Basics of Statistical Learning

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2019-08-30

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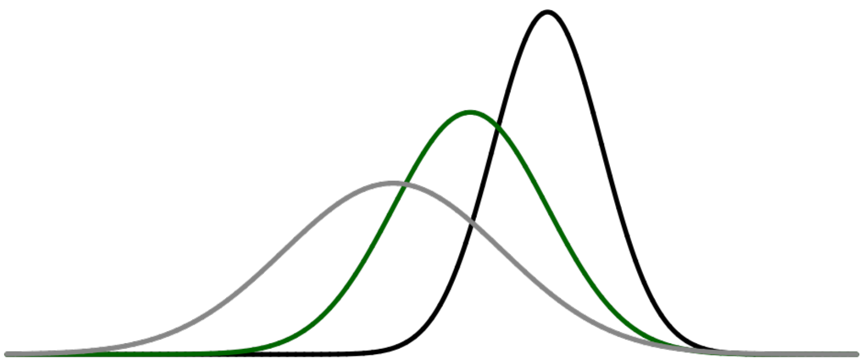
Preface



Welcome to Basics of Statistical Learning!

- TODO: Warning about development.
- TODO: Warning about PDF version.
- TODO: Transfer acknowledgements.
- TODO: discuss https://daviddalpiaz.github.io/r4sl/

License

Chapter 1

Introduction

```r
library(readr)
library(tibble)
library(dplyr)
library(purrr)
library(ggplot2)
library(ggridges)
library(lubridate)
library(randomForest)
library(rpart)
library(rpart.plot)
library(cluster)
library(caret)
library(factoextra)
library(rsample)
library(janitor)
library(rvest)
library(dendextend)
library(knitr)
library(kableExtra)
library(ggthemes)
```

- TODO: Show package messaging? check conflicts!
- TODO: Should this be split into three analyses with different packages?

1.1 Regression: Powerlifting

1.1.1 Background

- TODO: https://www.openpowerlifting.org/
- TODO: https://en.wikipedia.org/wiki/Powerlifting

1.1.2 Data

- TODO: Why readr::col_factor() and not just col_factor()?
- TODO: Characters should be character and "categories" should be factors.
- TODO: Is `na.omit()` actually a good idea?

```
pl = read_csv("data/pl.csv", col_types = cols(Sex = readr::col_factor()))
```

```
pl
```

```
## # A tibble: 3,604 x 8
##    Name             Sex   Bodyweight   Age Squat Bench Deadlift Total
##    <chr>            <fct>      <dbl> <dbl> <dbl> <dbl>    <dbl> <dbl>
##  1 Ariel Stier      F           60      32 128.   72.5     150   350
##  2 Nicole Bueno     F           60      26 110    60       135   305
##  3 Lisa Peterson    F           67.5    28 118.   67.5     138.  322.
##  4 Shelby Bandula   F           67.5    26  92.5  67.5     140   300
##  5 Lisa Lindhorst   F           67.5    28  92.5  62.5     132.  288.
##  6 Laura Burnett    F           67.5    30  90    45       108.  242.
##  7 Suzette Bradley  F           75      38 125    75       158.  358.
##  8 Norma Romero     F           75      20  92.5  42.5     125   260
##  9 Georgia Andrews  F           82.5    29 108.   52.5     120   280
## 10 Christal Bundang F           90      30 100    55       125   280
## # ... with 3,594 more rows
```

