

Movie Recommendation System in R

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07/11/2019

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Chapter 1

Introduction/Overview/Executive Summary

This section describes the dataset and summarizes the goal of the project and key steps that were performed.

Recommender systems plays an important role in e-commerce and online streaming services, such as Netflix, YouTube and Amazon. Making the right recommendation for the next product, music or movie increases user retention and satisfaction, leading to sales and profit growth. Companies competing for customer loyalty invest on systems that capture and analyses the user's preferences, and offer products or services with higher likelihood of purchase.

The economic impact of such company-customer relationship is clear: Amazon is the largest online retail company by sales and part of its success comes from the recommendation system and marketing based on user preferences. In 2006 Netflix offered a one million prize¹ for the person or group that could improve their recommender system by at least 10%.

Usually, recommendation systems are based on a rating scale from 1 to 5, with 1 indicating the user dislikes product or item and 5 the user likes the most. Other indicators can also be used, such as comments posted on previously used items; video, music or link shared with friends; percentage of movie watched or music listened; web pages visited and time spent on each page; product category; and any other interaction with the company's web site or app can be used as a predictor.

The primary goal of recommender systems is to help users find what they want based on their preferences and previous interactions, and predicting the rating for a new item. In this document, we create a recommendation system using the MovieLens dataset.

1.1 MovieLens Dataset

GroupLens is a research lab in the University of Minesota that has collected and mad available rating data for movies in the MovieLens [web site](#).

¹<https://www.netflixprize.com/>

The complete MovieLens [dataset](#) consists of 27 million ratings of 58,000 movies by 280,000 users, which is too large for research and testing purposes. So, the research presented in this paper is based in a [subset](#) of this dataset with 10 million ratings on 10,000 movies by 72,000 users.

1.2 Evaluation of Predicted Ratings

A typical method to evaluate the predicted ratings is to measure the deviation from the true rating, which is called the *Mean Average Error (MAE)*:

$$MAE = \frac{1}{N} \sum_{i=1}^N |\hat{y}_i - y_i|$$

Another method is the *Root Mean Squared Error (RMSE)*.

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (\hat{y}_i - y_i)^2}$$

The advantage of RMSE over MAE is that it penalizes large deviations from the mean, and is more appropriate in cases that small errors is not relevant.

-
- Describe the dataset,
 - summarizes the goal of the project
 - key steps that were performed.
-

1.3 # Methods/Analysis

This section explains the process and techniques used, - such as data cleaning, - data exploration and visualization, - any insights gained, - and your modeling approach —————

1.4 Data Preparation

The dataset

```
if(!require(tidyverse)) install.packages("tidyverse", repos = "http://cran.us.r-project.org")
if(!require(caret)) install.packages("caret", repos = "http://cran.us.r-project.org")
if(!require(data.table)) install.packages("data.table", repos = "http://cran.us.r-project.org")

# MovieLens 10M dataset:
# https://grouplens.org/datasets/movielens/10m/
```

```

# http://files.grouplens.org/datasets/movielens/ml-10m.zip

dl <- tempfile()
download.file("http://files.grouplens.org/datasets/movielens/ml-10m.zip", dl)

ratings <- fread(text = gsub("::", "\t", readLines(unzip(dl, "ml-10M100K/ratings.dat"))),
  col.names = c("userId", "movieId", "rating", "timestamp"))

movies <- str_split_fixed(readLines(unzip(dl, "ml-10M100K/movies.dat")), "\\::", 3)
colnames(movies) <- c("movieId", "title", "genres")
movies <- as.data.frame(movies) %>% mutate(movieId = as.numeric(levels(movieId))[movieId],
  title = as.character(title),
  genres = as.character(genres))

movielens <- left_join(ratings, movies, by = "movieId")

# 'Validation' set will be 10% of MovieLens data

set.seed(1, sample.kind="Rounding")
test_index <- createDataPartition(y = movielens$rating, times = 1, p = 0.1, list = FALSE)
edx <- movielens[-test_index,]
temp <- movielens[test_index,]

# Make sure userId and movieId in 'validation' set are also in 'edx' set

validation <- temp %>%
  semi_join(edx, by = "movieId") %>%
  semi_join(edx, by = "userId")

# Add rows removed from 'validation' set back into 'edx' set

removed <- anti_join(temp, validation)
edx <- rbind(edx, removed)

rm(dl, ratings, movies, test_index, temp, movielens, removed)

```

The *edx* set is used for training and testing, and the *validation* set is used for final validation to simulate the new data. Here, we split the *edx* set in 2 parts: the training set and the test set. The model building is done in the training set, and the test set is used to test the model. When the model is complete, we use the *validation* set to calculate the final RMSE. We use the same procedure used to create *edx* and *validation* sets.

The training set will be 90% of *edx* data and the test set will be the remaining 10%.

```

set.seed(1, sample.kind="Rounding")
test_index <- createDataPartition(y = edx$rating, times = 1, p = 0.1, list = FALSE)
train_set <- edx[-test_index,]
temp <- edx[test_index,]

# Make sure userId and movieId in test set are also in train set

test_set <- temp %>%
  semi_join(train_set, by = "movieId") %>%
  semi_join(train_set, by = "userId")

# Add rows removed from test set back into train set

removed <- anti_join(temp, test_set)
train_set <- rbind(train_set, removed)

rm(test_index, temp, removed)

```

1.5 Data Exploration

Before start building the model, we need to understand the structure of the data, the distribution of ratings and the relationship of the predictors.

This information will help to build a better model.

```
str(edx)
```

```

## 'data.frame':    9000055 obs. of  6 variables:
## $ userId      : int   1 1 1 1 1 1 1 1 1 1 ...
## $ movieId     : num   122 185 292 316 329 355 356 362 364 370 ...
## $ rating      : num    5 5 5 5 5 5 5 5 5 5 ...
## $ timestamp: int   838985046 838983525 838983421 838983392 838983392 838984474 838983653 8389848...
## $ title       : chr    "Boomerang (1992)" "Net, The (1995)" "Outbreak (1995)" "Stargate (1994)" ...
## $ genres      : chr    "Comedy|Romance" "Action|Crime|Thriller" "Action|Drama|Sci-Fi|Thriller" "Actio

```

From this initial exploration, we discover that *edx* has 6 columns: movieId: integer userId : integer rating: numeric timestamp: numeric title: character genres: character

How many rows and columns are there in the *edx* dataset?

```
dim(edx)
```

```
## [1] 9000055      6
```

Check the structure and content of *edx* dataset

```
head(edx)
```

	userId	movieId	rating	timestamp	title	genres
1	1	122	5	838985046	Boomerang (1992)	Comedy Romance
2	1	185	5	838983525	Net, The (1995)	Action Crime Thriller
4	1	292	5	838983421	Outbreak (1995)	Action Drama Sci-Fi Thriller
5	1	316	5	838983392	Stargate (1994)	Action Adventure Sci-Fi
6	1	329	5	838983392	Star Trek: Generations (1994)	Action Adventure Drama Sci-Fi
7	1	355	5	838984474	Flintstones, The (1994)	Children Comedy Fantasy

The dataset is in tidy format, i.e. each row has one observation and the column names are the features. The *rating* column is the desired outcome. The user information is stored in *userId*; the movie information is both in *movieId* and *title* columns. The rating date is available in *timestamp* measured in seconds since January 1st, 1970. Each movie is tagged with one or more genre in the *genres* column.

The next sections get more details about each feature and outcome. ### Genres Along with the movie title, MovieLens provides the list of genres for each movie. Although this information can be used to make better predictions, this research doesn't use it. However it's worth exploring this information as well.

How many different combinations of genres?

```
length(unique(edx$genres))
```

```
## [1] 797
```

List the first 6 genres.

```
edx %>% group_by(genres) %>%  
  summarise(n=n()) %>%  
  head()
```

genres	n
(no genres listed)	7
Action	24482
Action Adventure	68688
Action Adventure Animation Children Comedy	7467
Action Adventure Animation Children Comedy Fantasy	187
Action Adventure Animation Children Comedy IMAX	66

The table above shows that several movies are classified in more than one genre. The number of genres in each movie is listed in this table, sorted in descend order.

```
tibble(count = str_count(edx$genres, fixed("|")), genres = edx$genres) %>%
  group_by(count, genres) %>%
  summarise(n = n()) %>%
  arrange(-count) %>%
  head()
```

count	genres	n
7	Action Adventure Comedy Drama Fantasy Horror Sci-Fi Thriller	256
6	Adventure Animation Children Comedy Crime Fantasy Mystery	10975
6	Adventure Animation Children Comedy Drama Fantasy Mystery	355
6	Adventure Animation Children Comedy Fantasy Musical Romance	515
5	Action Adventure Animation Children Comedy Fantasy	187
5	Action Adventure Animation Children Comedy IMAX	66

1.5.1 Date

The rating period was collected over almost 14 years.

```
library(lubridate)
```

```
##
## Attaching package: 'lubridate'

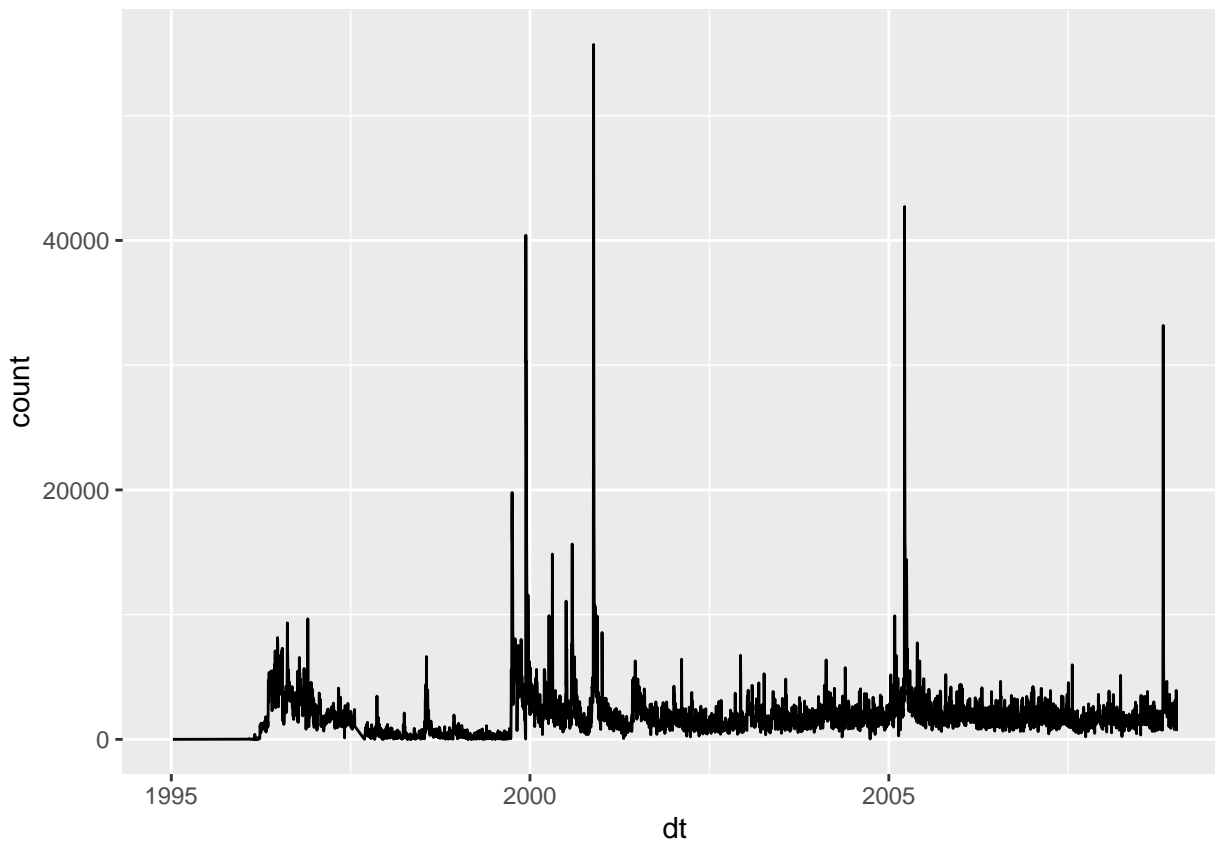
## The following objects are masked from 'package:data.table':
##
##   hour, isoweek, mday, minute, month, quarter, second, wday,
##   week, yday, year

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

