

Data Science Capstone - Movielens Recommendation Model

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February 27, 2020

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1 Introduction

This document presents a machine learning model, aiming to predict (recommend) movie ratings. This report is a capstone assignment for HarvardX's Professional Certificate in Data Science, which can be taken at the edX platform. The program is available at <https://www.edx.org/professional-certificate/harvardx-data-science>.

The data used in this exercise comes from the [Movielens 10M Dataset](#). After using the download code provided in the course, the resulting data frame contains a series of observations, each with the below attributes:

1. **userId** : Unique user identifier
2. **movieId** : Unique movie identifier
3. **rating** : Rating given to this movie by the particular user.
4. **timestamp** : Timestamp indicating when the the user submitted the rating.
5. **title** : Title of the film and its release year in brackets. Please note that different movies can have the same name (e.g. remakes), thus movieId is a better unique identifier.
6. **genres** : List of all genres, in which this movie can be classified.

The goal of this project is to generate a model that can predict a particular movie rating, as close as possible to the actual rating given to each film. In order to assess performance, the **Root Square Mean Error (RMSE)** will be calculated, with the error defined as the difference between predicted and actual ratings. The Training and validation datasets are generated using the code provided in the assignment instructions. In order to aim for a full mark, this report will target for a RMSE lower than **0.86490**.

The starting point of this project is the model presented in section [33.7 of the course's textbook](#). Then, the following steps are presented:

1. Analysis of the textbook's model and possible ways to improve it.
2. Improvement adding user clusters.
3. Tuning improved model.
4. Evaluation against validation dataset.
5. Conclusion.

The subsequent sections present the above points in further detail.

This file and its associated R file are available in [Github](#).

2 Methods and Analysis

2.1 Preparing the data

Before conducting any modelling, the data needs to be cleaned up a little bit, and then split into training and testing set.

In terms of data cleaning, three operations have been considered, namely:

- Remove the year from the title and store it in a different column. This may be useful for modelling.
- For the same reasons, convert the time stamp into a year number.
- Finally, add a sequential number (*row_id*). This will be create a single unique ID for each record (instead of a userId and movieId combination) and maybe useful to speed up filtering, given the large size of the dataset.

To achieve this, the function **Tidy_Up** has been created. The code for this function is available on the included R file. Then, training and test sets are created with the below code:

```
#tidy up data
edx_tidy_temp <- Tidy_Up(edx)

#divide Train and Test datasets
version_number<-as.double(version$minor)/10+as.double(version$major)
if(version_number<3.6){
  set.seed(200)
}else{
  set.seed(200, sample.kind="Rounding")
}

edx_train_test <- Train_Test(edx_tidy_temp)

#remove temporary and original dataset to avoid filling up memory.
rm("edx_tidy_temp","edx")
```

This is a sample of the generated training set (*edx_train_test\$train*):

Table 1: Training Dataset - Sample

userId	movieId	rating	timestamp	title	genres	release_year	rating_date	rating_year	row_id
1	122	5	838985046	Boomerang	Comedy Romance	1992	1996-08-02	1996	1
1	185	5	838983525	Net, The	Action Crime Thriller	1995	1996-08-02	1996	2
1	292	5	838983421	Outbreak	Action Drama Sci-Fi Thriller	1995	1996-08-02	1996	3
1	316	5	838983392	Stargate	Action Adventure Sci-Fi	1994	1996-08-02	1996	4
1	329	5	838983392	Star Trek: Generations	Action Adventure Drama Sci-Fi	1994	1996-08-02	1996	5
1	355	5	838984474	Flintstones, The	Children Comedy Fantasy	1994	1996-08-02	1996	6
1	356	5	838983653	Forrest Gump	Comedy Drama Romance War	1994	1996-08-02	1996	7
1	362	5	838984885	Jungle Book, The	Adventure Children Romance	1994	1996-08-02	1996	8
1	364	5	838983707	Lion King, The	Adventure Animation Children Drama Musical	1994	1996-08-02	1996	9
1	370	5	838984596	Naked Gun 33 1/3: The Final Insult	Action Comedy	1994	1996-08-02	1996	10

2.2 Textbook Model

As a starting point, the model presented in [section 33.7 of the course's textbook](#) will be used. This model estimates rating by assuming that a particular rating can be seen as a combination of the average rating for all movies (the *true* rating) plus movie and user effects (biases). In order to account for cases where movies and users don't have many reviews against them, weighting parameters have been added. All of this can be expressed by the below equation:

$$\text{predicted rating} = \hat{\mu} + b_i + b_u$$

where $\hat{\mu}$ is the average rating for all movies in the dataset, and b_i and b_u are the movie bias and user bias (respectively), both defined as follows:

$$b_i = \frac{1}{\lambda_1 + m} \sum_{j=1}^m (\text{rating}_j - \hat{\mu})$$

$$b_u = \frac{1}{\lambda_2 + n} \sum_{j=1}^n (\text{rating}_j - \hat{\mu} - b_{i,j})$$

where

- rating_j : is a particular movie rating
- m : is the number of all ratings for a particular movie
- n : is the total number of ratings submitted from a particular user (one rating per movie).
- $b_{i,j}$: is the *movie bias* for a particular movie
- λ_1 : is a weighting parameter for *movie biases*.
- λ_2 : is a weighting parameter for *user biases*.