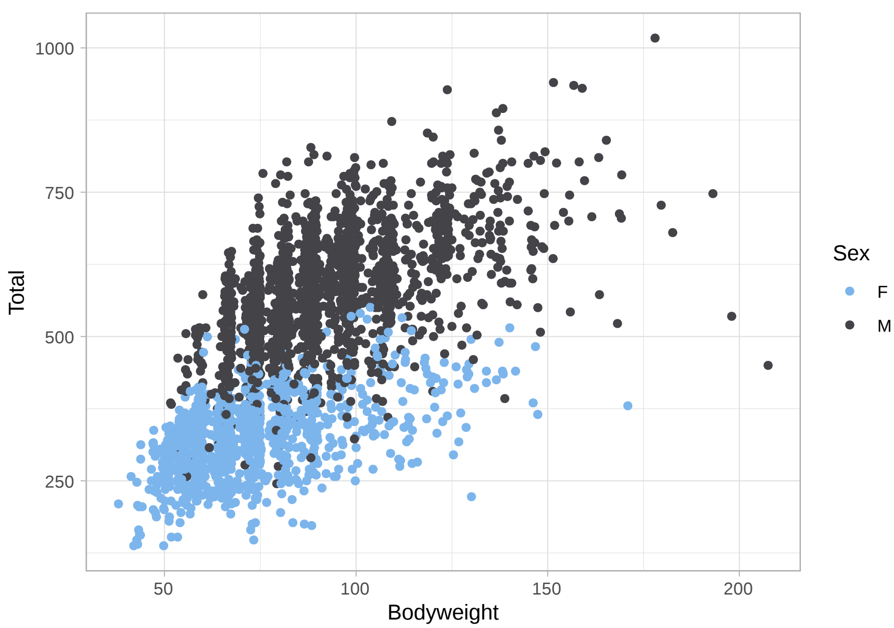
1.1.3 EDA

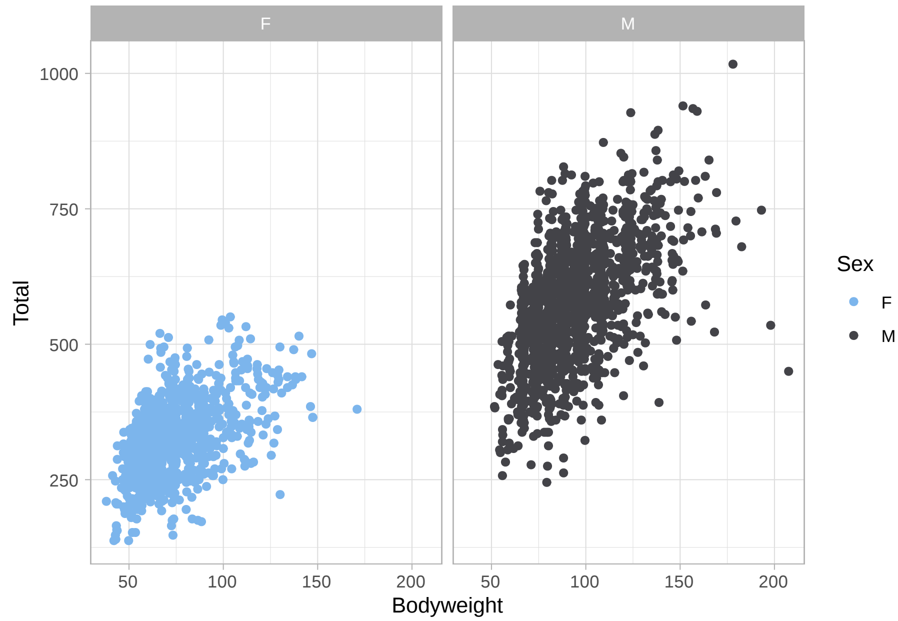
```
set.seed(1)

# test-train split
pl_tst_trn_split = initial_split(pl, prop = 0.80)
pl_trn = training(pl_tst_trn_split)
pl_tst = testing(pl_tst_trn_split)

# estimation-validation split
pl_est_val_split = initial_split(pl_trn, prop = 0.80)
```