```
tibble(`Initial Date` = date(as_datetime(min(edx$timestamp), origin="1970-01-01")),
       `Final Date`   = date(as_datetime(max(edx$timestamp), origin="1970-01-01"))) %>%
  mutate(Period = duration(max(edx$timestamp)-min(edx$timestamp)))
```


Initial Date	Final Date	Period
1995-01-09	2009-01-05	441479727s (~13.99 years)

```
edx %>% mutate(dt = date(as_datetime(timestamp, origin="1970-01-01"))) %>%
  group_by(dt) %>%
  summarise(count = n()) %>%
  ggplot(aes(x = dt, y = count, xlab = "Date")) +
  geom_line()
```



The following table lists the days with more ratings. Not surprisnly, the movies are

```
edx %>% mutate(date = date(as_datetime(timestamp, origin="1970-01-01"))) %>%
  group_by(date, title) %>%
  summarise(count = n()) %>%
  arrange(-count) %>%
  head(10)
```

date	title	count
1998-05-22	Chasing Amy (1997)	322
2000-11-20	American Beauty (1999)	277
1999-12-11	Star Wars: Episode IV - A New Hope (a.k.a. Star Wars) (1977)	254
1999-12-11	Star Wars: Episode V - The Empire Strikes Back (1980)	251
1999-12-11	Star Wars: Episode VI - Return of the Jedi (1983)	241
2005-03-22	Lord of the Rings: The Two Towers, The (2002)	239
2005-03-22	Lord of the Rings: The Fellowship of the Ring, The (2001)	227
2000-11-20	Terminator 2: Judgment Day (1991)	221
1999-12-11	Matrix, The (1999)	210
2000-11-20	Jurassic Park (1993)	201

1.5.2 Ratings

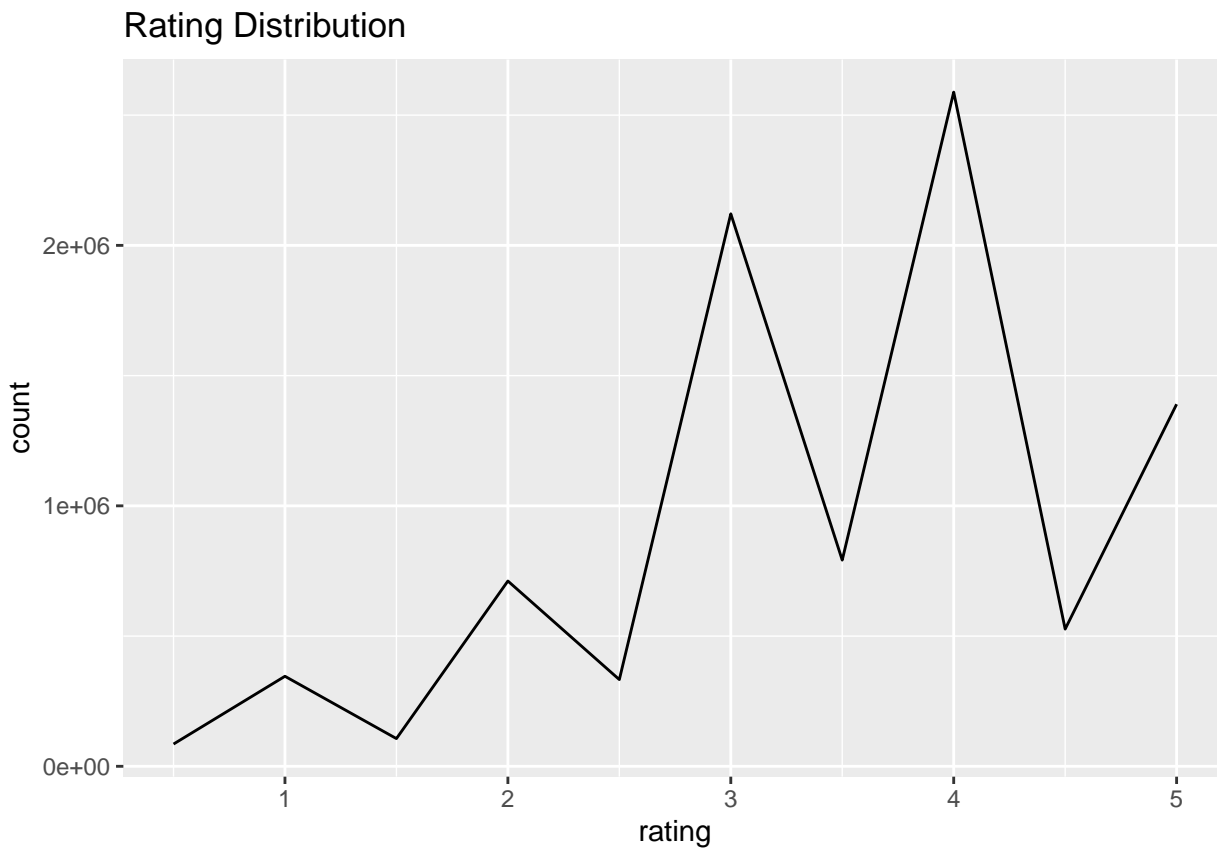
The MovieLens give users the option to choose a rating value from 0.5 to 5.0, totaling 10 possible values. This is unusual scale, so most movies get a rounded value rating, as shown in the chart below. Count the number of each ratings:

```
edx %>% group_by(rating) %>% summarize(n=n())
```

rating	n
0.5	85374
1.0	345679
1.5	106426
2.0	711422
2.5	333010
3.0	2121240
3.5	791624
4.0	2588430
4.5	526736
5.0	1390114

How many ratings are in *edx*?

```
edx %>% group_by(rating) %>%
  summarise(count=n()) %>%
  ggplot(aes(x=rating, y=count)) +
  geom_line() +
  ggtitle("Rating Distribution")
```



1.5.3 Movies

How many different movies are in the 'edx' set?

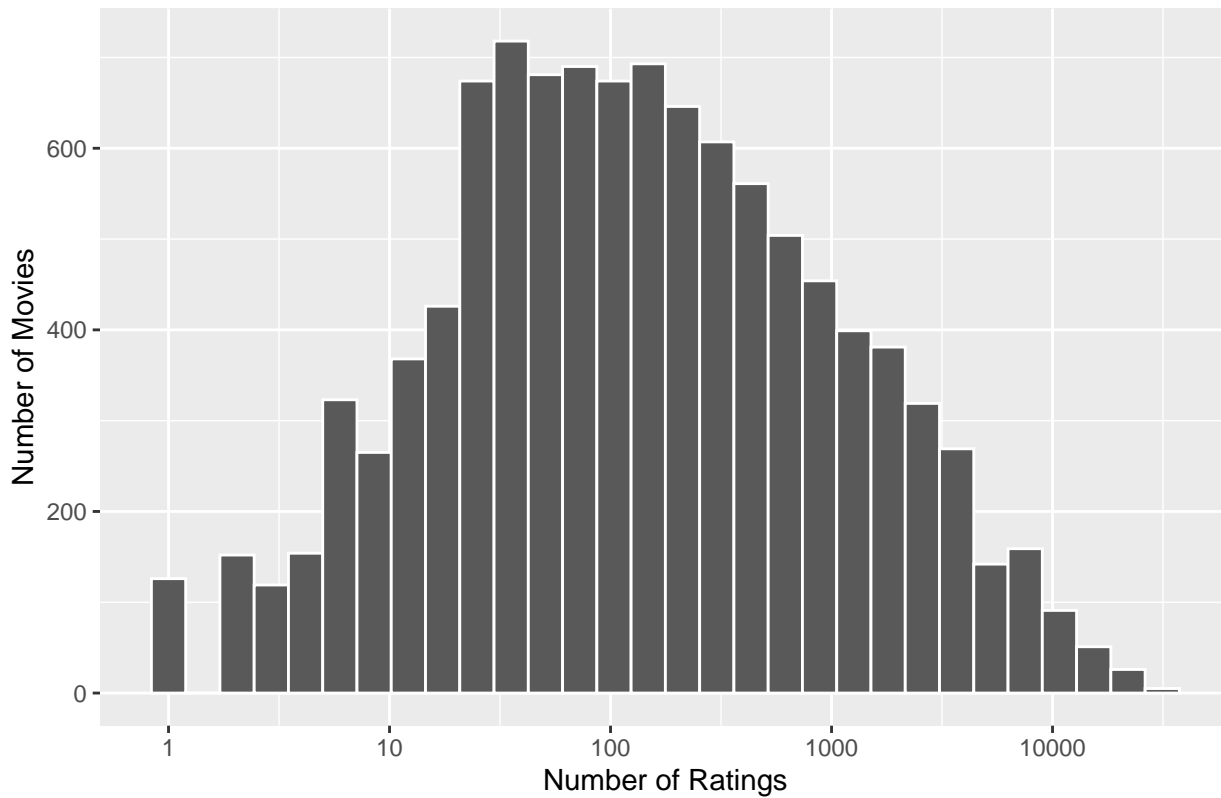
```
length(unique(edx$movieId))
```

```
## [1] 10677
```

We know from intuition that some movies are rated more than others, since many movies are watched by few users and blockbusters tend to have more ratings.

```
edx %>% group_by(movieId) %>%  
  summarise(n=n()) %>%  
  ggplot(aes(n)) +  
  geom_histogram(bin = 30, color = "white") +  
  scale_x_log10() +  
  ggtitle("Distribution of Movies") +  
  xlab("Number of Ratings") +  
  ylab("Number of Movies")
```

Distribution of Movies



1.5.4 Users

How many different users are in the *edx* set?

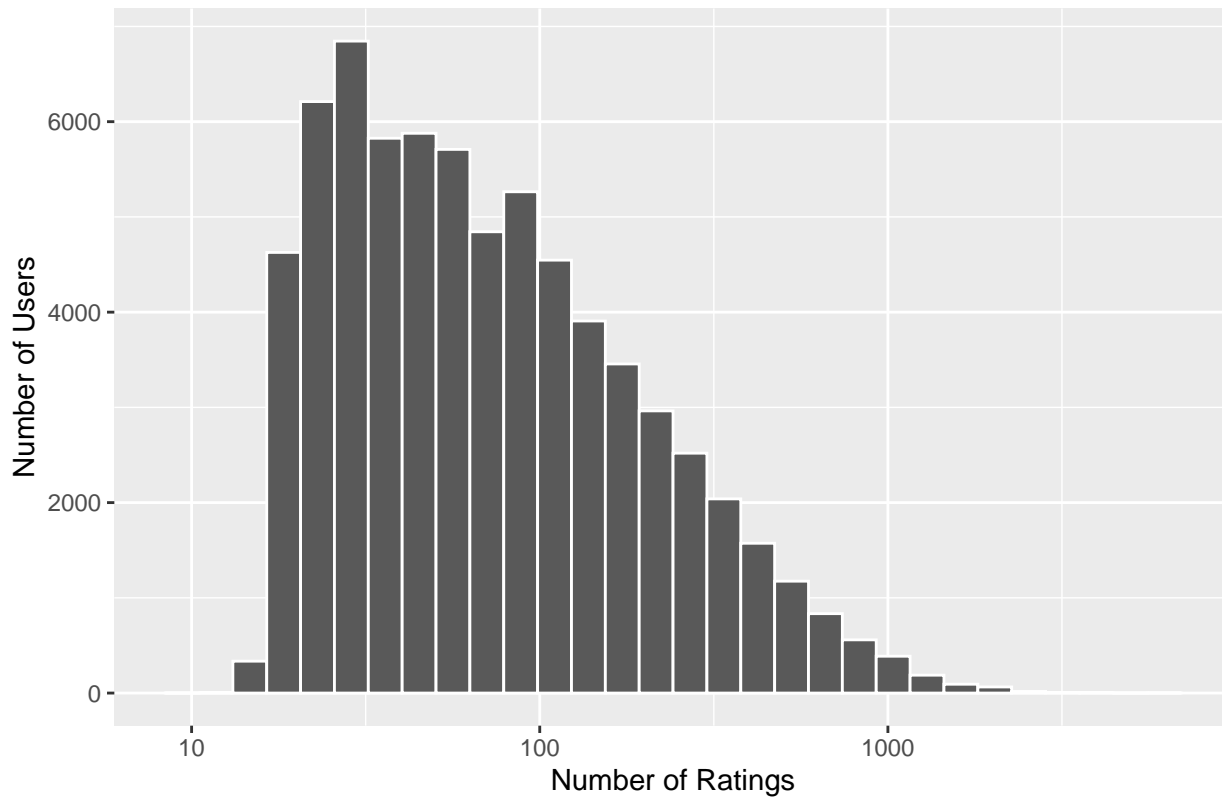
```
length(unique(edx$userId))
```

```
## [1] 69878
```

The majority of users rate few movies, while a few users rate more than a thousand movies.

