388 0.008216414         0.008783153
## 12 0.8370225         0.6835181 0.008144093         0.012842109
## 14 0.8360153         0.6813548 0.007142089         0.010796819
## 16 0.8367599         0.6723572 0.010716422         0.014199800
## 26 0.8176220         0.6658393 0.015616427         0.011562755
## 28 0.8172406         0.6534285 0.011821935         0.016198839
## 30 0.8224824         0.6661431 0.012772905         0.011850953
## 32 0.8208097         0.6574677 0.012503777         0.016906064
```

```r
# Modified plot_roc_curves function to return a ggplot object
plot_roc_curves_gg <- function(model, test_data, model_name) {
  pred_probs_class <- predict(model, newdata = test_data %>% select(-popularity_level), type = "prob")
  class_levels <- levels(test_data$popularity_level)
  roc_objects_class <- list()

  # Create ROC objects for each class
  for (i in seq_along(class_levels)) {
    current_class <- class_levels[[i]]
    # Ensure binary_response is a factor with levels 0 and 1 for pROC
    binary_response <- factor(ifelse(test_data$popularity_level == current_class, 1, 0), levels = c(0, 1
    predictor <- pred_probs_class[, current_class]
    roc_objects_class[[current_class]] <- roc(response = binary_response, predictor = predictor)
  }

  roc_data_list <- lapply(names(roc_objects_class), function(class_name) {
    roc_obj <- roc_objects_class[[class_name]]
    data.frame(
      FPR = 1 - roc_obj$specificities,
      TPR = roc_obj$sensitivities,
      Class = class_name
      # REMOVED: AUC = auc(roc_obj) -- This was causing the row mismatch
    )
  })

  roc_data_df <- bind_rows(roc_data_list)

  # Calculate AUCs separately for annotation
  auc_values <- sapply(roc_objects_class, auc)
  auc_labels <- data.frame(
    Class = names(auc_values),
    AUC = round(auc_values, 3)
  )

  roc_plot <- ggplot(roc_data_df, aes(x = FPR, y = TPR, color = Class)) +
```

```
    geom_line(size = 1) +
    geom_abline(linetype = "dashed", color = "gold") +
    # Use auc_labels data frame for annotation
    # Adjust y-position based on number of classes to prevent overlap
    geom_text(data = auc_labels,
              aes(x = 0.7, y = 0.1 + (match(Class, class_levels) - 1) * 0.08,
                  label = paste0("AUC (", Class, ") = ", AUC)),
              color = "white", size = 4, hjust = 0) +
    labs(title = paste("One-vs-Rest ROC Curves (", model_name, ")", sep = ""),
         x = "False Positive Rate (1 - Specificity)",
         y = "True Positive Rate (Sensitivity)") +
    theme_dark_custom() +
    scale_color_manual(values = c("very_low" = "#66c2a5", "low" = "#fc8d62", "high" = "#8da0cb", "very_
    theme(legend.position = "bottom")