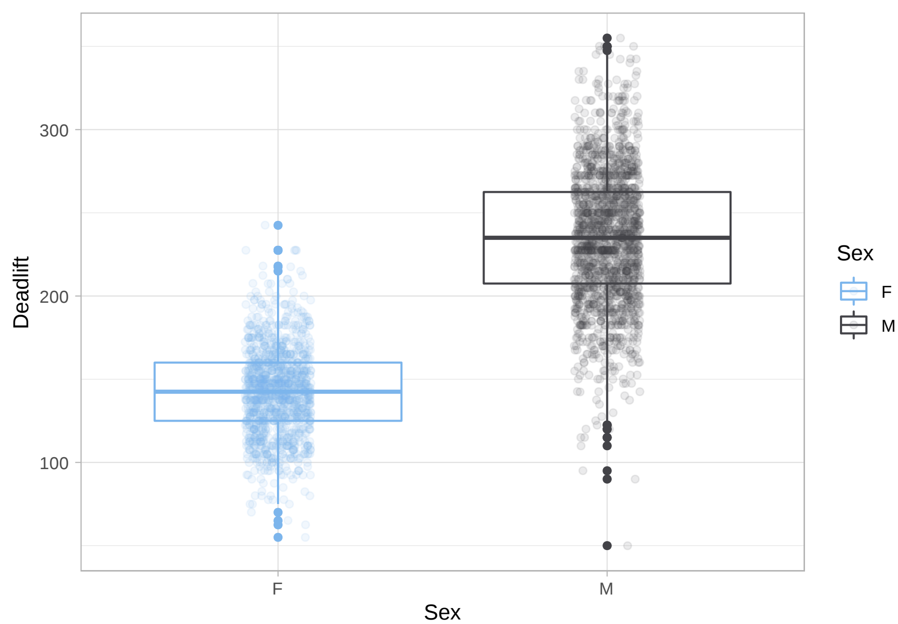
```r
pl_est = training(pl_est_val_split)
pl_val = testing(pl_est_val_split)
```

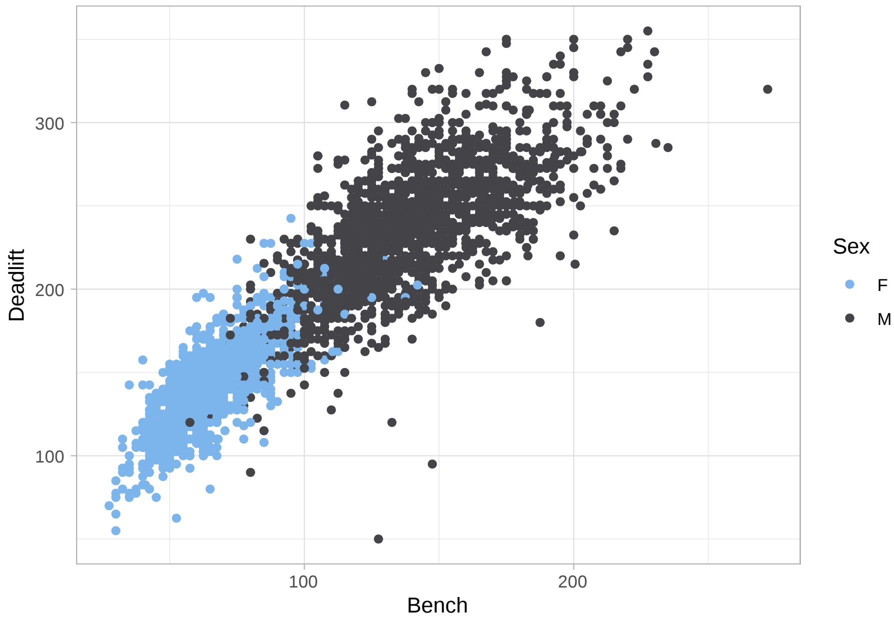
```r
rm(pl)
```

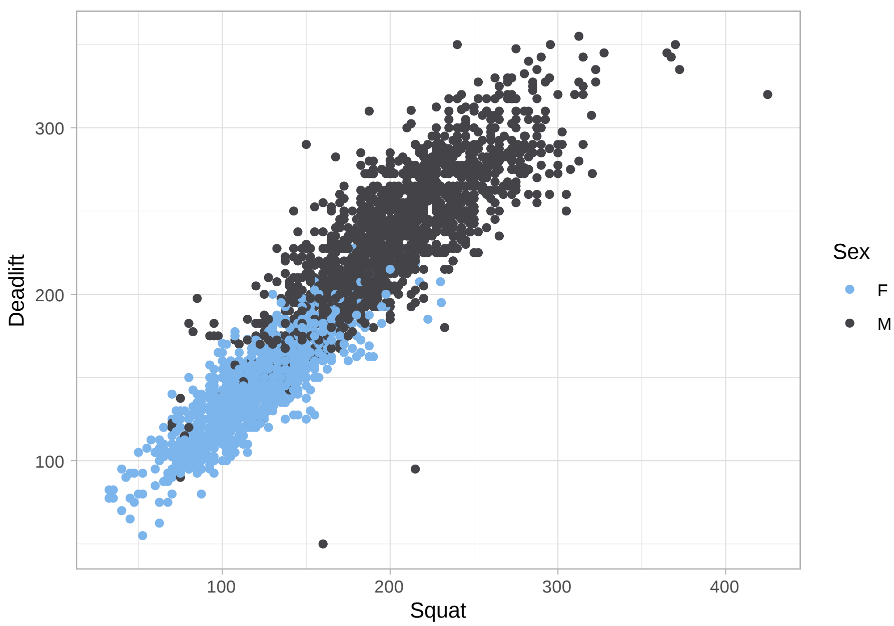
- TODO: Train can be used however you want. (Including EDA.)
- TODO: Test can only be used after all model decisions have been made!