```
edx %>% group_by(userId) %>%
  summarise(n=n()) %>%
  ggplot(aes(n)) +
  geom_histogram(bin = 30, color = "white") +
  scale_x_log10() +
  ggtitle("Distribution of Users") +
  xlab("Number of Ratings") +
  ylab("Number of Users")
```

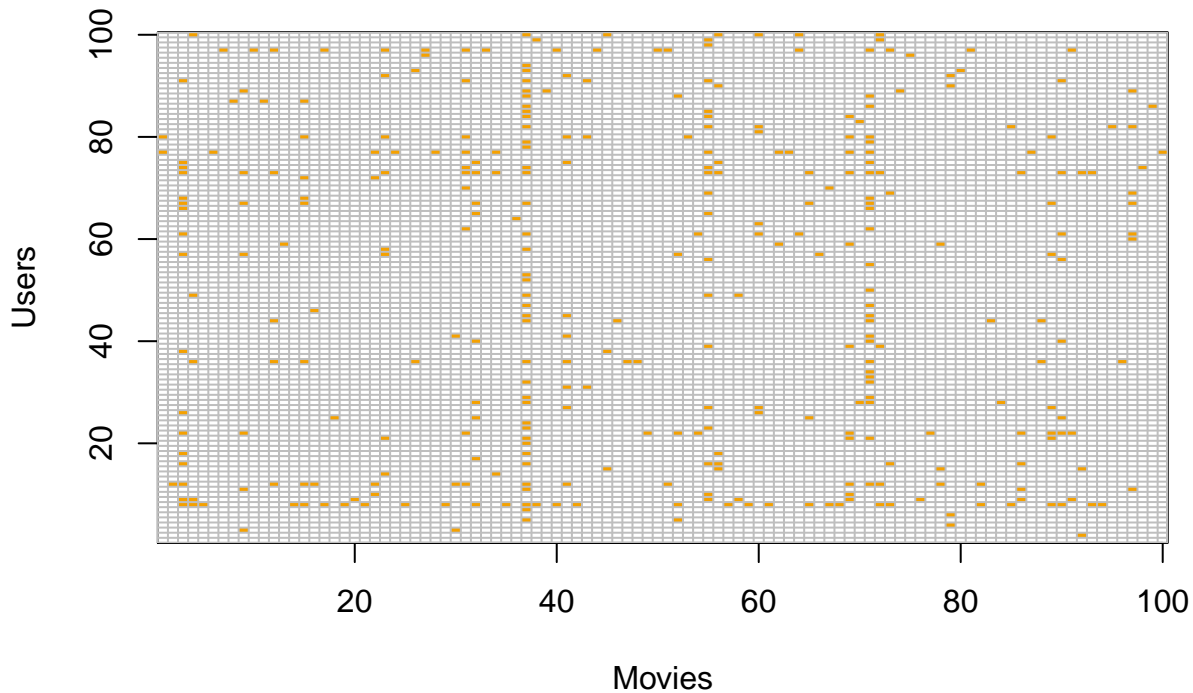
Distribution of Users



Show the heatmap of users x movies The distribution of u

```
users <- sample(unique(edx$userId), 100)
edx %>% filter(userId %in% users) %>%
  select(userId, movieId, rating) %>%
  mutate(rating = 1) %>%
  spread(movieId, rating) %>%
  select(sample(ncol(.), 100)) %>%
  as.matrix() %>% t(.) %>%
  image(1:100, 1:100, ., xlab="Movies", ylab="Users")
abline(h=0:100+0.5, v=0:100+0.5, col = "grey")
title("Rating distribution")
```

Rating distribution



1.6 Data Cleaning

As previously discussed, several features can be used to predict the rating from a given user. However, many predictors increases the model complexity and requires more computer resourses, so in this research the estimated rating uses only movie and user information.

```
train_set <- train_set %>% select(userId, movieId, rating, title)
test_set  <- test_set  %>% select(userId, movieId, rating, title)
```

1.7 Modeling

1.7.1 Model Validation

The standard metric to measure the efficacy of ML algorithms is the Root Mean Squared Error (RMSE), defined by the formula:

$$RMSE = \sqrt{\frac{1}{N} \sum_{u,i} (\hat{y}_{u,i} - y_{u,i})^2}$$

where N is the number of ratings, $y_{u,i}$ is the rating of movie i by user u and $\hat{y}_{u,i}$ is the prediction of movie i by user u .

The objective of the recommendation system is to minimize the RMSE. If the user consistently selects the predicted movie, the RMSE is equal to zero and the algorithm works very well.

1.7.2 Linear Model

The simplest model predicts all users will give the same rating to all movies and assumes the movie to movie variation is the randomly distributed error. Although the predicted rating can be any value, statistics theory says that the average minimizes the RMSE, so the initial prediction is just the average of all observed ratings, as described in this formula:

$$\hat{Y}_{u,i} = \mu + \epsilon_{i,u}$$

Where \hat{Y} is the predicted rating, μ is the mean of observed data and $\epsilon_{i,u}$ is the error distribution. Any value other than the mean increases the RMSE, so this is a good initial estimation.

Part of the movie to movie variability can be explained by the fact that different movie receive different rating. This is called movie effect or movie bias, and is expressed as b_i in this formula:

$$\hat{Y}_{u,i} = \mu + b_i + \epsilon_{i,u}$$

The movie effect can be calculated as the mean of the difference between the observed rating y and the mean μ .

$$\hat{b}_i = \frac{1}{N} \sum_{i=1}^N (y_i - \hat{\mu})$$

Similarly to the movie effect, different users have different rating pattern or distribution. For example, some users like most movies and consistently rate 4 or 5, while other users dislike most movies rating 1 or 2. This is called user effect or user bias and is expressed in this formula:

$$\hat{b}_u = \frac{1}{N} \sum_{i=1}^N (y_{u,i} - \hat{b}_i - \hat{\mu})$$

The prediction model that includes the user effect becomes:

$$\hat{Y}_{u,i} = \mu + b_i + b_u + \epsilon_{u,i}$$

Another important aspect is the fact that similar movies get similar ratings, and movies of the same genre also get similar ratings.

$$\hat{y} = \mu + b_i + b_u + \sum_{k=1}^K x_{u,i} \beta_k + f(d_{u,i}) + \epsilon_{u,i}$$

1.7.3 Regularization

The linear model provides a good estimation for the ratings, but doesn't consider that many movies have very few number of ratings, and some users rate very few movies. This means that the sample size is very small for these movies and these users. Statistically, this leads to large estimated error. The estimated value can be improved adding a factor that penalizes small sample sizes and have little or no impact otherwise. Thus, estimated movie and user effects can be calculated with these formulas:

$$\hat{b}_i = \frac{1}{n_i + \lambda} \sum_{u=1}^{n_i} (y_{u,i} - \hat{\mu})$$
$$\hat{b}_u = \frac{1}{n_u + \lambda} \sum_{i=1}^{n_u} (y_{u,i} - \hat{b}_i - \hat{\mu})$$

For values of N smaller than or similar to λ , \hat{b}_i and \hat{b}_u is smaller than the original values, whereas for values of N much larger than λ , \hat{b}_i and \hat{b}_u change very little.

An effective method to choose λ that minimizes the RMSE is running simulations with serveral values of λ .

1.7.4 Matrix Factorization

Matrix factorization is widely used machine learning tool for predicting ratings in recommender systems. This method became widely known during the Netflix Prize challenge².

The data can be converted into a matrix with each user in a row and each movie in a column, then the algorithm attempts to fill in the missing values. The table below provides a simple example of a 4×5 matrix.

	movie 1	movie 2	movie 3	movie 4	movie 5
user 1	?	?	4	?	3
user 2	2	?	?	?	4
user 3	?	?	3	?	?
user 4	3	?	?	2	?

The concept is to approximate a large rating matrix $R_{m \times n}$ into the product of two lower dimension matrices $P_{k \times m}$ and $Q_{k \times n}$, such that

$$R \approx P'Q$$

The R [recsystem](https://www.recsystem.org/) package provides methods to decompose the rating matrix and estimate the user rating, using parallel matrix factorization.

²<https://www.netflixprize.com/>

Chapter 2

Results

This section presents the modeling results and discusses the model performance

2.1 Linear Model

Chapter 3

<https://rafalab.github.io/dsbook/large-datasets.html#recommendation-systems>

We're building the linear model based on the formula:

$$\hat{y} = \mu + b_i + b_u + \epsilon_{u,i}$$

3.0.1 Predict the same rating for all movies.

The initial prediction is the mean of the ratings, μ .

$$\hat{y} = \mu$$

```
mu <- mean(train_set$rating)
```

Calculate the RMSE

```
result <- tibble(Method = "Mean", RMSE = RMSE(test_set$rating, mu))
```

3.0.2 Include movie effect (bi)

bi is the movie effect (bias) for movie i.

$$\hat{y} = \mu + b_i$$