The calculation of these parameters has been written into the function `General_Biases`. To create the first prediction, `lamdba` parameters are set to zero. The results are evaluated using the provided `RMSE` function.

```
# create biases

general_biases <- General_Biases(edx_train_test$train)

# join with dataset and predict

data_set <- edx_train_test$test %>%
  left_join(general_biases$movie_avgs, by = "movieId") %>%
  left_join(general_biases$user_avgs, by = "userId")

first_prediction <- data_set %>%
  mutate(predicted_rating = general_biases$mu_hat +
           b_i + b_u, error = rating - predicted_rating) %>%
  filter(!(predicted_rating == general_biases$mu_hat))
```

```

# Calculate RMSE and put it in comparison table
rmse_value <- RMSE(first_prediction$rating,
                  first_prediction$predicted_rating)
compare_RMSE <- tibble(Model=character(),
                      RMSE = double(),
                      "Below Target"=logical())
compare_RMSE <- add_row(compare_RMSE,
                      Model="Textbook",
                      RMSE=rmse_value,
                      "Below Target"=(rmse_value<target_rmse))

# clean up
general_biases_first <- general_biases
rm(first_prediction,data_set,rmse_value)

```

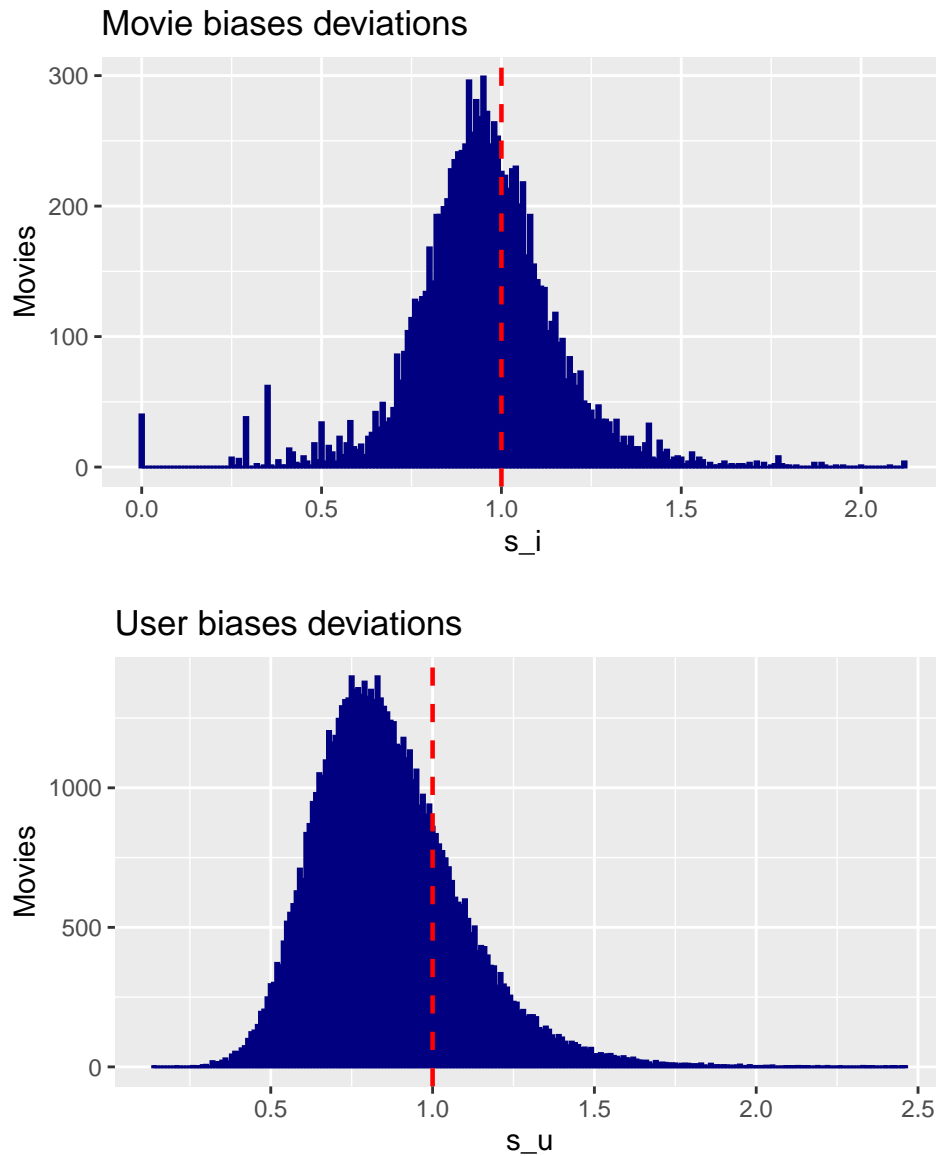
Table 2: First Prediction

Model	RMSE	Below Target
Textbook	0.8663964	FALSE

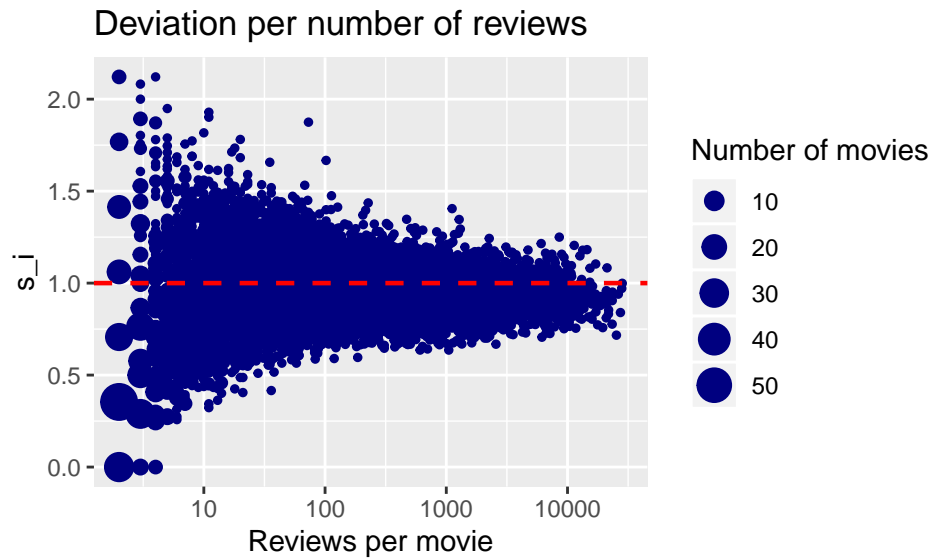
As expected, the RMSE is higher than the target value. After considering the possible causes for this result, part of this may be related to the fact that this model is based on averages: although this is not necessarily a bad approach and works for many cases, it also has some limitations, namely:

- it won't perform well with *divisive* movies. For example a niche film will obtain 5 stars from the fans, but will be many users which will dislike. This won't be reflected by an average bias (and the user bias may not necessarily compensate this).
- There will be users with extreme ratings (i.e. who absolutely like family movies and completely dislike horror films). A user bias average will fail to reflect this situation.
- Already mentioned in the textbook, when the number of reviews for a user or a film is low, this model won't predict accurately.

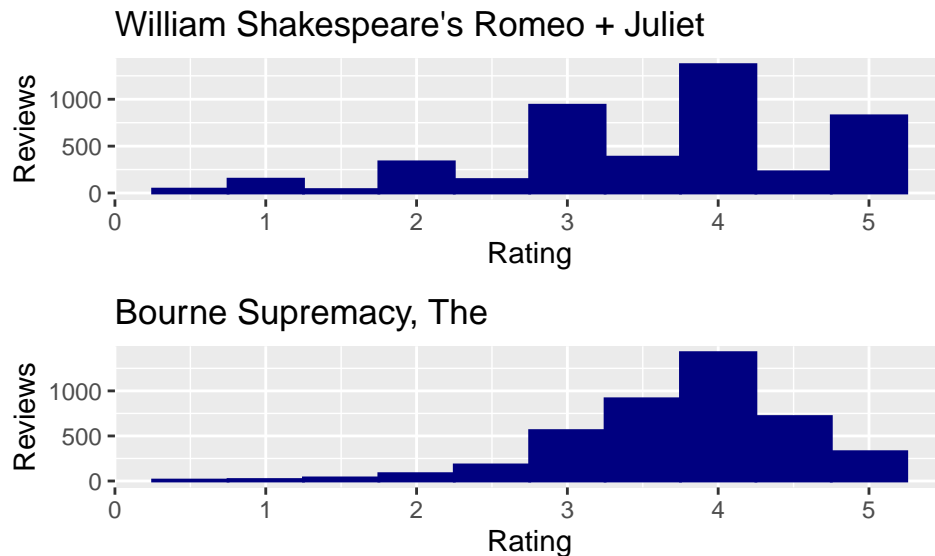
Taking all those points into account, the *General_Biases* function has been implemented to also calculate the standard deviation of the movie and user biases (named s_i and s_u respectively). The below charts show their results:



As shown, there is a significant percentage of movie (37.84 %) and user (24.03 %) biases equal or larger than 1. This means there will be many cases where this model with values contributing to a larger RMSE. Although movies/users with lower number of reviews have higher deviations, this is not always the case, as illustrated in the below graph.



Perhaps, a way to illustrate this is to look at two films with similar number of reviews and average rating (and close b_i) but different standard deviations for their ratings.



Looking at the charts above, it looks like *Romeo+Juliet* has a wider range of opinions, compared to a more concentrated range of ratings in the case of *The Bourne Supremacy*. This means the model won't be as effective for this two films in the cases for the 7 908 users who have rated both films and may be in all sections of liking/disliking this particular combination of films.

2.3 An Improved Model : User Clustering

All the previous observations notwithstanding, it is still worth pointing out that the above model still has merit, given its relative simplicity and ease of calculation.

Perhaps, 8 million reviews is a large number of reviews and it is possible to generate ratings based on smaller groups without loss of accuracy or without invalidating the averages approach. Perhaps, if data is segmented in groups with similar traits, the overall error may decrease.

One way to achieve this is to group the users with similar movie preferences (i.e split the ones who like Shakespearean romances from the fans of action thrillers). In this exercise, the chosen way to undertake this task is to leverage the genres of the already rated films to create distinct user vectors or *profiles*.

As mentioned before, each film has a set of genres they belong (from one to many). Collectively, there are 20 genres, listed below.

Table 3: Genres in training set, ordered by occurrences

genres	n_t
Drama	3 519 116
Comedy	3 187 491
Action	2 303 879
Thriller	2 091 981
Adventure	1 717 390
Romance	1 541 444
Sci-Fi	1 206 991
Crime	1 194 987
Fantasy	833 007
Children	664 073
Horror	622 441
Mystery	511 345
War	460 314
Animation	420 486
Musical	389 793
Western	170 421
Film-Noir	106 798
Documentary	83 754
IMAX	7 357
(no genres listed)	6

In order to profile each user, this report has used the genre property in two ways:

- The average rating each user gives to each genre, for each film rated (i.e. how much each user likes each genre).
- The percentage of each genre compared to the overall reviews per user (i.e. how much each user watches each genre).

This will result in a *user_vector*, for each user in the training set. The algorithm has been written in the *User_Vectoriser* function, available in the project's R file. The below table shows a sample of the user vectors created with this code.