F
M
1000
750
500
250
Total
50
100
150
200
Bodyweight
Sex
F
M


300
200
100
Deadlift
F
M
Sex
Sex
F
M

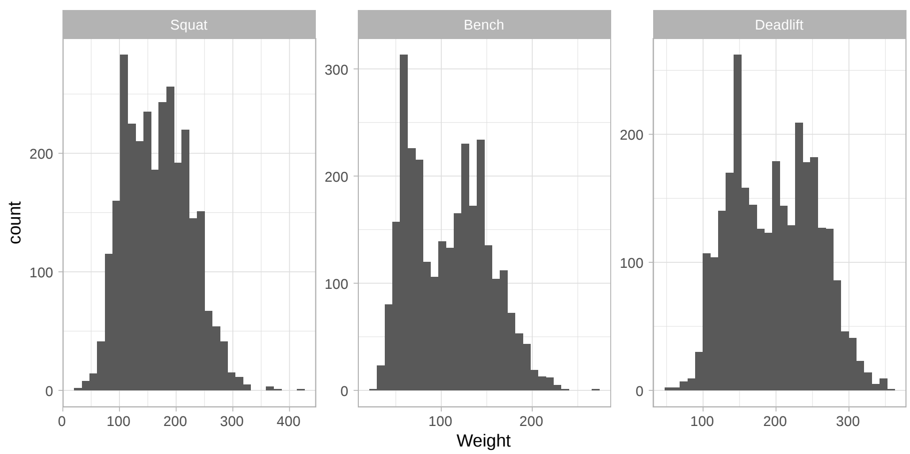


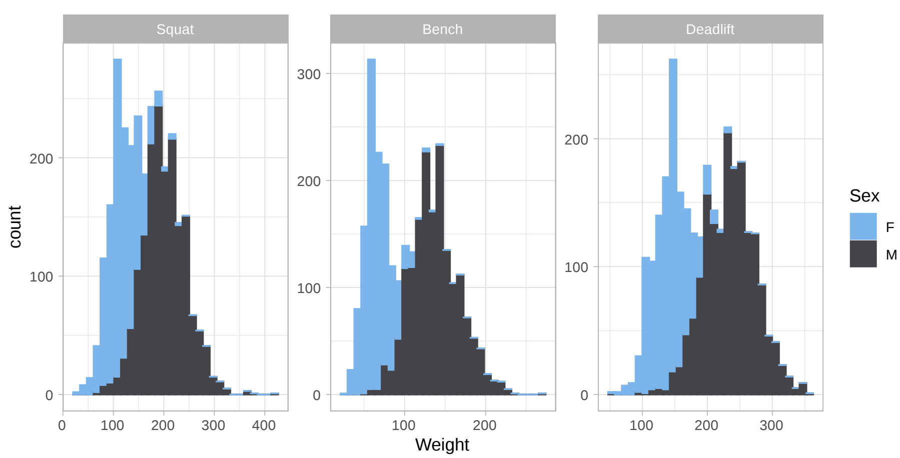


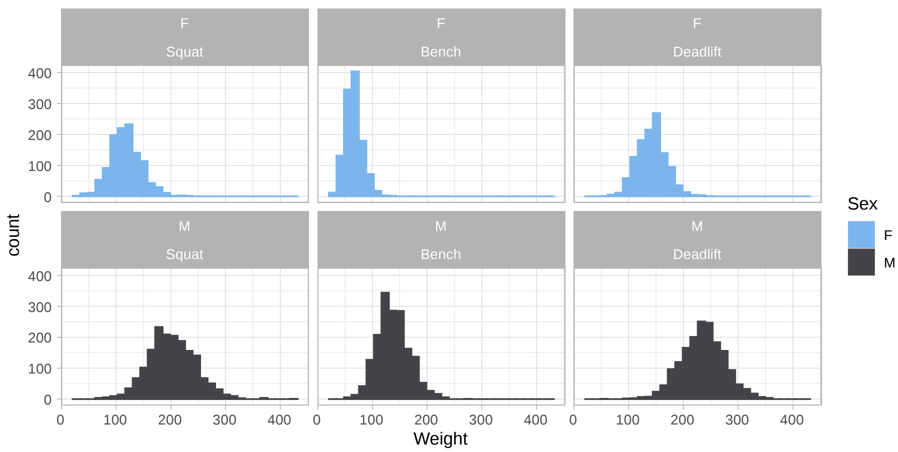

```
pl_trn_tidy = gather(pl_trn, key = "Lift", value = "Weight",
                     Squat, Bench, Deadlift)
```

```
pl_trn_tidy$Lift = factor(pl_trn_tidy$Lift, levels = c("Squat", "Bench", "Deadlift"))
```

- TODO: https://www.tidyverse.org/