  return(roc_plot)
}

# Generate ROC plots for both models
roc_rf_plot <- plot_roc_curves_gg(classification_models$R.F, test_data_class, "Random Forest")
```

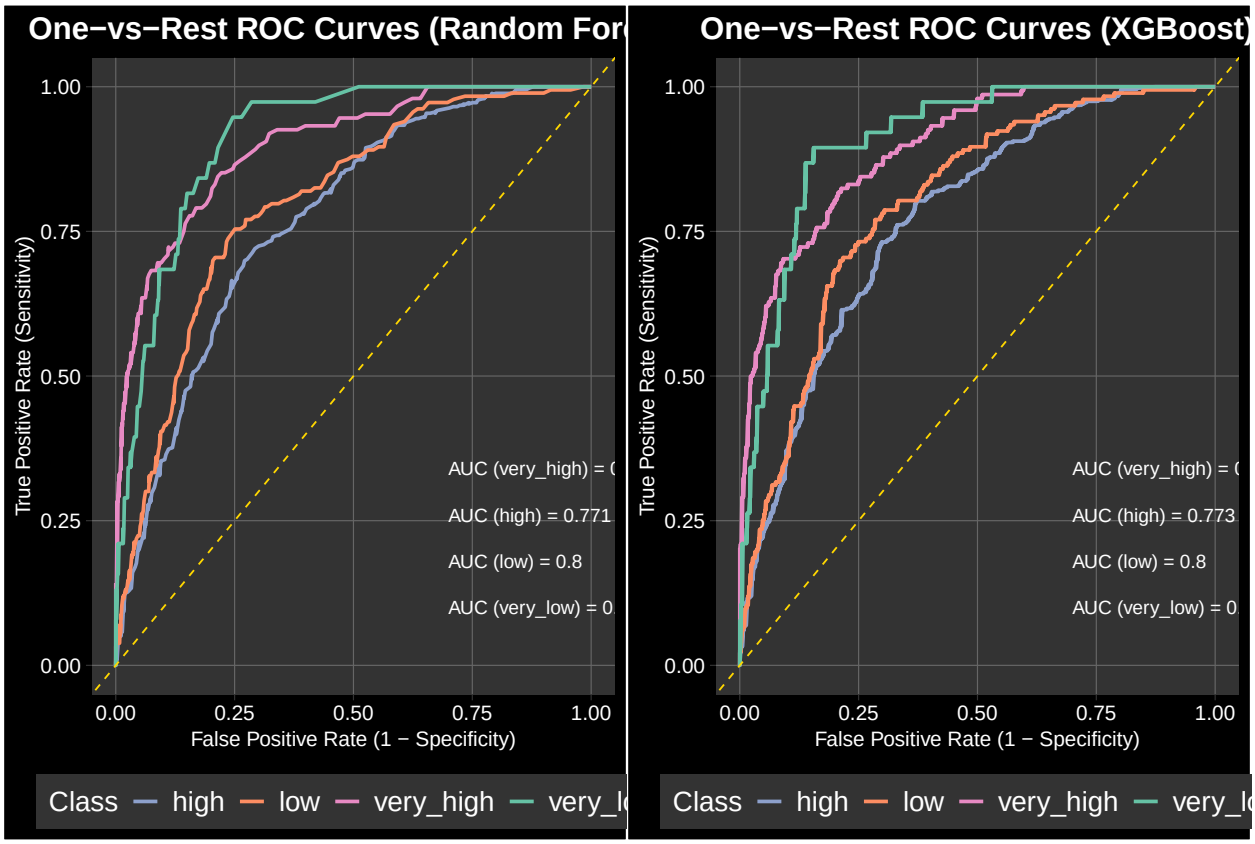
```
## Setting levels: control = 0, case = 1
## Setting direction: controls < cases
## Setting levels: control = 0, case = 1
## Setting direction: controls < cases
## Setting levels: control = 0, case = 1
## Setting direction: controls < cases
## Setting levels: control = 0, case = 1
## Setting direction: controls < cases
```

```
## Warning: Using `size` aesthetic for lines was deprecated in ggplot2 3.4.0.
## i Please use `linewidth` instead.
## This warning is displayed once every 8 hours.
## Call `lifecycle::last_lifecycle_warnings()` to see where this warning was
## generated.
```