```
bi <- train_set %>%  
  group_by(movieId) %>%  
  summarize(b_i = mean(rating - mu))  
bi
```

movieId	b_i
1	0.4150040
2	-0.3064057
3	-0.3613952
4	-0.6372808
5	-0.4416058
6	0.3018943
7	-0.1522810
8	-0.3972265
9	-0.5136835
10	-0.0856076
11	0.1584887
12	-0.9445544
13	-0.3307096
14	-0.0795631
15	-0.7864782
16	0.2410574
17	0.4712154
18	-0.1834913
19	-0.9357296
20	-0.6452012
21	0.0831626
22	-0.1768093
23	-0.3509650
24	-0.2827511
25	0.1745580
26	0.1477870
27	-0.1334949
28	0.5695444
29	0.4538365
30	0.1427661
31	-0.2350542
32	0.3631728
33	-0.4335083
34	0.1896546
35	-0.0225185
36	0.4532656
37	-0.6260920
38	-0.6910271
39	-0.0857445
40	0.0884412
41	0.3365265
42	-0.4715176
43	-0.0596467

movieId	b_i
44	-0.8276708
45	-0.1300639
46	-0.2554897
47	0.5229510
48	-0.6040632
49	0.2658052
50	0.8540962
51	-1.0579102
52	0.0296851
53	0.2178075
54	-0.6274231
55	-0.2981699
56	-1.6695985
57	-0.1797785
58	0.4968053
59	0.0445619
60	-0.3501443
61	-0.1939309
62	0.2292935
63	-0.4678208
64	-0.6611043
65	-1.0965476
66	-1.3982159
67	-0.1241578
68	-0.0570710
69	0.0689030
70	-0.2573890
71	-1.2018728
72	-0.0012680
73	0.3276207
74	-0.2185539
75	-0.9532222
76	-0.5136440
77	-0.1500703
78	-0.3530005
79	-0.3910397
80	0.2840961
81	-0.2185327
82	0.5234819
83	0.1422319
84	-0.1791223
85	-0.0232160
86	-0.0345637

movieId	b_i
87	-1.1489162
88	-0.4298826
89	-0.3731522
90	-0.2603189
92	-0.6360214
93	-0.9503438
94	-0.0024605
95	-0.3954393
96	0.1569321
97	0.3976412
98	-1.0002605
99	-0.4857177
100	-0.2844063
101	0.3046727
102	-1.0702988
103	-0.2159339
104	-0.0884990
105	-0.2036513
106	-0.1092298
107	-0.3174538
108	-0.4638445
109	-1.8457890
110	0.5694726
111	0.6251105
112	-0.1003758
113	-0.4121240
114	0.1057876
115	0.0153221
116	0.3879681
117	0.0767774
118	-0.5156252
119	-0.6457890
120	-0.7811124
121	0.2560433
122	-0.6570796
123	0.4787208
124	0.1038234
125	0.2591081
126	-1.2382621
127	-0.0650872
128	-0.0450643
129	-0.3506909
130	-0.8249556

movieId	b_i
131	-0.2180631
132	-0.7601279
133	-0.7124556
134	0.4287208
135	-0.5047146
136	-0.1676281
137	-0.1491744
138	-0.3029962
139	-0.1791223
140	-0.2277574
141	0.0110408
142	-0.6033647
143	-1.2397284
144	-0.0047170
145	-0.2477608
146	-0.6779847
147	0.0451724
148	-0.6380967
149	0.1391401
150	0.3742239
151	0.0176143
152	-0.3580214
153	-0.5922452
154	0.2902129
155	-0.1197488
156	-0.0238877
157	-0.7225102
158	-0.5595761
159	-0.0994654
160	-0.9058184
161	0.2400601
162	0.4949074
163	-0.0641928
164	-0.0420197
165	-0.0293488
166	-0.8099634
167	-0.3803802
168	-0.4348458
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1855	-1.2324556
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movieId	b_i
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movieId	b_i
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1942	0.4875444
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movieId	b_i
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1997	0.2556427
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movieId	b_i
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movieId	b_i
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2070	0.4779938
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movieId	b_i
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movieId	b_i
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movieId	b_i
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movieId	b_i
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4133	-1.1955767

movieId	b_i
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movieId	b_i
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movieId	b_i
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movieId	b_i
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movieId	b_i
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movieId	b_i
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movieId	b_i
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movieId	b_i
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8332	0.1852188
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movieId	b_i
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8486	0.0500444
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movieId	b_i
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movieId	b_i
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movieId	b_i
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8999	0.1152039
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movieId	b_i
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9006	-0.7624556
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9010	0.1771995
9011	0.1958777
9012	-0.2624556
9013	0.2602716
9014	0.0463679
9015	-0.7902334
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9017	-0.3874556
9018	0.2912827
9019	-1.5124556
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25759	0.4161158
25762	-0.3948086
25763	0.3856925
25764	0.0275444
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25769	0.3971829
25771	0.2611293
25773	0.1693625
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25789	-0.0124556
25793	0.1750444
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25797	0.0875444

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25856	0.1768647
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26107	0.1125444
26110	-0.2624556
26111	0.4466353
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26113	0.5589729
26116	-0.1273205
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26119	0.0316620
26122	0.3822812
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26134	-0.4215465
26136	0.4875444
26138	-0.1715465
26139	-0.1791223
26142	0.4875444
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26147	0.3446872
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26158	0.4475444
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movieId	b_i
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26228	-0.0124556
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26231	0.2535018
26240	0.0875444
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26323	-0.7902334
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movieId	b_i
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36527	0.0276037
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37857	0.0357759
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39231	-0.4360308
39234	0.0718140
39292	0.3359525
39307	-0.0298975
39369	0.2375444
39381	0.2653221
39390	-0.2624556

movieId	b_i
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39402	-0.5124556
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39425	0.1542110
39427	-0.1011653
39429	-1.0124556
39435	-0.5552066
39439	-0.0124556
39441	0.0616184
39444	-0.2422478
39446	-0.3569762
39449	-0.4275933
39474	0.4875444
39659	-1.0124556
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39886	-0.0503344
39896	-0.1488193
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40278	0.0473219
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40414	0.2446872
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40583	0.0916031
40586	0.3446872
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movieId	b_i
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40952	-0.6086095
40955	0.1243368
40959	-0.4058206
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movieId	b_i
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movieId	b_i
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55190	-0.4124556
55205	-0.1272097
55232	-0.4172175
55241	-0.8420011
55245	-0.8201479

movieId	b_i
55247	0.4280368
55250	-0.4262487
55253	0.1857151
55255	-0.5469384
55257	-0.9082890
55259	-0.6124556
55261	-0.6721195
55267	-0.0611662
55269	0.1892018
55272	-0.2445985
55274	-0.1136461
55276	0.2803433
55278	-0.2047633
55280	0.2104015
55282	-0.4920475
55284	-0.1891798
55286	-0.1327088
55288	-0.2505509
55290	0.3214456
55292	-1.3924556
55324	-2.5124556
55363	0.1147120
55391	-0.7624556
55402	0.0784535
55417	-0.5124556
55419	-0.2937056
55440	-0.5124556
55442	0.4148948
55444	0.3100552
55451	-0.1687056
55492	-0.6488193
55498	-0.7397284
55507	-0.2624556
55517	-0.5124556
55553	-0.3558900
55555	0.4686764
55566	-0.7267414
55577	-0.6930112
55603	-1.0124556
55620	0.3625444
55668	-1.1374556
55687	0.1503351
55721	0.2764332

movieId	b_i
55726	-0.0124556
55729	-0.2916764
55732	-0.0319362
55765	0.3818352
55768	-0.3739941
55805	0.0334627
55814	0.5113539
55820	0.5120765
55830	-0.2116200
55844	-0.3124556
55851	-0.3695985
55854	0.0986555
55872	-0.0270542
55895	0.1542110
55901	0.3875444
55908	0.5009031
55926	-0.0418674
55946	-0.5008277
55955	-0.8024556
55995	-0.3366315
55999	-0.2926754
56001	-0.6124556
56003	-1.1405044
56015	0.9875444
56028	-1.5124556
56030	0.1542110
56060	0.0986555
56067	-1.2624556
56141	0.2522502
56145	-0.1301027
56152	0.0715961
56156	-0.4601829
56158	-0.8065733
56165	-1.2724556
56167	-0.7397284
56169	-0.3686200
56171	-0.2317539
56174	-0.0362286
56176	-0.7602034
56251	0.1607900
56253	-0.0124556
56274	-0.5445069
56286	-0.0865297

movieId	b_i
56333	0.0970682
56339	0.2795152
56367	0.4968810
56389	-0.1249556
56508	0.0729102
56511	-1.2346779
56563	-0.0235668
56587	0.0964401
56607	0.3343652
56633	-0.4499556
56671	0.3625444
56700	-1.5124556
56715	0.2246578
56719	-0.0749556
56744	-0.0124556
56748	-0.0124556
56757	0.1088580
56775	-0.3176666
56782	0.4246640
56788	0.2352166
56801	-1.0674556
56805	-0.2353128
56885	0.2556166
56908	0.3312944
56915	-0.2255704
56921	0.2732586