Table 4: User Vectors - Averages

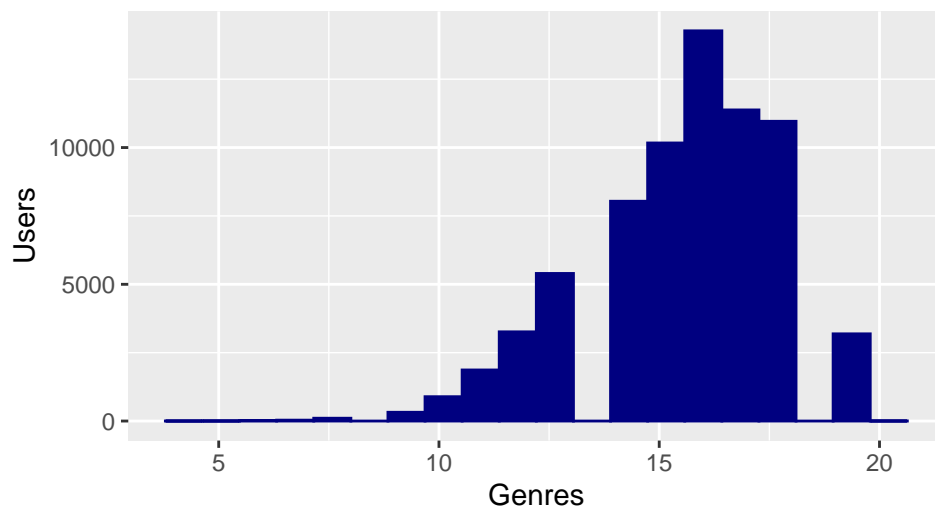
userId	Drama	Comedy	Action	Thriller	Adventure	Romance	Sci-Fi	Crime	Fantasy	Children	Horror	Mystery	War	Animation	Musical	Western	Film-Noir	Documentary	IMAX	(no genres listed)
1	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.000	0.000	5.000	5.000	5.000	0.000	0.000	0	0	0
2	3.250	3.000	3.333	2.833	3.250	2.667	3.600	0.000	3.000	3.000	0.000	2.000	4.000	0.000	3.000	0.000	0.000	0	0	0
3	4.176	3.600	3.857	4.083	3.700	4.150	0.000	4.000	4.167	4.000	0.000	4.500	4.000	4.000	3.000	3.750	4.000	0	0	0
4	4.667	3.846	4.143	4.111	4.778	3.857	4.667	4.200	4.500	5.000	0.000	0.000	5.000	5.000	5.000	5.000	0.000	0	0	0
5	4.098	3.609	1.500	4.091	3.000	3.737	3.000	4.500	3.333	3.333	4.400	4.250	3.800	1.000	4.000	0.000	5.000	0	0	0
6	4.429	3.909	3.731	3.643	3.857	4.333	4.154	3.500	4.000	0.000	1.000	4.000	4.000	3.000	0.000	5.000	4.000	0	0	0
7	4.000	3.479	3.385	3.972	3.733	3.607	3.000	4.214	2.750	3.375	4.000	4.342	5.000	3.333	4.750	3.462	4.367	3	0	0
8	3.409	3.405	3.475	3.491	3.474	3.221	3.522	3.539	3.382	3.243	3.387	3.595	3.543	3.543	3.133	3.000	3.500	4	0	0
9	4.136	4.100	4.500	4.833	3.000	3.875	4.500	4.917	3.500	0.000	0.000	5.000	3.250	0.000	3.500	0.000	5.000	0	0	0
10	3.940	4.053	3.857	3.538	3.400	3.943	5.000	3.500	4.000	3.667	2.500	3.778	4.333	3.000	0.000	4.000	4.000	0	0	0

Table 5: User Vectors - Percentages

userId	Drama	Comedy	Action	Thriller	Adventure	Romance	Sci-Fi	Crime	Fantasy	Children	Horror	Mystery	War	Animation	Musical	Western	Film-Noir	Documentary	IMAX	(no genres listed)
1	0.11321	0.15094	0.15094	0.05660	0.07547	0.07547	0.075472	0.03774	0.037736	0.09434	0.000000	0.000000	0.037736	0.056604	0.037736	0.000000	0.000000	0.000000	0	0
2	0.08333	0.08333	0.25000	0.12500	0.16667	0.06250	0.104167	0.00000	0.020833	0.02083	0.000000	0.020833	0.041667	0.000000	0.020833	0.000000	0.000000	0.000000	0	0
3	0.22368	0.13158	0.09211	0.07895	0.06579	0.13158	0.000000	0.02632	0.039474	0.02632	0.000000	0.039474	0.065789	0.026316	0.013158	0.026316	0.013158	0.000000	0	0
4	0.12903	0.13978	0.15054	0.09677	0.09677	0.07527	0.064516	0.05376	0.043011	0.03226	0.000000	0.000000	0.032258	0.032258	0.032258	0.021505	0.000000	0.000000	0	0
5	0.33333	0.15033	0.02614	0.07190	0.05229	0.12418	0.026144	0.05229	0.019608	0.01961	0.032680	0.026144	0.032680	0.006536	0.019608	0.000000	0.006536	0.000000	0	0
6	0.12500	0.09821	0.23214	0.12500	0.12500	0.05357	0.116071	0.01786	0.044643	0.00000	0.008929	0.008929	0.017857	0.008929	0.000000	0.008929	0.008929	0.000000	0	0
7	0.14103	0.10256	0.05556	0.15385	0.06410	0.05983	0.051282	0.08974	0.008547	0.01709	0.025641	0.081197	0.004274	0.012821	0.008547	0.055556	0.064103	0.0042735	0	0
8	0.10479	0.16056	0.15887	0.12732	0.08789	0.03944	0.078310	0.06535	0.038310	0.01972	0.052394	0.023662	0.012958	0.012958	0.008451	0.005634	0.002813	0.0005634	0	0
9	0.20000	0.18182	0.03636	0.10909	0.03636	0.07273	0.054545	0.10909	0.036364	0.00000	0.000000	0.072727	0.036364	0.000000	0.036364	0.000000	0.018182	0.000000	0	0
10	0.40097	0.09179	0.03382	0.06280	0.02415	0.16908	0.004831	0.06763	0.028986	0.01449	0.009662	0.043478	0.028986	0.004831	0.000000	0.004831	0.009662	0.000000	0	0

The average number of genres per user is 15.559.