```
roc_xgb_plot <- plot_roc_curves_gg(classification_models$XGB, test_data_class, "XGBoost")
```

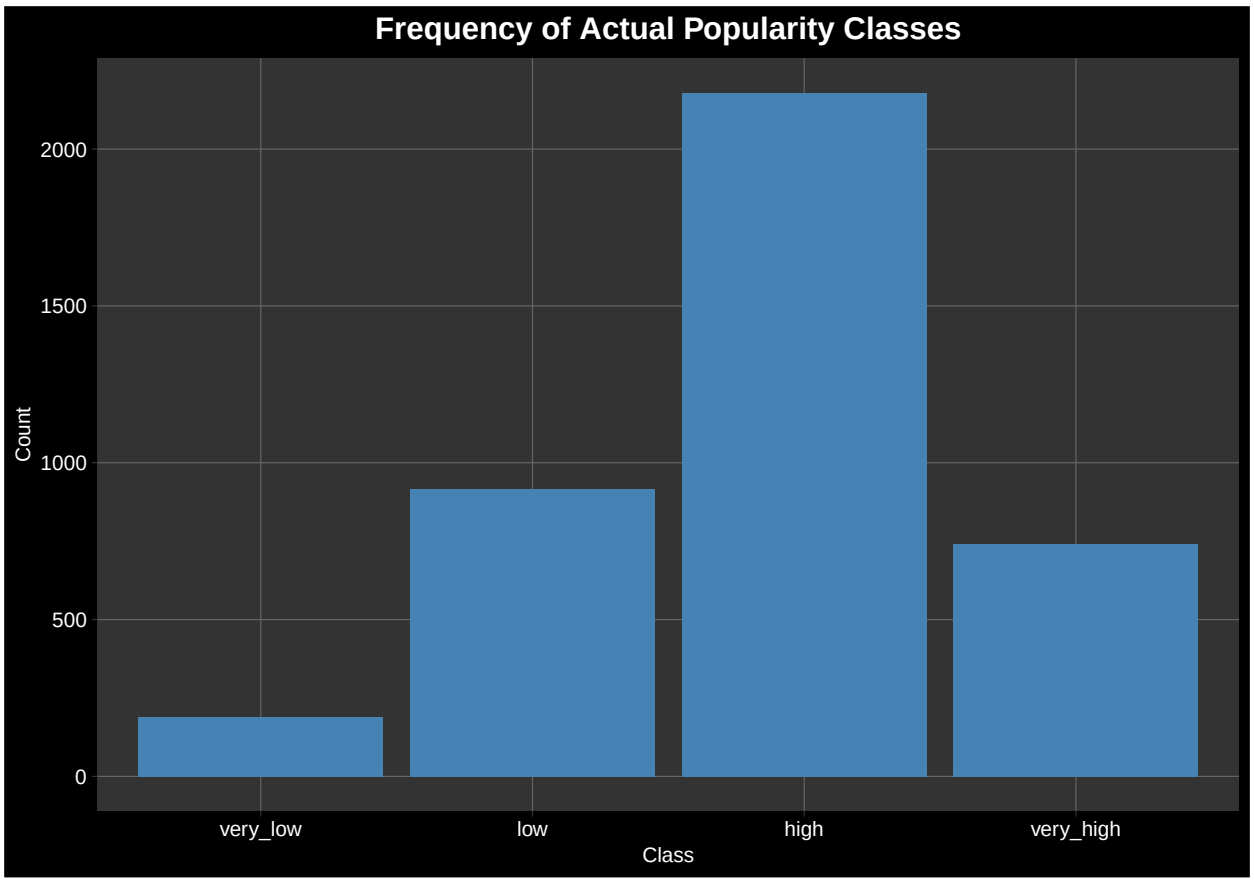
```
## Setting levels: control = 0, case = 1
## Setting direction: controls < cases
## Setting levels: control = 0, case = 1
## Setting direction: controls < cases
## Setting levels: control = 0, case = 1
## Setting direction: controls < cases
## Setting levels: control = 0, case = 1
## Setting direction: controls < cases
```