56941	-0.1409279
56945	-0.4291223
56949	-0.4269043
57147	-0.2840606
57223	-1.6104949
57243	0.2683663
57274	0.2841545
57326	-1.6541223
57353	-0.0378794
57357	-0.0124556
57368	-0.0601707
57370	-0.4779729
57401	-0.3602817
57464	0.0113539
57473	-0.7624556
57476	-0.1791223
57478	0.2375444

movieId	b_i
57480	0.2375444
57484	-0.1124556
57499	-0.2624556
57504	0.2602716
57509	-0.9569001
57520	-1.1966662
57522	-1.1687056
57526	-0.4248268
57528	-0.1733553
57530	-0.7267414
57532	-1.8938116
57534	-0.9826049
57536	-1.0656471
57538	-0.8201479
57550	0.7375444
57640	-0.0416334
57655	-0.2624556
57669	0.3608082
57690	0.0292110
57792	0.0708777
57811	0.4875444
57845	0.2531694
57848	0.1125444
57865	-0.5124556
57910	-0.2397284
57949	-1.5387714
57951	-0.4351829
57964	0.0875444
58025	-0.6111569
58029	0.1542110
58047	0.0359315
58059	0.2375444
58078	-0.1791223
58084	-0.0124556
58103	-0.2510177
58105	-0.1148653
58107	-0.5800232
58146	-1.7950643
58154	-0.1493983
58156	-0.5933380
58162	-0.1092298
58185	0.9875444
58191	0.1845141

movieId	b_i
58246	-0.0490410
58291	-1.7624556
58293	-0.9875594
58295	0.1446285
58297	-0.5603280
58299	0.0311490
58301	-0.3338842
58303	0.4465608
58306	0.1705801
58309	0.3966353
58315	-1.1639708
58332	-0.5303128
58334	-0.1553128
58347	0.0892393
58351	0.2924224
58367	-0.3695985
58376	0.0083777
58381	-0.2346779
58418	-0.6420853
58439	-0.3624556
58490	0.0450156
58492	-0.2249556
58494	-0.4053128
58520	0.4875444
58559	0.7870670
58564	-0.0124556
58595	-0.0124556
58622	0.2602716
58627	-0.4812056
58652	-0.4624556
58655	-0.7894827
58706	0.3208777
58783	-0.5124556
58803	-0.0864282
58806	-0.3635195
58808	0.7375444
58839	-0.5256135
58876	-0.2024556
58879	-0.0124556
58898	0.4875444
58964	-0.0124556
58972	-0.4543161
58975	-0.7663018

movieId	b_i
58998	0.1724260
59000	-0.2624556
59014	-1.2403968
59016	-0.1259010
59018	0.3331819
59022	-0.1782310
59026	0.0232586
59037	-0.2267414
59044	-2.0124556
59065	-1.3306375
59103	-0.3643075
59105	-0.3324556
59107	-0.0957890
59118	-0.0033647
59126	0.2275444
59129	-0.4291223
59141	0.1181750
59143	-0.1737460
59154	-0.2624556
59157	-0.8874556
59173	-0.3874556
59256	-0.7851829
59258	-0.2819869
59290	-1.5957890
59295	-1.8586095
59306	-1.8189073
59313	-0.2624556
59315	0.4719680
59333	-0.7081078
59336	-0.0567594
59339	-0.5624556
59362	-0.8306375
59369	0.3446872
59382	-0.6315033
59387	0.4241641
59392	0.0329989
59404	-0.2724556
59418	0.1542110
59421	-0.4114455
59440	-0.2445985
59478	-0.8457890
59501	-0.1201792
59519	-0.1153968

movieId	b_i
59590	0.0939273
59594	-0.8173337
59604	-0.1737460
59607	0.0430999
59615	-0.4899331
59625	0.4875444
59655	-0.8457890
59680	-0.5124556
59684	0.1542110
59709	-0.3041223
59715	-0.9090074
59721	-0.5994122
59725	-0.4791223
59727	-0.6374556
59729	-0.8201479
59731	0.2918922
59738	-0.5124556
59784	0.2492704
59795	-0.6374556
59810	0.1571872
59816	0.1125444
59832	0.3625444
59834	-0.7624556
59840	-1.0124556
59854	-0.2624556
59858	0.4875444
59900	-0.6868742
59908	-0.3400418
59910	-0.1791223
59912	-0.0124556
59915	-0.3760920
59985	-0.0437056
59995	0.1640149
60037	-1.0087519
60040	-0.0655806
60044	-0.3457890
60046	0.1125444
60069	0.6163922
60072	-0.1841728
60074	-0.2275951
60126	-0.2054648
60133	-0.3695985
60135	-0.0124556

movieId	b_i
60137	-0.0124556
60141	-1.0124556
60147	-0.2902334
60161	0.1542110
60189	-0.5124556
60201	-0.7981699
60237	-0.5124556
60284	-1.0124556
60286	-0.9291223
60289	-0.0124556
60291	0.5088210
60293	0.1125444
60295	0.1011807
60309	0.4875444
60322	-0.6033647
60333	0.3589729
60336	0.9875444
60341	-0.2397284
60363	-1.5124556
60389	-0.7124556
60391	-0.5124556
60393	-0.0124556
60397	-0.1893787
60405	-0.5124556
60411	0.2375444
60418	-0.2207890
60421	-1.0124556
60471	-0.1791223
60475	0.3625444
60484	0.3208777
60487	0.1099220
60494	-0.5124556
60503	0.2375444
60514	-0.4846779
60516	-0.9335083
60522	-0.4791223
60524	-0.5124556
60526	-0.7207890
60530	-0.1124556
60590	-0.8124556
60618	-0.7624556
60647	-0.1440346
60649	-1.3249556

movieId	b_i
60654	-0.5124556
60666	0.4875444
60674	0.0270180
60688	-0.5124556
60728	0.2375444
60735	-0.1553128
60745	0.6125444
60753	0.1857426
60756	-0.1791223
60758	-0.2047633
60760	-0.6964556
60763	-0.3359851
60766	0.3625444
60768	-0.8457890
60832	-0.4754186
60880	0.4875444
60894	-0.0124556
60937	-0.9569001
60939	-0.3791223
60941	-0.4291223
60943	0.4085970
60946	-0.1124556
60948	-0.6791223
60950	0.3133019
60983	-0.0124556
60990	0.9875444
61011	-0.9124556
61024	0.0866227
61037	0.7375444
61048	-0.2624556
61071	-1.0228723
61073	-1.3948086
61075	0.0589729
61123	-1.0882132
61132	-0.0060454
61160	-0.7897284
61167	-0.1331453
61210	-1.0749556
61236	0.3625444
61240	0.5708777
61246	-0.5565733
61248	-0.3842505
61250	-0.8276730

movieId	b_i
61253	0.3208777
61255	-0.2624556
61257	-0.1791223
61262	-0.3562056
61264	-0.3457890
61267	-1.5838842
61269	-0.5124556
61279	0.4875444
61289	-0.2029318
61312	0.1125444
61323	0.1545702
61348	-2.7457890
61350	-0.6874556
61352	0.0618687
61354	-1.3041223
61357	0.3875444
61361	-0.3808767
61394	-0.4907165
61401	-1.8874556
61414	-0.7624556
61434	0.1125444
61465	-0.7981699
61467	-1.5124556
61470	-0.5124556
61473	-0.0124556
61475	-0.0124556
61560	-0.0124556
61586	-0.2624556
61628	0.2375444
61634	-1.1791223
61638	-2.0124556
61646	0.1542110
61678	-0.3545609
61692	-1.8457890
61695	0.9875444
61697	-0.5473394
61705	-0.2047633
61707	-0.0124556
61724	-0.2124556
61729	0.1125444
61742	-0.0124556
61768	-3.0124556
61816	0.3208777

movieId	b_i
61818	-0.8874556
61862	-1.0124556
61913	-0.5124556
61931	-0.7397284
61934	-1.0124556
61937	-0.0124556
61941	-0.5124556
61948	-1.5124556
61950	0.2375444
61961	-0.1488193
61967	0.6542110
61970	-1.5124556
61986	-0.0267414
61991	-0.6124556
62000	-0.3874556
62008	-1.5124556
62010	-0.6374556
62049	0.2097666
62054	0.2375444
62063	-0.5124556
62081	-0.2490628
62113	-0.0529962
62137	-0.5579102
62153	-0.1374556
62155	0.0396277
62198	-0.1124556
62203	-0.3457890
62235	-0.1124556
62237	-0.0124556
62245	0.4875444
62250	-0.0124556
62254	0.7375444
62265	-1.1791223
62277	-0.8457890
62293	0.1839729
62299	-1.3874556
62331	0.4875444
62334	-0.8874556
62336	0.4440661
62344	0.0812944
62374	0.1319888
62376	-0.1791223
62378	-0.2624556

movieId	b_i
62383	-0.0124556
62385	-0.5124556
62390	-0.7624556
62394	-0.9124556
62434	0.0190404
62437	-0.2954745
62439	-0.3457890
62474	-2.0124556
62511	-0.1924556
62526	-0.4215465
62553	-0.2624556
62577	-0.6791223
62586	-1.1124556
62644	-0.0124556
62660	-1.0124556
62662	0.4875444
62671	-1.5124556
62718	0.2375444
62721	-0.0124556
62729	-0.2624556
62733	-0.5291223
62764	-1.0124556
62788	-1.0749556
62792	-0.2207890
62796	-0.8124556
62799	-0.2624556
62801	0.4161158
62803	0.4490828
62834	-1.1195985
62836	-0.8124556
62847	-1.0124556
62849	0.1875444
62851	-0.0124556
62912	-1.8808767
62916	-1.0124556
62920	-0.2624556
62925	-0.6791223
62956	-0.0857315
62970	-0.3948086
62972	-0.3457890
62999	-0.1760920
63033	-0.3643075
63062	0.3386082

movieId	b_i
63069	0.2375444
63082	0.7091353
63113	0.0073012
63119	-0.6791223
63121	-0.2981699
63131	0.3589729
63141	-1.5124556
63179	0.9875444
63181	-0.0124556
63187	-0.2624556
63189	-0.0124556
63194	-0.2624556
63222	-0.0124556
63237	-0.6374556
63239	-0.6942738
63271	-1.5124556
63273	-1.0124556
63276	0.7375444
63283	0.2375444
63310	-0.0124556
63312	0.4875444
63327	-0.5124556
63329	0.1239080
63332	-1.0124556
63339	0.2375444
63393	-2.3249556
63433	0.3144674
63436	-0.8180112
63446	-0.6374556
63458	-1.1791223
63468	-0.5124556
63479	-0.4670011
63481	-0.2624556
63515	-0.6374556
63540	-2.1033647
63617	-0.0124556
63645	0.7375444
63647	0.4875444
63662	0.4875444
63676	0.4875444
63688	-0.0124556
63698	0.2375444
63760	0.4875444

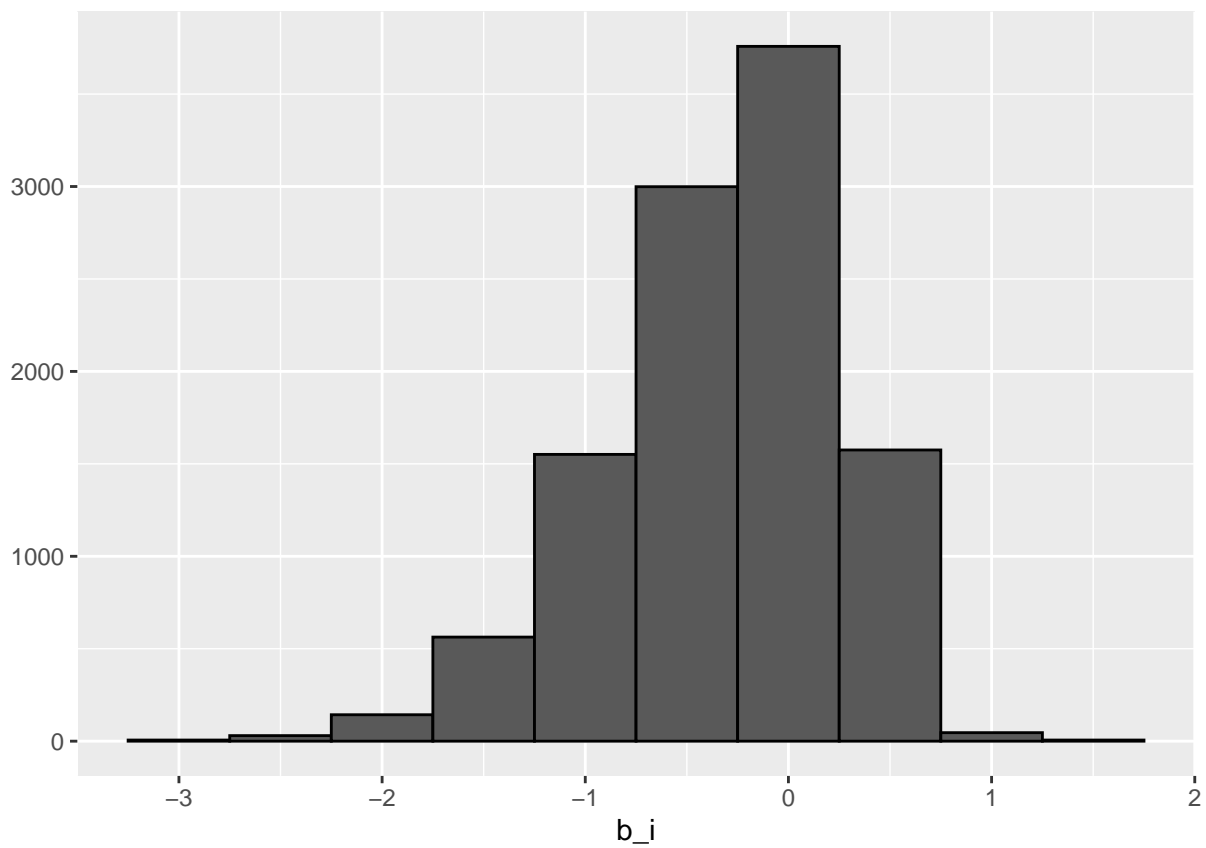
movieId	b_i
63768	-0.0124556
63772	0.7375444
63781	-0.5124556
63788	-1.0124556
63791	-1.5124556
63793	0.3208777
63806	-0.0124556
63808	1.1542110
63810	-0.0124556
63826	0.4875444
63828	-3.0124556
63836	-2.0124556
63840	0.4875444
63853	-0.3189073
63859	-0.1301027
63862	-0.5124556
63876	0.6168547
63989	-0.2624556
63992	-0.2369454
64030	-0.8917660
64032	-1.0124556
64034	-0.0124556
64114	-1.5124556
64116	-1.0124556
64153	-1.0124556
64197	0.3208777
64229	-0.4124556
64231	-0.2624556
64234	-1.5124556
64243	-0.0124556
64245	-0.0124556
64249	-0.3249556
64273	-0.2624556
64275	1.4875444
64278	0.8208777
64280	0.7375444
64283	-0.0124556
64285	-0.0838842
64288	-1.5124556
64321	0.2375444
64325	-0.5124556
64327	-0.5124556
64338	0.0875444

movieId	b_i
64365	-0.5124556
64368	-1.1791223
64408	-0.0124556
64410	-0.2624556
64418	0.9875444
64427	0.4875444
64497	-0.7733252
64499	-0.6791223
64501	0.4875444
64508	-1.1663018
64519	-0.1374556
64550	-1.0124556
64575	0.1125444
64611	-0.0124556
64614	0.2375444
64620	0.5131854
64622	-0.3874556
64652	-1.5124556
64701	-0.3874556
64716	0.2522502
64750	-0.8124556
64754	-0.0124556
64839	0.5644674
64895	-0.2624556
64897	-0.5124556
64900	0.1542110
64903	-0.0124556
64906	0.4875444
64918	-0.5124556
64921	-0.2624556
64923	-0.5124556
64926	-0.0124556
64930	0.4875444
64942	-0.0124556
64944	-0.5124556
64953	-0.0124556
64957	0.3234819
64969	-0.0806375
64976	-2.0124556
64983	0.3684967
64986	-0.1791223
64990	0.3208777
64993	-0.2624556

movieId	b_i
64997	-0.6050482
64999	-3.0124556
65001	1.2375444
65006	0.4875444
65011	0.4875444
65025	-1.5124556
65027	-1.0124556
65037	-0.0957890
65088	-0.0124556
65091	0.1542110
65126	0.1542110
65130	-1.5124556
65133	-0.2624556

Plot the distribution of movie effects