Distribution of Number of Genres per User



Using the vectors it is possible to leverage existing clustering algorithms such as k-means (presented in [section 34 of the textbook](#)). However after an initial test other methods were considered and **Gaussian Mixture Model clustering** (GMM) was chosen instead. [This link](#) offers an explanation of this method and the reasons why can be a better way in this particular case. In this exercise, the GMM implementation in **ClusterR** package is used. The code below shows a sample of how GMM is used in this project.

```
#First we need to combine weights and averages, and remove the first columns
user_profiles <- user_vector$user_averages %>%
  left_join(user_vector$user_weights, by = "userId")
us <- user_profiles %>% select(-userId)
```

```

## Then we need to specified the number of clusters
## we want the users to be classified into, eg 5
cluster_n <- 5

###The, we run GMM as per the manual
fit <- GMM(us, cluster_n, dist_mode = "maha_dist",
           seed_mode = "random_subset", km_iter = 10,
           em_iter = 10, verbose = F)

pr <- predict_GMM(us, fit$centroids, fit$covariance_matrices, fit$weights)
user_profiles$group <- pr$cluster_labels

###Show user profiles

user_profiles

```

Before running the above code, it is worth noticing that:

- The combined average and weight vectors have 40 dimensions. In most cases, a vector only has present on subset of those dimensions (in this particular training set, none has). Potentially there are vectors without common touchpoints (action&adventure fans opposite documentaries&film-noir followers).
- Although no analysis has been done for this report, it is reasonable to assume that some genres have a big overlap. Hence, it is reasonable to assume that not all dimensions are *independent variables*.
- Based on the previous numbers, it is also reasonable to assume that a large percentage of users can be group using only a subset of the most popular genres.
- Taking this into account, using all dimensions may not be the best method of clustering - and it is interesting to assess how this impacts the RMSE.
- In addition, the number of clusters - which will certainly have an impact on the RMSE - is an input parameter.

Considering all the points above and after some initial tests, this document proposes a clustering algorithm based on GMM which follows the below steps:

1. User vector is created.
2. The number of genres used for clustering (n) is set.
3. Using the genre percentages, the relative weight of the n most popular genres is calculated.
4. The user vector is filtered to only keep the cases where the previously calculated relative weight meets/exceeds a threshold; This filters out the users for which the selected genres are not relevant.
5. The filtered vector is fed into the GMM functions and users are group into an initial set of clusters.
6. The remaining users are sorted, and filtered by their n most popular genres. Again, they are filtered by the predefined threshold and fit into a new set of clusters.

7. Step 6 repeated as many times as desired or until there are either no users left or there is not enough data to cluster them.
8. All remaining users (if any) and classified in a residual group.

This algorithm has been written into the **User_Classifier** function, available in the R file. It is worth noticing this process has four *arbitrary* parameters that will change the number of resulting clusters and therefore they may have an impact on the RMSE - this will be discussed later in the document.

Once the users have been segmented, it is possible to use the *textbook* model to calculate the average and biases for each of these groups and then predict ratings (the objective of this entire process!). The first part of this step is straightforward (just add the group to the dataset and use this parameter to group prior to summarising) and it has been written into a function called **Group_Biases**.

However, it needs to be considered that potentially some user weren't not grouped into a meaningful cluster and thus this method makes no sense. Additionally, there may be situations where a particular group or movie is absent from the training data and this method is not valid. To cover those situations, the prediction algorithm has two steps:

1. A prediction method using group averages and biases for all qualifying reviews - just like the textbook model but split per group.
2. A *backstop* method for all reviews don't fit the above - for this the 'textbook' method is used.

Please note that both segments have tuning parameters (λ_{1-4}).

This prediction algorithm has been written into a function called **Rating_Predictor**.

2.4 Tuning Step 1 - Optimise Clustering.

The first optimisation step consists in finding the optimal clustering parameters to minimise the RMSE. These parameters are:

1. the number of genres (*genres*) to consider in each clustering round.
2. the number of target clusters per round (*cluster_n*).
3. the cut-off value to filter the users for each clustering round (*cut-off*).
4. the number of times clustering will be attempted (*iterations*).