```
# Arrange ROC curves side-by-side
grid.arrange(roc_rf_plot, roc_xgb_plot, ncol = 2,
             top = textGrob("One-vs-Rest ROC Curves for Classification Models",
                            gp = gpar(col = "white", fontsize = 20, fontface = "bold")))
```

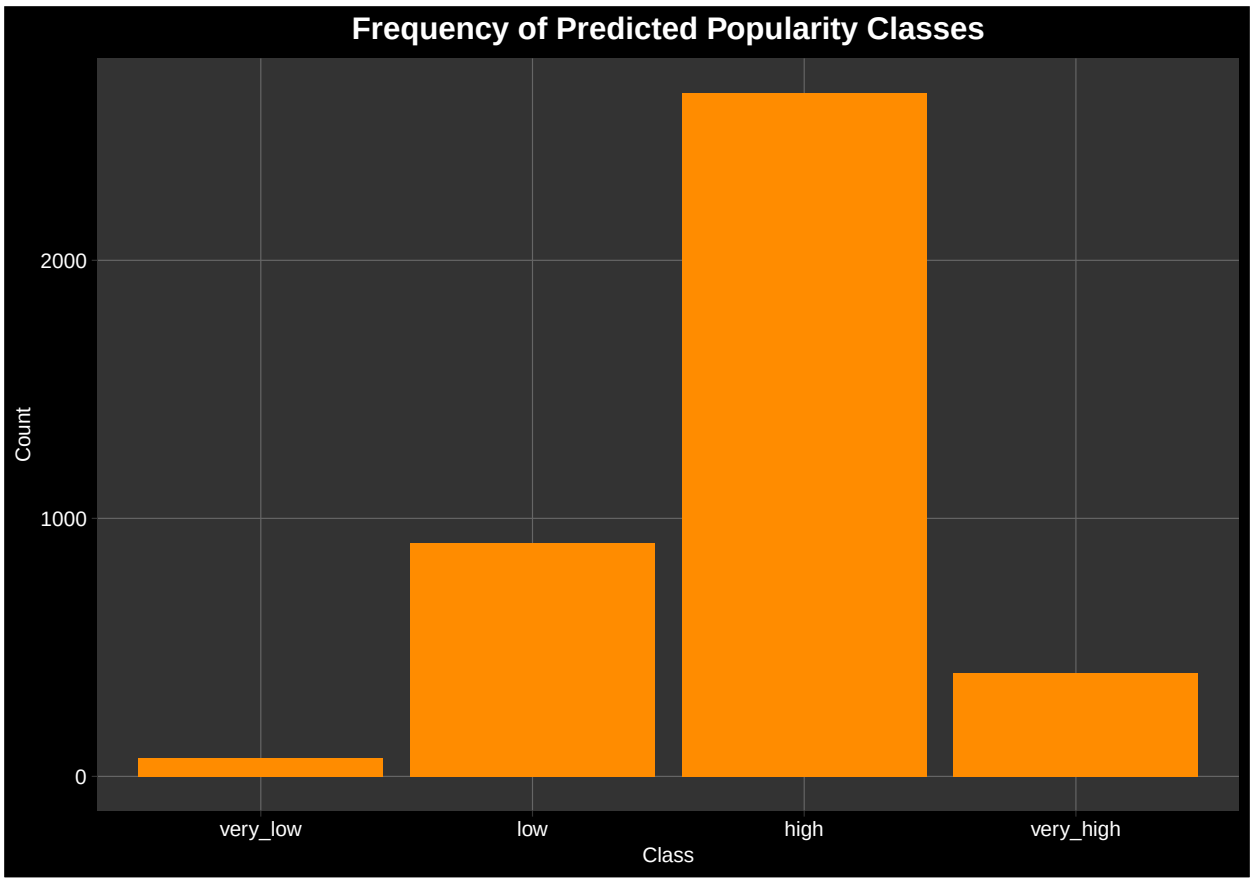



```
# ================================================================================
# Frequency Plots for Popularity Class Labels
# ================================================================================

# Actual popularity class distribution
actual_class_plot <- ggplot(data.frame(Class = actual_popularity_level), aes(x = Class)) +
  geom_bar(fill = "steelblue") +
  labs(title = "Frequency of Actual Popularity Classes", x = "Class", y = "Count") +
  theme_dark_custom()
print(actual_class_plot)
```




```
# Predicted popularity class distribution
predicted_class_plot <- ggplot(data.frame(Class = predicted_popularity_level), aes(x = Class)) +
  geom_bar(fill = "darkorange") +
  labs(title = "Frequency of Predicted Popularity Classes", x = "Class", y = "Count") +
  theme_dark_custom()
print(predicted_class_plot)
```




```
# ================================================================================
# 7. CONFUSION MATRIX AND CLASSIFICATION METRICS
# ================================================================================

cat("\n====================\n")
```

```
##
## ====================
```

```
cat("Confusion Matrix and Classification Metrics\n")
```

```
## Confusion Matrix and Classification Metrics
```

```
cat("====================\n")
```

```
## ====================
```

```
# Function to evaluate and print classification metrics
evaluate_classification_model <- function(model, test_data, model_name) {
  # Make predictions on the test set
  predictions_class <- predict(model, newdata = test_data %>% select(-popularity_level))