```
qplot(b_i, data = bi, bins = 10, color = I("black"))
```



Predict the rating with mean + bi

```
y_hat_bi <- mu + test_set %>%  
  left_join(bi, by = "movieId") %>%  
  .$b_i
```

Calculate the RMSE

```
result <- bind_rows(result,  
  tibble(Method = "Mean + bi",  
    RMSE = RMSE(test_set$rating, y_hat_bi)))
```

Show the RMSE improvement

```
result
```

Method	RMSE
Mean	1.0600537
Mean + bi	0.9429615

3.0.3 Include user effect (bu)

bu is the user effect (bias) for user u.

$$\hat{y} = \mu + b_i + b_u$$

```
bu <- train_set %>%  
  left_join(bi, by = 'movieId') %>%  
  group_by(userId) %>%  
  summarize(b_u = mean(rating - mu - b_i))
```

Predict the rating with mean + bi + bu

```
y_hat_bi_bu <- test_set %>%  
  left_join(bi, by='movieId') %>%  
  left_join(bu, by='userId') %>%  
  mutate(pred = mu + b_i + b_u) %>%  
  .$pred  
  
result <- bind_rows(result,  
  tibble(Method = "Mean + bi + bu",  
    RMSE = RMSE(test_set$rating, y_hat_bi_bu)))
```

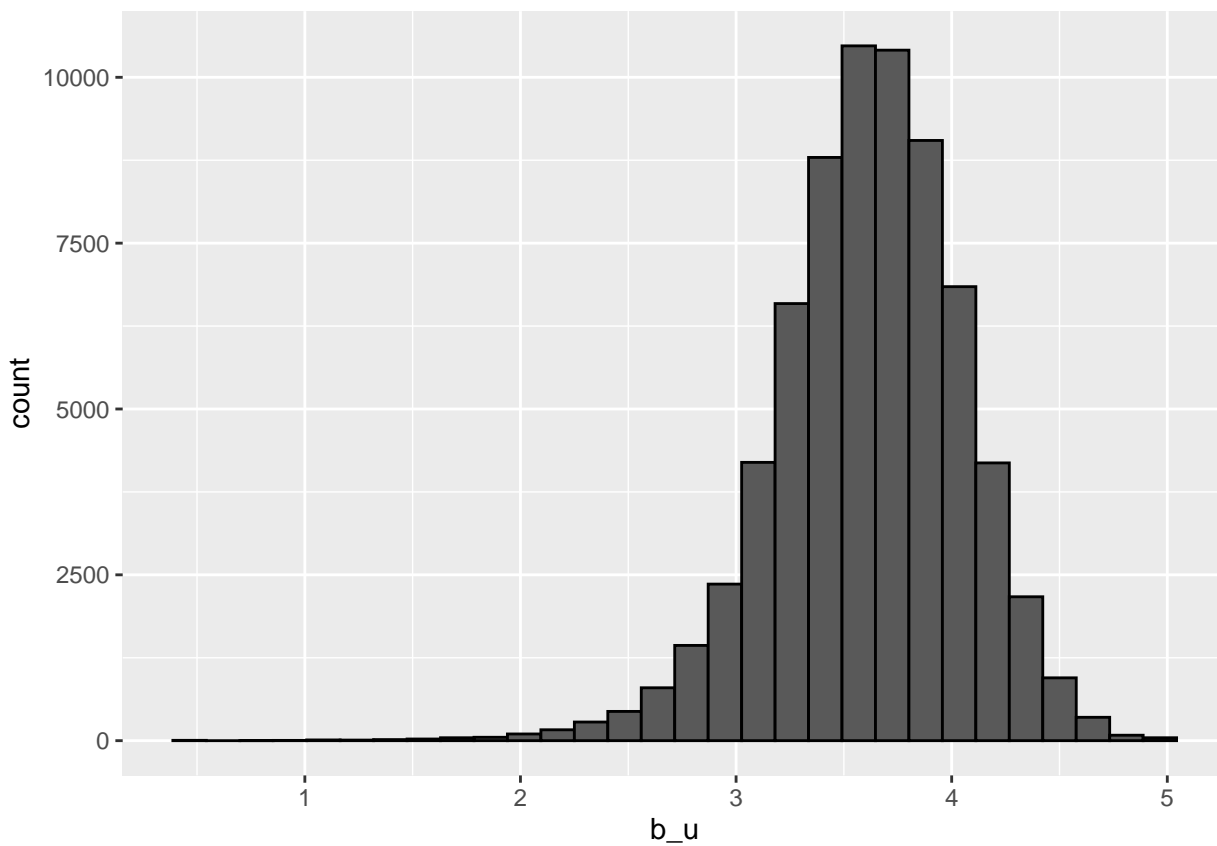
Show the RMSE improvement

```
result
```

Method	RMSE
Mean	1.0600537
Mean + bi	0.9429615
Mean + bi + bu	0.8646843

Plot the distribution of user effects

```
train_set %>%  
  group_by(userId) %>%  
  summarize(b_u = mean(rating)) %>%  
  filter(n())>=100 %>%  
  ggplot(aes(b_u)) +  
  geom_histogram(bins = 30, color = "black")
```



3.0.4 Checking the model result

The RMSE improved from the initial estimation based on the mean. However, we still need to check if the model makes good ratings predictions.

Check the 10 largest residual differences

```
train_set %>%
  left_join(bi, by='movieId') %>%
  mutate(residual = rating - (mu + b_i)) %>%
  arrange(desc(abs(residual))) %>%
  slice(1:10)
```

userId	movieId	rating	title	b_i	residual
26423	6483	5.0	From Justin to Kelly (2003)	-2.638139	4.125683
5279	6371	5.0	Pok�mon Heroes (2003)	-2.472133	3.959677
57863	6371	5.0	Pok�mon Heroes (2003)	-2.472133	3.959677
2507	318	0.5	Shawshank Redemption, The (1994)	0.944111	-3.956567
7708	318	0.5	Shawshank Redemption, The (1994)	0.944111	-3.956567
9214	318	0.5	Shawshank Redemption, The (1994)	0.944111	-3.956567
9568	318	0.5	Shawshank Redemption, The (1994)	0.944111	-3.956567
9975	318	0.5	Shawshank Redemption, The (1994)	0.944111	-3.956567
10749	318	0.5	Shawshank Redemption, The (1994)	0.944111	-3.956567
13496	318	0.5	Shawshank Redemption, The (1994)	0.944111	-3.956567

```
titles <- train_set %>%
  select(movieId, title) %>%
  distinct()
```

Top 10 best movies (ranked by bi). These are unknown movies

```
bi %>%
  inner_join(titles, by = "movieId") %>%
  arrange(-b_i) %>%
  head() %>%
  pull(title)
```

```
## [1] "Hellhounds on My Trail (1999)"
## [2] "Satan's Tango (S t ntang ) (1994)"
## [3] "Shadows of Forgotten Ancestors (1964)"
## [4] "Fighting Elegy (Kenka erejii) (1966)"
## [5] "Sun Alley (Sonnenallee) (1999)"
## [6] "Blue Light, The (Das Blaue Licht) (1932)"
```

Top 10 worst movies (ranked by bi), also unknown movies:

```
bi %>%
  inner_join(titles, by = "movieId") %>%
  arrange(b_i) %>%
  head() %>%
  pull(title)

## [1] "Besotted (2001)"
## [2] "Hi-Line, The (1999)"
## [3] "Accused (Anklaget) (2005)"
## [4] "Confessions of a Superhero (2007)"
## [5] "War of the Worlds 2: The Next Wave (2008)"
## [6] "SuperBabies: Baby Geniuses 2 (2004)"
```

Number of ratings for 10 best movies:

```
train_set %>%
  left_join(bi, by = "movieId") %>%
  arrange(desc(b_i)) %>%
  group_by(title) %>%
  summarise(n = n()) %>%
  slice(1:10)
```

title	n
'burbs, The (1989)	1201
'night Mother (1986)	178
'Round Midnight (1986)	40
'Til There Was You (1997)	242
"Great Performances" Cats (1998)	4
batteries not included (1987)	389
...All the Marbles (a.k.a. The California Dolls) (1981)	17
...And God Created Woman (Et Dieu... cr��a la femme) (1956)	68
...And God Spoke (1993)	19
...And Justice for All (1979)	500

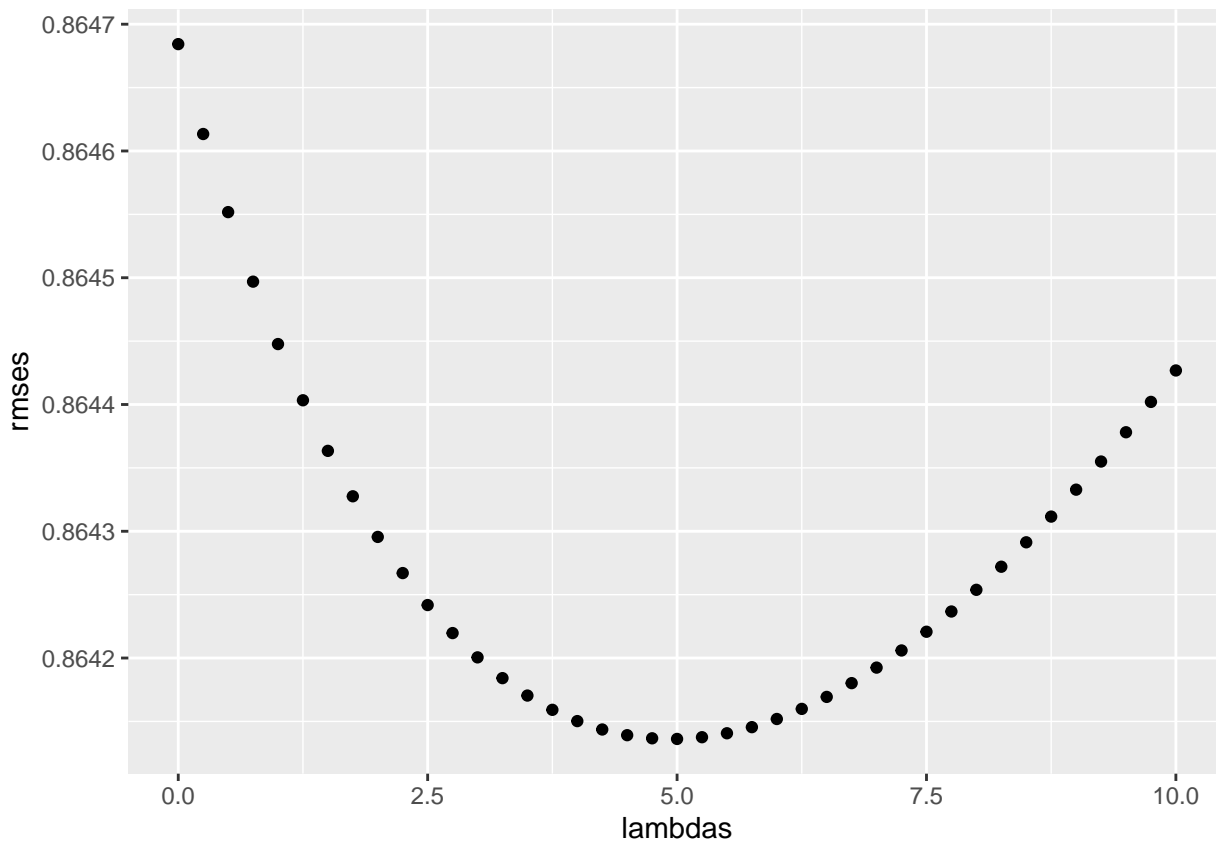
```
train_set %>% count(movieId) %>%
  left_join(bi, by="movieId") %>%
  arrange(desc(b_i)) %>%
  slice(1:10) %>%
  pull(n)
```