- TODO: https://en.wikipedia.org/wiki/Tidy_data
- TODO: http://vita.had.co.nz/papers/tidy-data.pdf





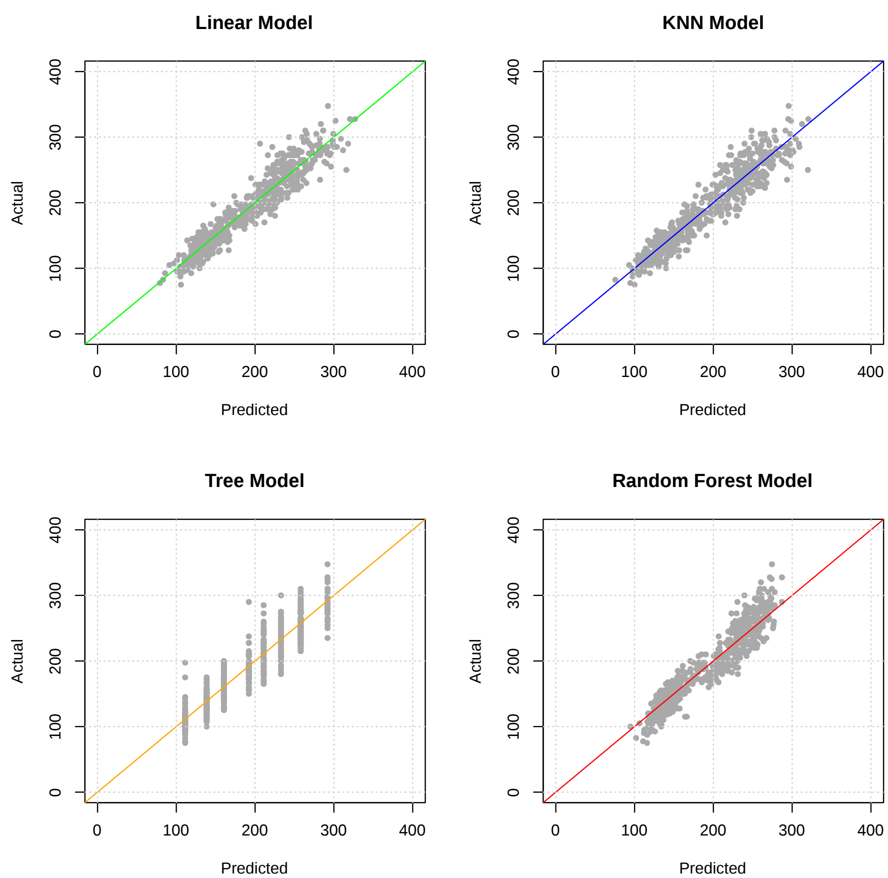


1.1.4 Modeling

```
dl_mod_form = formula(Deadlift ~ Sex + Bodyweight + Age + Squat + Bench)

set.seed(1)
lm_mod  = lm(dl_mod_form, data = pl_est)
knn_mod = caret::knnreg(dl_mod_form, data = pl_est)
rf_mod  = randomForest(dl_mod_form, data = pl_est)
rp_mod = rpart(dl_mod_form, data = pl_est)
```