  # Create confusion matrix
```

```r
  conf_matrix_class <- confusionMatrix(data = predictions_class, reference = test_data$popularity_level

  # Print confusion matrix
  cat(paste("\nConfusion Matrix (", model_name, " on Test Set):\n", sep = ""))
  print(conf_matrix_class)

  # Extract overall metrics
  overall_metrics_class <- data.frame(conf_matrix_class$overall)
  cat("\nOverall Classification Metrics:\n")
  print(overall_metrics_class)

  # Extract class-specific metrics
  class_metrics_class <- data.frame(conf_matrix_class$byClass)
  cat("\nClass-Specific Classification Metrics:\n")
  print(class_metrics_class)

  return(list(confusion_matrix = conf_matrix_class,
              overall_metrics = overall_metrics_class,
              class_metrics = class_metrics_class))
}

# ggplot confusion matrices
plot_confusion_matrix_gg <- function(conf_matrix_obj, model_name) {
  cm_df <- as.data.frame(conf_matrix_obj$table)
  colnames(cm_df) <- c("Prediction", "Reference", "Freq")

  ggplot(cm_df, aes(x = Prediction, y = Reference, fill = Freq)) +
    geom_tile(color = "white") +
    geom_text(aes(label = Freq), color = "white", size = 5) +
    scale_fill_gradient(low = "skyblue", high = "blue") +
    labs(title = paste("Confusion Matrix -", model_name),
         x = "Predicted Class", y = "Actual Class") +
    theme_dark_custom()
}

# Evaluate Random Forest and XGBoost
rf_evaluation_results <- evaluate_classification_model(classification_models$R.F, test_data_class, "Rand
```

```
##
## Confusion Matrix (Random Forest on Test Set):
## Confusion Matrix and Statistics
##
##            Reference
## Prediction  very_low low high very_high
##   very_low         6   3    0         0
##   low             21  75   44         2
##   high            11 104  372        70
##   very_high        0   1   20        76
##
## Overall Statistics
##
##                Accuracy : 0.6571
##                  95% CI : (0.6232, 0.6899)
```

```
##     No Information Rate : 0.5416
##     P-Value [Acc > NIR] : 1.859e-11
##
##                   Kappa : 0.3904
##
##  Mcnemar's Test P-Value : NA
##
## Statistics by Class:
##
##                      Class: very_low Class: low Class: high Class: very_high
## Sensitivity                 0.157895    0.40984      0.8532          0.51351
## Specificity                 0.996089    0.89228      0.4986          0.96804
## Pos Pred Value              0.666667    0.52817      0.6679          0.78351
## Neg Pred Value              0.959799    0.83710      0.7419          0.89831
## Prevalence                  0.047205    0.22733      0.5416          0.18385
## Detection Rate              0.007453    0.09317      0.4621          0.09441
## Detection Prevalence        0.011180    0.17640      0.6919          0.12050
## Balanced Accuracy           0.576992    0.65106      0.6759          0.74078
##
## Overall Classification Metrics:
##                conf_matrix_class.overall
## Accuracy                    6.571429e-01
## Kappa                       3.904343e-01
## AccuracyLower               6.232027e-01
## AccuracyUpper               6.899270e-01
## AccuracyNull                5.416149e-01
## AccuracyPValue              1.858858e-11
## McnemarPValue                        NaN
##
## Class-Specific Classification Metrics:
##                   Sensitivity Specificity Pos.Pred.Value Neg.Pred.Value
## Class: very_low     0.1578947   0.9960887      0.6666667      0.9597990
## Class: low          0.4098361   0.8922830      0.5281690      0.8371041
## Class: high         0.8532110   0.4986450      0.6678636      0.7419355
## Class: very_high    0.5135135   0.9680365      0.7835052      0.8983051
##                   Precision    Recall        F1 Prevalence Detection.Rate
## Class: very_low  0.6666667 0.1578947 0.2553191 0.04720497    0.007453416
## Class: low       0.5281690 0.4098361 0.4615385 0.22732919    0.093167702
## Class: high      0.6678636 0.8532110 0.7492447 0.54161491    0.462111801
## Class: very_high 0.7835052 0.5135135 0.6204082 0.18385093    0.094409938
##                   Detection.Prevalence Balanced.Accuracy
## Class: very_low             0.01118012         0.5769917
## Class: low                  0.17639752         0.6510595
## Class: high                 0.69192547         0.6759280
## Class: very_high            0.12049689         0.7407750
```