```
## [1] 1 1 1 1 1 1 4 2 4 4
```

3.1 Regularization

```
regularization <- function(lambda, trainset, testset){  
  
  mu <- mean(trainset$rating)  
  
  b_i <- trainset %>%  
    group_by(movieId) %>%  
    summarize(b_i = sum(rating - mu)/(n()+lambda))  
  
  b_u <- trainset %>%  
    left_join(b_i, by="movieId") %>%  
    filter(!is.na(b_i)) %>%  
    group_by(userId) %>%  
    summarize(b_u = sum(rating - b_i - mu)/(n()+lambda))  
  
  predicted_ratings <- testset %>%  
    left_join(b_i, by = "movieId") %>%  
    left_join(b_u, by = "userId") %>%  
    filter(!is.na(b_i), !is.na(b_u)) %>%  
    mutate(pred = mu + b_i + b_u) %>%  
    pull(pred)  
  
  return(RMSE(predicted_ratings, testset$rating))  
}
```

```
lambdas <- seq(0, 10, 0.25)  
  
rmsees <- sapply(lambdas,  
  regularization,  
  trainset = train_set,  
  testset = test_set)  
  
qplot(lambdas, rmsees)
```

We pick the lambda that returns the lowest RMSE

```
lambda <- lambdas[which.min(rmses)]
lambda
```

```
## [1] 5
```

Then, we calculate the predicted rating using the best parameters achieved from regularization.

```
mu <- mean(train_set$rating)

b_i <- train_set %>%
  group_by(movieId) %>%
  summarize(b_i = sum(rating - mu)/(n()+lambda))

b_u <- train_set %>%
  left_join(b_i, by="movieId") %>%
  group_by(userId) %>%
  summarize(b_u = sum(rating - b_i - mu)/(n()+lambda))
```

```

y_hat_reg <- test_set %>%
  left_join(b_i, by = "movieId") %>%
  left_join(b_u, by = "userId") %>%
  mutate(pred = mu + b_i + b_u) %>%
  pull(pred)

result <- bind_rows(result,
  tibble(Method = "Regularized bi and bu",
    RMSE = RMSE(test_set$rating, y_hat_reg)))

```

Regularization made a small improvement in RMSE.

result

Method	RMSE
Mean	1.0600537
Mean + bi	0.9429615
Mean + bi + bu	0.8646843
Regularized bi and bu	0.8641362

3.2 Matrix Factorization

Matrix factorization approximates a large user-movie matrix into the product of two smaller dimension matrices. Information in the train set is stored in tidy format, with one observation per row, so it needs to be converted to the user-movie matrix before using matrix factorization. This code executes this transformation.

```

train_data <- train_set %>%
  select(userId, movieId, rating) %>%
  spread(movieId, rating) %>%
  as.matrix()

```

Because it uses more memory than a commodity laptop is able process, we use an alternative method: the **recosystem** package, which provides the complete solution for a recommender system using matrix factorization.

The package vignette¹ describes how to use **recosystem**:

Usage of **recosystem**

The usage of **recosystem** is quite simple, mainly consisting of the following steps:

¹<https://cran.r-project.org/web/packages/recosystem/vignettes/introduction.html>

1. Create a model object (a Reference Class object in R) by calling `Reco()`.
2. (Optionally) call the `$tune()` method to select best tuning parameters along a set of candidate values.
3. Train the model by calling the `$train()` method. A number of parameters can be set inside the function, possibly coming from the result of `$tune()`.
4. (Optionally) export the model via `$output()`, i.e. write the factorization matrices P and Q into files or return them as R objects.
5. Use the `$predict()` method to compute predicted values.

```
if(!require(recosystem)) install.packages("recosystem", repos = "http://cran.us.r-project.org")
```

```
## Loading required package: recosystem
```

```
set.seed(123, sample.kind = "Rounding") # This is a randomized algorithm
```

```
## Warning in set.seed(123, sample.kind = "Rounding"): non-uniform 'Rounding'  
## sampler used
```

```
# Convert the train and test sets into recosystem input format
```

```
train_data <- with(train_set, data_memory(user_index = userId, item_index = movieId, rating = rating))  
test_data  <- with(test_set,  data_memory(user_index = userId, item_index = movieId, rating = rating))
```

```
# Create the model object
```

```
r <- recosystem::Reco()
```

```
# Select the best tuning parameters
```

```
opts <- r$tune(train_data, opts = list(dim = c(10, 20, 30), lrate = c(0.1, 0.2),  
                                       costp_l2 = c(0.01, 0.1),  
                                       costq_l2 = c(0.01, 0.1),  
                                       nthread  = 4, niter = 10))
```

```
opts
```

```
## $min  
## $min$dim  
## [1] 30  
##  
## $min$costp_l1  
## [1] 0  
##  
## $min$costp_l2  
## [1] 0.01  
##
```

```

## $min$costq_l1
## [1] 0
##
## $min$costq_l2
## [1] 0.1
##
## $min$lrate
## [1] 0.1
##
## $min$loss_fun
## [1] 0.8014281
##
##
## $res
##      dim costp_l1 costp_l2 costq_l1 costq_l2 lrate  loss_fun
## 1    10      0.0    0.01      0.0    0.01    0.1 0.8285196
## 2    20      0.0    0.01      0.0    0.01    0.1 0.8129755
## 3    30      0.0    0.01      0.0    0.01    0.1 0.8222560
## 4    10      0.1    0.01      0.0    0.01    0.1 0.8420957
## 5    20      0.1    0.01      0.0    0.01    0.1 0.8292921
## 6    30      0.1    0.01      0.0    0.01    0.1 0.8260175
## 7    10      0.0    0.10      0.0    0.01    0.1 0.8300243
## 8    20      0.0    0.10      0.0    0.01    0.1 0.8076036
## 9    30      0.0    0.10      0.0    0.01    0.1 0.8077474
## 10   10      0.1    0.10      0.0    0.01    0.1 0.8428053
## 11   20      0.1    0.10      0.0    0.01    0.1 0.8277358
## 12   30      0.1    0.10      0.0    0.01    0.1 0.8268194
## 13   10      0.0    0.01      0.1    0.01    0.1 0.8469414
## 14   20      0.0    0.01      0.1    0.01    0.1 0.8293933
## 15   30      0.0    0.01      0.1    0.01    0.1 0.8320393
## 16   10      0.1    0.01      0.1    0.01    0.1 0.8607591
## 17   20      0.1    0.01      0.1    0.01    0.1 0.8628680
## 18   30      0.1    0.01      0.1    0.01    0.1 0.8607049
## 19   10      0.0    0.10      0.1    0.01    0.1 0.8469807
## 20   20      0.0    0.10      0.1    0.01    0.1 0.8484551
## 21   30      0.0    0.10      0.1    0.01    0.1 0.8481214
## 22   10      0.1    0.10      0.1    0.01    0.1 0.8560111
## 23   20      0.1    0.10      0.1    0.01    0.1 0.8628224
## 24   30      0.1    0.10      0.1    0.01    0.1 0.8741435
## 25   10      0.0    0.01      0.0    0.10    0.1 0.8317547
## 26   20      0.0    0.01      0.0    0.10    0.1 0.8063920
## 27   30      0.0    0.01      0.0    0.10    0.1 0.8014281
## 28   10      0.1    0.01      0.0    0.10    0.1 0.8602015
## 29   20      0.1    0.01      0.0    0.10    0.1 0.8523777
## 30   30      0.1    0.01      0.0    0.10    0.1 0.8524993

```

## 31	10	0.0	0.10	0.0	0.10	0.1	0.8385871
## 32	20	0.0	0.10	0.0	0.10	0.1	0.8310129
## 33	30	0.0	0.10	0.0	0.10	0.1	0.8301570
## 34	10	0.1	0.10	0.0	0.10	0.1	0.8748559
## 35	20	0.1	0.10	0.0	0.10	0.1	0.8675934
## 36	30	0.1	0.10	0.0	0.10	0.1	0.8659628
## 37	10	0.0	0.01	0.1	0.10	0.1	0.8522305
## 38	20	0.0	0.01	0.1	0.10	0.1	0.8355141
## 39	30	0.0	0.01	0.1	0.10	0.1	0.8319086
## 40	10	0.1	0.01	0.1	0.10	0.1	0.8620247
## 41	20	0.1	0.01	0.1	0.10	0.1	0.8614159
## 42	30	0.1	0.01	0.1	0.10	0.1	0.8648520
## 43	10	0.0	0.10	0.1	0.10	0.1	0.8721160
## 44	20	0.0	0.10	0.1	0.10	0.1	0.8612761
## 45	30	0.0	0.10	0.1	0.10	0.1	0.8585676
## 46	10	0.1	0.10	0.1	0.10	0.1	0.8802561
## 47	20	0.1	0.10	0.1	0.10	0.1	0.8755927
## 48	30	0.1	0.10	0.1	0.10	0.1	0.8817786
## 49	10	0.0	0.01	0.0	0.01	0.2	0.8692446
## 50	20	0.0	0.01	0.0	0.01	0.2	0.9196232
## 51	30	0.0	0.01	0.0	0.01	0.2	1.0166916
## 52	10	0.1	0.01	0.0	0.01	0.2	0.8327117
## 53	20	0.1	0.01	0.0	0.01	0.2	1.0140032
## 54	30	0.1	0.01	0.0	0.01	0.2	1.0621373
## 55	10	0.0	0.10	0.0	0.01	0.2	0.8229051
## 56	20	0.0	0.10	0.0	0.01	0.2	0.9134850
## 57	30	0.0	0.10	0.0	0.01	0.2	0.9147912
## 58	10	0.1	0.10	0.0	0.01	0.2	0.8760700
## 59	20	0.1	0.10	0.0	0.01	0.2	0.9239697
## 60	30	0.1	0.10	0.0	0.01	0.2	1.0168403
## 61	10	0.0	0.01	0.1	0.01	0.2	0.8337280
## 62	20	0.0	0.01	0.1	0.01	0.2	0.8381345
## 63	30	0.0	0.01	0.1	0.01	0.2	0.8430096
## 64	10	0.1	0.01	0.1	0.01	0.2	0.9144403
## 65	20	0.1	0.01	0.1	0.01	0.2	0.8797799
## 66	30	0.1	0.01	0.1	0.01	0.2	0.8819939
## 67	10	0.0	0.10	0.1	0.01	0.2	0.8549741
## 68	20	0.0	0.10	0.1	0.01	0.2	0.8682369
## 69	30	0.0	0.10	0.1	0.01	0.2	0.8768318
## 70	10	0.1	0.10	0.1	0.01	0.2	0.8816354
## 71	20	0.1	0.10	0.1	0.01	0.2	0.8858959
## 72	30	0.1	0.10	0.1	0.01	0.2	0.8880739
## 73	10	0.0	0.01	0.0	0.10	0.2	0.8242995
## 74	20	0.0	0.01	0.0	0.10	0.2	0.8043641
## 75	30	0.0	0.01	0.0	0.10	0.2	0.8048758

## 76	10	0.1	0.01	0.0	0.10	0.2	0.8424847
## 77	20	0.1	0.01	0.0	0.10	0.2	0.8530010
## 78	30	0.1	0.01	0.0	0.10	0.2	0.8559863
## 79	10	0.0	0.10	0.0	0.10	0.2	0.8402604
## 80	20	0.0	0.10	0.0	0.10	0.2	0.8266534
## 81	30	0.0	0.10	0.0	0.10	0.2	0.8263765
## 82	10	0.1	0.10	0.0	0.10	0.2	0.8562759
## 83	20	0.1	0.10	0.0	0.10	0.2	0.8591894
## 84	30	0.1	0.10	0.0	0.10	0.2	0.8705514
## 85	10	0.0	0.01	0.1	0.10	0.2	0.8393132
## 86	20	0.0	0.01	0.1	0.10	0.2	0.8269993
## 87	30	0.0	0.01	0.1	0.10	0.2	0.8315588
## 88	10	0.1	0.01	0.1	0.10	0.2	0.8793528
## 89	20	0.1	0.01	0.1	0.10	0.2	0.8764315
## 90	30	0.1	0.01	0.1	0.10	0.2	0.8839535
## 91	10	0.0	0.10	0.1	0.10	0.2	0.8583695
## 92	20	0.0	0.10	0.1	0.10	0.2	0.8736027
## 93	30	0.0	0.10	0.1	0.10	0.2	0.8726661
## 94	10	0.1	0.10	0.1	0.10	0.2	0.8893849
## 95	20	0.1	0.10	0.1	0.10	0.2	0.8881822
## 96	30	0.1	0.10	0.1	0.10	0.2	0.8938311

Train the algorithm