This process has been executed through the below code.

```
#create tibble to record stats

stats <- tibble(clustering=character(),iterations=double(),cutoff=double(),
               genres=double(),cluster_n=double(),RMSE = double(),
               RMSE_1 = double(),RMSE_2 = double(),
               RMSE_3 = double(),
               method_1=double(),method_2=double(),
```

```

        method_3=double())

#define ranges to iterate

genres_n<-3:6
cluster_n <- 3:6
cutoff <- c(0.4,0.5,0.6)
iterations <-2:4

#iterate predictions
for(g in iterations){
  for(h in cutoff){
    for (i in genres_n){
      for(j in cluster_n){

        #create groups, biases and predict

        user_classification <- User_Classifier(edx_train_test$train,
                                                user_vector,
                                                genres=i,
                                                step_cutoff=h,
                                                cluster_n=j,
                                                cluster_type="GMM",
                                                iterations=g)

        biases_by_group <- Group_Biases(edx_train_test$train,
                                         user_classification)

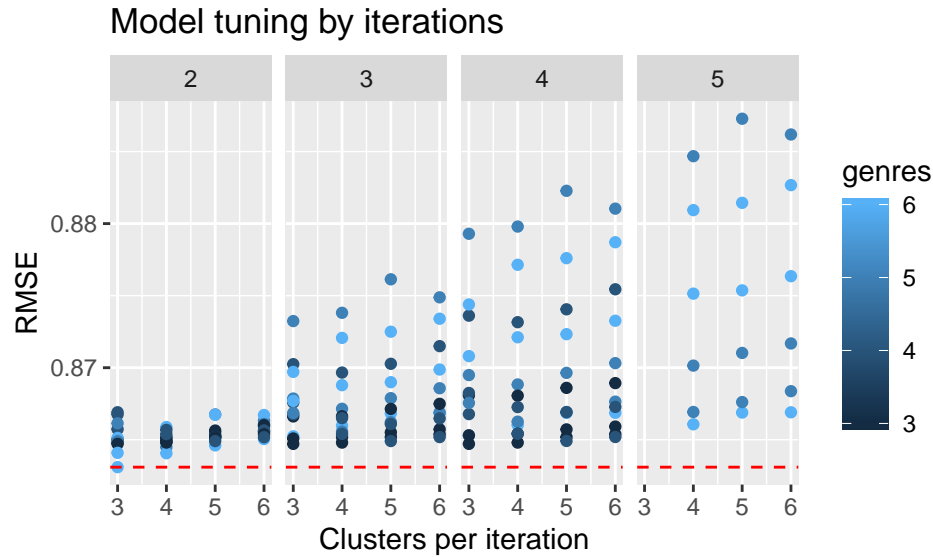
        results<-Rating_Predictor(edx_train_test$test,user_classification,
                                   biases_by_group,general_biases)

        # store results in stats tibble
        stats <- add_row(stats,clustering="GMM",iterations=g,
                          cutoff=h,genres=i,cluster_n=j,
                          RMSE = results$RMSE$overall,
                          RMSE_1=results$RMSE$`1`,RMSE_2=results$RMSE$`2`,
                          RMSE_3=results$RMSE$`3`,
                          method_1=results$distribution_percentage$`1`,
                          method_2=results$distribution_percentage$`2`,
                          method_3=results$distribution_percentage$`3`)
      }
    }
  }
}
#cleanup
clustering_stats <- stats

```

```
rm(g,h,i,j,results,stats)
```

This code generates the results represented in the below chart.



The optimal solution has the below parameters, (also displaying the resulting overall RMSE plus the RMSE for the clustered (RMSE_1) and non-clusters (RMSE_2) groups, along with the proportion of reviews in each method).

Table 6: Optimal Clustering Parameters

clustering	iterations	cutoff	genres	cluster_n	RMSE	RMSE_1	RMSE_2	method_1	method_2	method_3
GMM	2	0.5	6	3	0.8630969	0.8629808	1.050733	0.9994422	0.0005578	0

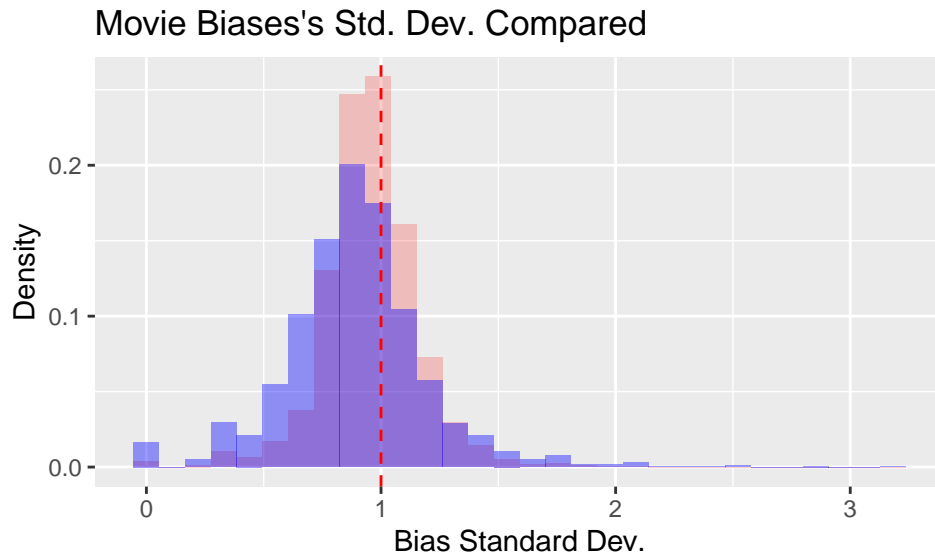
When compared with the *textbook* method, this procedure clearly a better RMSE:

Table 7: First and Second Predictions

Model	RMSE	Below Target
Textbook	0.8663964	FALSE
Optimal Clusters	0.8630969	TRUE

What are reasons this method has a better performance? Some explanations are:

- There are different averages for different groups, having more accurate stating points.
- Grouping provides movie biases with smaller deviations, contributing to a smaller RMSE. In this case, 69.035 % of the deviations are lower than 1, compared to 62.161 % for the *textbook* case. This can be visualised in the below chart:



This solution splits the training set into 6 groups of users, with the below characteristics:

Table 8: Optimal User Groups

group	users	movies	top_movies
0	6 140	10 450	Jurassic Park Pulp Fiction Shawshank Redemption, The Silence of the Lambs, The Star Wars: Episode IV - A New Hope (a.k.a. Star Wars)
1	9 287	9 649	Matrix, The Pulp Fiction Shawshank Redemption, The Silence of the Lambs, The Star Wars: Episode IV - A New Hope (a.k.a. Star Wars)
2	7 944	9 768	Fargo Pulp Fiction Schindler's List Shawshank Redemption, The Silence of the Lambs, The
200	9 622	8 903	Forrest Gump Four Weddings and a Funeral Pretty Woman Pulp Fiction Sleepless in Seattle
201	15 308	9 921	Batman Forrest Gump Jurassic Park Pulp Fiction True Lies
202	21 577	9 327	Forrest Gump Fugitive, The Jurassic Park Terminator 2: Judgment Day True Lies

Looking at this and the compared deviation histogram's, it looks like there are groups that maybe are similar. Although left out of scope for this report, perhaps exploring better clustering mechanisms will deliver significantly improved results.