```
xgb_evaluation_results <- evaluate_classification_model(classification_models$XGB, test_data_class, "XG
```

```
##
## Confusion Matrix (XGBoost on Test Set):
## Confusion Matrix and Statistics
##
##            Reference
## Prediction  very_low low high very_high
```

```
##   very_low         5   6    0         0
##   low             26  71   44         0
##   high             7 105  372        71
##   very_high        0   1   20        77
##
## Overall Statistics
##
##                Accuracy : 0.6522
##                  95% CI : (0.6181, 0.6851)
##     No Information Rate : 0.5416
##     P-Value [Acc > NIR] : 1.271e-10
##
##                   Kappa : 0.383
##
##  Mcnemar's Test P-Value : NA
##
## Statistics by Class:
##
##                      Class: very_low Class: low Class: high Class: very_high
## Sensitivity                 0.131579     0.3880      0.8532          0.52027
## Specificity                 0.992177     0.8875      0.5041          0.96804
## Pos Pred Value              0.454545     0.5035      0.6703          0.78571
## Neg Pred Value              0.958438     0.8313      0.7440          0.89958
## Prevalence                  0.047205     0.2273      0.5416          0.18385
## Detection Rate              0.006211     0.0882      0.4621          0.09565
## Detection Prevalence        0.013665     0.1752      0.6894          0.12174
## Balanced Accuracy           0.561878     0.6377      0.6786          0.74415
##
## Overall Classification Metrics:
##                conf_matrix_class.overall
## Accuracy                    6.521739e-01
## Kappa                       3.830067e-01
## AccuracyLower               6.181408e-01
## AccuracyUpper               6.850877e-01
## AccuracyNull                5.416149e-01
## AccuracyPValue              1.270787e-10
## McnemarPValue                        NaN
##
## Class-Specific Classification Metrics:
##                   Sensitivity Specificity Pos.Pred.Value Neg.Pred.Value
## Class: very_low     0.1315789   0.9921773      0.4545455      0.9584383
## Class: low          0.3879781   0.8874598      0.5035461      0.8313253
## Class: high         0.8532110   0.5040650      0.6702703      0.7440000
## Class: very_high    0.5202703   0.9680365      0.7857143      0.8995757
##                   Precision    Recall        F1 Prevalence Detection.Rate
## Class: very_low  0.4545455 0.1315789 0.2040816 0.04720497     0.00621118
## Class: low       0.5035461 0.3879781 0.4382716 0.22732919     0.08819876
## Class: high      0.6702703 0.8532110 0.7507568 0.54161491     0.46211180
## Class: very_high 0.7857143 0.5202703 0.6260163 0.18385093     0.09565217
##                   Detection.Prevalence Balanced.Accuracy
## Class: very_low              0.0136646         0.5618781
## Class: low                   0.1751553         0.6377190
## Class: high                  0.6894410         0.6786380
## Class: very_high             0.1217391         0.7441534
```

```r
# ...
# Get confusion matrix plots
rf_cm_plot <- plot_confusion_matrix_gg(rf_evaluation_results$confusion_matrix, "Random Forest")
xgb_cm_plot <- plot_confusion_matrix_gg(xgb_evaluation_results$confusion_matrix, "XGBoost")

# Arrange confusion matrices side-by-side
grid.arrange(rf_cm_plot, xgb_cm_plot, ncol = 2,
             top = textGrob("Confusion Matrices for Classification Models",
                            gp = gpar(col = "white", fontsize = 20, fontface = "bold")))
```