```
r$train(train_data, opts = c(opts$min, nthread = 4, niter = 20))
```

## iter	tr_rmse	obj
## 0	0.9802	1.1007e+007
## 1	0.8765	8.9985e+006
## 2	0.8430	8.3511e+006
## 3	0.8210	7.9619e+006
## 4	0.8049	7.6957e+006
## 5	0.7929	7.5078e+006
## 6	0.7828	7.3646e+006
## 7	0.7743	7.2492e+006
## 8	0.7668	7.1548e+006
## 9	0.7603	7.0739e+006
## 10	0.7545	7.0048e+006
## 11	0.7493	6.9444e+006
## 12	0.7447	6.8959e+006
## 13	0.7404	6.8518e+006
## 14	0.7365	6.8137e+006
## 15	0.7330	6.7761e+006
## 16	0.7298	6.7457e+006

```
##    17      0.7267  6.7160e+006
##    18      0.7240  6.6889e+006
##    19      0.7215  6.6663e+006
```

Calculate the predicted values

```
y_hat_recon <- r$predict(test_data, out_memory())
head(y_hat_recon, 10)
```

```
## [1] 4.880081 3.796338 3.205281 3.013128 3.546894 3.964699 3.628160
## [8] 3.306902 4.107758 3.156383
```

Matrix factorization improved substantially the RMSE.

```
result <- bind_rows(result,
  tibble(Method = "Matrix Fatorization - recosystem",
    RMSE = RMSE(test_set$rating, y_hat_recon)))
result
```

Method	RMSE
Mean	1.0600537
Mean + bi	0.9429615
Mean + bi + bu	0.8646843
Regularized bi and bu	0.8641362
Matrix Fatorization - recosystem	0.7855035

3.3 Final Validation

As we can see from the result table, regularization alone achieved the lowest RMSE. So, finally we train the complete ‘edx’ set with the final model and calculate the RMSE in the ‘validation’ set.

```
mu_edx <- mean(edx$rating)

b_i_final <- edx %>%
  group_by(movieId) %>%
  summarize(b_i = sum(rating - mu_edx)/(n()+lambda))

b_u_final <- edx %>%
  left_join(b_i_final, by="movieId") %>%
  group_by(userId) %>%
```

```

summarize(b_u = sum(rating - b_i - mu_edx)/(n()+lambda))

y_hat_final <- validation %>%
  left_join(b_i_final, by = "movieId") %>%
  left_join(b_u_final, by = "userId") %>%
  mutate(pred = mu_edx + b_i + b_u) %>%
  pull(pred)

result <- bind_rows(result,
  tibble(Method = "Final (edx vs validation)",
    RMSE = RMSE(validation$rating, y_hat_final)))

# Show the RMSE improvement
result %>% knitr::kable()

```

Method	RMSE
Mean	1.0600537
Mean + bi	0.9429615
Mean + bi + bu	0.8646843
Regularized bi and bu	0.8641362
Matrix Factorization - recosystem	0.7855035
Final (edx vs validation)	0.8648177

As expected, the RMSE calculated on the ‘validation’ set is slightly higher than the value from the test set.

Top 10 best movies

```

validation %>%
  left_join(b_i_final, by = "movieId") %>%
  left_join(b_u_final, by = "userId") %>%
  mutate(pred = mu_edx + b_i + b_u) %>%
  arrange(-pred) %>%
  group_by(title) %>%
  select(title) %>%
  head(10)

```

title
Usual Suspects, The (1995)
Shawshank Redemption, The (1994)
Shawshank Redemption, The (1994)
Shawshank Redemption, The (1994)

title
Eternal Sunshine of the Spotless Mind (2004)
Star Wars: Episode IV - A New Hope (a.k.a. Star Wars) (1977)
Schindler's List (1993)
Donnie Darko (2001)
Star Wars: Episode VI - Return of the Jedi (1983)
Schindler's List (1993)

Top 10 worst movies

```
validation %>%
  left_join(b_i_final, by = "movieId") %>%
  left_join(b_u_final, by = "userId") %>%
  mutate(pred = mu_edx + b_i + b_u) %>%
  arrange(pred) %>%
  group_by(title) %>%
  select(title) %>%
  head(10)
```

title
Battlefield Earth (2000)
Police Academy 4: Citizens on Patrol (1987)
Karate Kid Part III, The (1989)
Pok��mon Heroes (2003)
Turbo: A Power Rangers Movie (1997)
Kazaam (1996)
Pok��mon Heroes (2003)
Free Willy 3: The Rescue (1997)
Shanghai Surprise (1986)
Steel (1997)

```
set.seed(1234, sample.kind = "Rounding")
```

```
## Warning in set.seed(1234, sample.kind = "Rounding"): non-uniform 'Rounding'
## sampler used
```

```
# Convert 'edx' and 'validation' sets to recomsystem input format
edx_final <- with(edx, data_memory(user_index = userId, item_index = movieId, rating = rating))
validation_final <- with(validation, data_memory(user_index = userId, item_index = movieId, rating = rating))

# Create the model object
```

```

r <- recosystem::Reco()

# Tune the parameters
opts <- r$tune(edx_final, opts = list(dim = c(10, 20, 30), lrate = c(0.1, 0.2),
                                     costp_l2 = c(0.01, 0.1),
                                     costq_l2 = c(0.01, 0.1),
                                     nthread = 4, niter = 10))

# Train the model
r$train(edx_final, opts = c(opts$min, nthread = 4, niter = 20))

```

```

## iter      tr_rmse      obj
##    0        0.9728 1.2040e+007
##    1        0.8761 9.9510e+006
##    2        0.8394 9.1857e+006
##    3        0.8174 8.7630e+006
##    4        0.8018 8.4849e+006
##    5        0.7900 8.2814e+006
##    6        0.7801 8.1294e+006
##    7        0.7719 8.0066e+006
##    8        0.7648 7.9076e+006
##    9        0.7587 7.8261e+006
##   10        0.7534 7.7574e+006
##   11        0.7487 7.6978e+006
##   12        0.7445 7.6469e+006
##   13        0.7406 7.6048e+006
##   14        0.7371 7.5639e+006
##   15        0.7340 7.5313e+006
##   16        0.7311 7.4978e+006
##   17        0.7284 7.4707e+006
##   18        0.7260 7.4449e+006
##   19        0.7238 7.4238e+006

```

```

# Calculate the prediction
y_hat_final <- r$predict(validation_final, out_memory())

result <- bind_rows(result,
                    tibble(Method = "Final Matrix Factorization - recosystem",
                           RMSE = RMSE(validation$rating, y_hat_final)))

# Show the RMSE improvement
result %>% knitr::kable()

```

Method	RMSE
Mean	1.0600537
Mean + bi	0.9429615
Mean + bi + bu	0.8646843
Regularized bi and bu	0.8641362
Matrix Fatorization - recosystem	0.7855035
Final (edx vs validation)	0.8648177
Final Matrix Fatorization - recosystem	0.7822912
Top 10 best movies:	

```
tibble(title = validation$title, rating = y_hat_final) %>%
  arrange(-rating) %>%
  group_by(title) %>%
  select(title) %>%
  head(10)
```

title
Lord of the Rings: The Return of the King, The (2003)
Schindler's List (1993)
Shawshank Redemption, The (1994)
Contempt (MÃ©pris, Le) (1963)
Shawshank Redemption, The (1994)
Star Wars: Episode IV - A New Hope (a.k.a. Star Wars) (1977)
Shawshank Redemption, The (1994)
Boys Life 2 (1997)
Fight Club (1999)
Star Wars: Episode V - The Empire Strikes Back (1980)

Top 10 worst movies:

```
tibble(title = validation$title, rating = y_hat_final) %>%
  arrange(rating) %>%
  group_by(title) %>%
  select(title) %>%
  head(10)
```

title
Dead Girl, The (2006)
Time Walker (a.k.a. Being From Another Planet) (1982)
Beast of Yucca Flats, The (1961)

title

Phish: Bittersweet Motel (2000)

Pok mon Heroes (2003)

Dirty Love (2005)

Horror Planet (a.k.a. Inseminoid) (1981)

Free Willy 2: The Adventure Home (1995)

Ernest in the Army (1998)

What Time Is It There? (Ni neibian jidian) (2001)

Chapter 4

Conclusion

This section gives a brief summary of the report, its limitations and future work (the last two are recommended but not necessary)

4.1 Limitations

Time is a major limitation to create and evaluate the machine learning models. This research is part of the capstone project of HarvardX's Data Science Professional Certificate¹ program, and the deadline to complete the project is tight.

Some machine learning algorithms are computationally expensive to run in a commodity laptop and therefore were unable to test. The amount of memory far exceeded the available in a commodity laptop, even with increased virtual memory.

4.2 Future Work

This report briefly discusses simple models that predicts ratings based on user-movie ratings. Modern recommendation systems should evaluate other predictor features, such as percentage of movie watched, bookmarks, purchases and comments to name a few. Adding extra features increases the model complexity and improves the estimation accuracy.

Other recommendation system packages are available in *The Comprehensive R Archive Network* (CRAN) website² and deserve evaluation. Example of such packages are `recommenderlab`, `rrecsys`, `slimrec` and `Myrrix`.

¹<https://www.edx.org/professional-certificate/harvardx-data-science>

²https://cran.r-project.org/web/packages/available_packages_by_name.html

References

Rafael A. Irizarry (2019), [Introduction to Data Science: Data Analysis and Prediction Algorithms with R](#)

Yixuan Qiu (2017), [recosystem: Recommender System Using Parallel Matrix Factorization](#)

Michael Hahsler (2019), [recommenderlab: Lab for Developing and Testing Recommender Algorithms. R package version 0.2-5.](#)