2.5 Tuning Step 2: λ parameters

Having settled on a set of optimal clustering parameters, there is still room to attempt improving the RMSE by tuning the λ parameters in the movie and user bias equations:

$$b_i = \frac{1}{\lambda_1 + m} \sum_{j=1}^m (rating_j - \hat{\mu})$$

$$b_u = \frac{1}{\lambda_2 + n} \sum_{j=1}^n (rating_j - \hat{\mu} - b_{i,j})$$

In the proposed model, there are four lambda parameters: two for the clustering biases (from now on, λ_1 and λ_2) and two for the backstop model (λ_3 and λ_4). Given that the previous result shows that over 99% of the dataset fit in the cluster method, at this stage no tuning of (λ_3 and λ_4) will be done.

Additionally, it would be good to see how much the RMSE varies due to being a random variable, in order to have a level of confidence how well the method will perform against the validation set. To address this, k-fold cross validation will be conducted.

However, there is one problem: there are three variables to tune and each iteration requires data partition, user clustering, calculating biases and predictions. As per the experience from the previous optimisation step, it is safe to assume this will take **several** hours to complete. To alleviate this tuning will proceed the following way:

1. First, we will run iterations to run λ_1 and λ_2 .
2. From this first set, we will choose the twenty combinations with the lowest RMSE.
3. Then, we will run k-fold validation for those twenty combinations.
4. Finally, the optimal set of λ_1 and λ_2 will be chosen picking the lowest average RMSE (from all k iterations).

The first iteration will be implemented with the below code:

```
stats <- tibble(k=double(),lambda_1=double(),lambda_2=double(),
               RMSE = double(),RMSE_1 = double(),RMSE_2 = double(),
               RMSE_3 =double(),
               method_1=double(),method_2=double(),method_3=double())

lambda_1 <- seq(0,8,0.5)
lambda_2 <- seq(0,8,0.5)

for(k in 1:1){

  edx_cross_validation <- Train_Test(edx_train_test$train)

  user_vector <-User_Vectoriser(edx_cross_validation$train)
  general_biases <- General_Biases(edx_cross_validation$train)
```

```

user_classification <- User_Classifier(edx_cross_validation$train,
                                       user_vector,
                                       genres=genres,
                                       step_cutoff=step_cutoff,
                                       cluster_n=cluster_n,
                                       cluster_type=cluster_type,
                                       iterations=clustering_iterations)

for (i in lambda_1){
  for(j in lambda_2){

    biases_by_group<-Group_Biases(edx_cross_validation$train,
                                   user_classification,
                                   lambda_1=i,lambda_2=j)

    results<-Rating_Predictor(edx_cross_validation$test,
                              user_classification,
                              biases_by_group,general_biases)

    stats <- add_row(stats, k=k, lambda_1=i,lambda_2=j,
                      RMSE = results$RMSE$overall,
                      RMSE_1=results$RMSE$`1`,
                      RMSE_2=results$RMSE$`2`,
                      RMSE_3=results$RMSE$`3`,
                      method_1=results$distribution_percentage$`1`,
                      method_2=results$distribution_percentage$`2`,
                      method_3=results$distribution_percentage$`3`)
  }
}

rm(edx_cross_validation)
}

group_lambda_stats_1 <- stats
rm(i,j,k)

```

The 20 lowest RMSE combinations are presented in the below table:

Table 9: Lambda Optimisation - Step 1

lambda_1	lambda_2	RMSE	RMSE_1	RMSE_2	method_1	method_2
2.0	4.0	0.8618505	0.8616856	1.096348	0.9993815	0.0006185
2.0	4.5	0.8618516	0.8616867	1.096348	0.9993815	0.0006185
2.0	3.5	0.8618548	0.8616900	1.096348	0.9993815	0.0006185
2.5	4.0	0.8618559	0.8616910	1.096348	0.9993815	0.0006185
2.5	4.5	0.8618569	0.8616920	1.096348	0.9993815	0.0006185
2.0	5.0	0.8618576	0.8616927	1.096348	0.9993815	0.0006185
2.5	3.5	0.8618604	0.8616955	1.096348	0.9993815	0.0006185
2.5	5.0	0.8618627	0.8616978	1.096348	0.9993815	0.0006185
2.0	3.0	0.8618652	0.8617004	1.096348	0.9993815	0.0006185
2.0	5.5	0.8618680	0.8617031	1.096348	0.9993815	0.0006185
2.5	3.0	0.8618710	0.8617061	1.096348	0.9993815	0.0006185
2.5	5.5	0.8618729	0.8617081	1.096348	0.9993815	0.0006185
2.0	6.0	0.8618824	0.8617175	1.096348	0.9993815	0.0006185
2.0	2.5	0.8618824	0.8617176	1.096348	0.9993815	0.0006185
2.5	6.0	0.8618872	0.8617223	1.096348	0.9993815	0.0006185
2.5	2.5	0.8618883	0.8617235	1.096348	0.9993815	0.0006185
1.5	4.0	0.8618892	0.8617243	1.096348	0.9993815	0.0006185
3.0	4.0	0.8618899	0.8617250	1.096348	0.9993815	0.0006185
1.5	4.5	0.8618905	0.8617256	1.096348	0.9993815	0.0006185
3.0	4.5	0.8618906	0.8617258	1.096348	0.9993815	0.0006185

Then, using a modified version of the previous code, 5 more iterations of those 20 sets of *lambdas* are generated and average RMSEs are calculated. The best five results are presented in the below table.

Table 10: Lambda Optimisation - Step 2

lambda_1	lambda_2	Avg_RMSE
2.0	4.5	0.8623377
2.0	4.0	0.8623385
2.5	4.5	0.8623390
2.5	4.0	0.8623400
2.0	5.0	0.8623419

Using these parameters, the model is retrained using the whole training set and RMSE is calculated against the test set for comparison with the previous two cases.

Table 11: Result with Optimal Lambdas on Test Set

lambda_1	lambda_2	RMSE	RMSE_1	RMSE_2	method_1	method_2
2	4.5	0.8619723	0.8618554	1.050733	0.9994422	0.0005578

Table 12: All Training Predictions Compared

Model	RMSE	Below Target
Textbook	0.8663964	FALSE
Optimal Clusters	0.8630969	TRUE
Optimal Clusters + Optimised Lambdas	0.8619723	TRUE

2.6 Checks prior to prediction

Before moving to assess the model against the validation set, there are two points to look at. The first point (as mentioned before) is the RMSE variance when k-fold validation was done. Taking the 5 best results, it is possible to build the below box plot, which shows all combinations well below the RMSE threshold.

The second inspection is to have a look at the films that couldn't be rated by the clustering mechanism. The below table shows the top 20 films in that category. After reviewing this list, those films seem to be mostly obscure and thus seems reasonable that couldn't be found in the clustering movie biases. Even if the user is not new, this result would be expected for rare films.

Table 13: Non Clusterable Reviews - Movies

title	n
Dying of Laughter (Muertos de risa)	4
Bitter Sugar (Azúcar amarga)	3
Evil Aliens	3
Reflections In A Golden Eye	3
All Night Long	2
Anna	2
As in Heaven (Så som i Himmelen)	2
Baby Doll	2
Battle for Haditha	2
Biker Boyz	2
Bordertown	2
Burning, The	2
Comandante	2
Dakota	2
DarkBlueAlmostBlack (Azuloscurocasinegro)	2
Demonlover	2
Fathom	2
Free Zone	2
Grisbi (Touchez pas au grisbi)	2
Happily Ever After	2

3 Results

With all optimised parameters, it is time now to try to predict the ratings for the validation set. This has been done in two parts:

- First, the model has been re-trained using all optimal parameters and the whole combined training+test dataset.
- Then, the model will be used to predict the ratings for the validation set and the RMSE will be calculated.

The code to achieve this is presented below.

```
# Prediction against validation dataset

##re-join training test tests
edx <- rbind(edx_train_test$train,edx_train_test$test)

### Retrain : reclustering and re-calculation of biases with new dataset
```

```

user_vector_prediction <- User_Vectoriser(edx)
general_biases_prediction <- General_Biases(edx)
user_classification_prediction <- User_Classifier(edx,user_vector_prediction,
                                                    genres=genres,
                                                    step_cutoff=step_cutoff,
                                                    cluster_n=cluster_n,
                                                    cluster_type=cluster_type,
                                                    iterations=clustering_iterations)
biases_by_group_prediction <- Group_Biases(edx,
                                             user_classification_prediction,
                                             lambda_1=lambda_1,
                                             lambda_2=lambda_2)

### tidy up validation table

validation<-Tidy_Up(validation)

# Predict ratings

prediction <- Rating_Predicter(validation,
                                user_classification_prediction,
                                biases_by_group_prediction,
                                general_biases_prediction)

##Calculate method split and RMSE

stats <- tibble(RMSE = double(),RMSE_1 = double(),
                RMSE_2 = double(),
                method_1=double(),method_2=double())

stats <- tibble(RMSE = prediction$RMSE$overall,
                RMSE_1=prediction$RMSE$`1`,
                RMSE_2=prediction$RMSE$`2`,
                method_1=prediction$distribution_percentage$`1`,
                method_2=prediction$distribution_percentage$`2`)
prediction_stats <-stats

rm("stats")

```

The RMSE results are shown in the following table:

Table 14: RMSE for validation set

RMSE	RMSE_1	RMSE_2	method_1	method_2
0.8613139	0.8611952	1.083573	0.999527	0.000473

In terms of meeting the RMSE requirements, this model has met the objective. However, as mentioned and hinted through this report, the following limitations have been discovered:

- First, the time required to fit and tune the model is considerable. On a laptop, this can take up a day or more, which makes the whole process slow to run and even slower if it requires multiple test and repetitions to find the optimal results.
- Second, the issues regarding user variability have not been addressed (e.g. big variance of rating for one user). This is an area of improvement that perhaps will further improve the model.

Having said that, this model is still relative simple and fast for predictions, which is a big advantage - future work may still want to leverage this feature, through further modifications or combination with other methods.

4 Conclusion

In conclusion, this report contains the development of a recommendation system, based on the one presented in the course's textbook. From this starting point, the model was improved by segmenting users into groups. Through this re-fitting and further tuning, a RMSE of 0.86197 was obtained. This results exceeds the goal of achieving a value lower than 0.86490.

As mentioned in the previous sections, despite its simplicity the resulting model is time-intensive when it comes to fitting. This is mainly due to the clustering process, which potentially requires multiple iterations. Although it provides an improvement to the previous model, there are still many individual cases where the error is greater than acceptable to provide a reliable prediction of whether a user will like or dislike a particular movie.

Of course, this model can be improved if further work is undertaken, namely:

- Assess if λ parameters per user cluster/movie improve the results vs. the extra time it will take to fit the model.
- Cluster films by common characteristics (genre but also perhaps actor,director, etc.) and see if it is worth to use that to provide more accurate user biases.
- Explore other clustering methods, assessing both changes in RMSE and fitting effort.

In addition to the above, but perhaps out of scope in the context of this exercise (due to the way the validation set is created), it would be interesting to explore if there is an optimal dataset size. For instance, if we consider the that user cinematic preferences change over time, perhaps the oldest reviews are not as important as the ones from last year. Therefore, this opens the opportunity to treat the biases as function of time, or simply discard older reviews and have a leaner dataset resulting in faster processing times without a significant loss of accuracy.