- TODO: Note: we are not using `Name`. Why? We are not using `Total`. Why?
- TODO: look what happens with `Total`! You'll see it with `lm()`, you'll be optimistic with `randomForest()`.
- TODO: What variables are allowed? (With respect to real world problem.)
- TODO: What variables lead to the best predictions?

1.1.5 Model Evaluation




```
calc_rmse = function(actual, predicted) {
  sqrt(mean((actual - predicted) ^ 2))
}
```

```
c(calc_rmse(actual = pl_val$Deadlift, predicted = predict(lm_mod, pl_val)),
  calc_rmse(actual = pl_val$Deadlift, predicted = predict(knn_mod, pl_val)),
  calc_rmse(actual = pl_val$Deadlift, predicted = predict(rp_mod, pl_val)),
  calc_rmse(actual = pl_val$Deadlift, predicted = predict(rf_mod, pl_val)))
```

```
## [1] 18.26654 19.19625 21.68142 19.23643
```

```
reg_preds = map(list(lm_mod, knn_mod, rp_mod, rf_mod), predict, pl_val)
map_dbl(reg_preds, calc_rmse, actual = pl_val$Deadlift)
```

```
## [1] 18.26654 19.19625 21.68142 19.23643
```

- TODO: **Never** supply `data = df` to `predict()`. You have been warned.

```
knitr::include_graphics("img/sim-city.jpg")
```


```
calc_mae = function(actual, predicted) {
  mean(abs(actual - predicted))
}
```

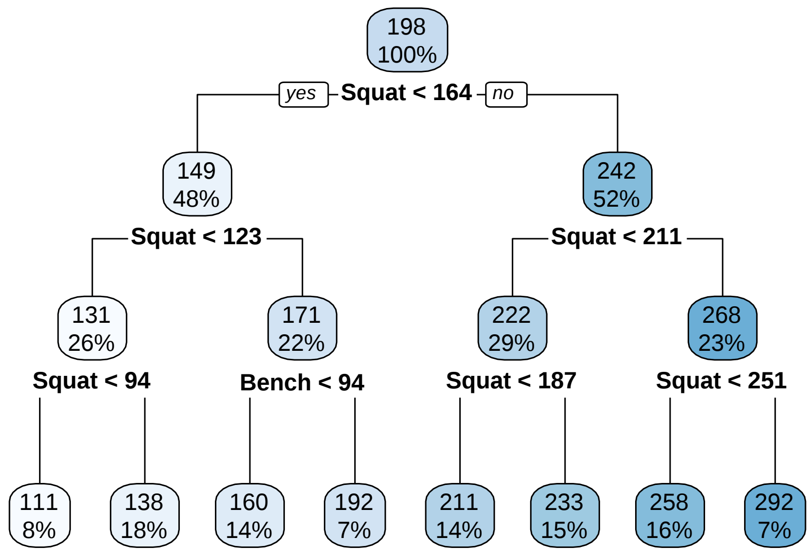
```
map_dbl(reg_preds, calc_mae,  actual = pl_val$Deadlift)
```

```
## [1] 14.38953 14.99748 17.14823 15.28626
```

```
reg_results = tibble(
  Model = c("Linear", "KNN", "Tree", "Forest"),
  RMSE = map_dbl(reg_preds, calc_rmse, actual = pl_val$Deadlift),
  MAE = map_dbl(reg_preds, calc_mae,  actual = pl_val$Deadlift))
```

Model	RMSE	MAE
Linear	18.26654	14.38953
KNN	19.19625	14.99748
Tree	21.68142	17.14823
Forest	19.23643	15.28626

1.1.6 Discussion




```r
lm_mod_final = lm(dl_mod_form, data = pl_trn)
```

```r
calc_rmse(actual = pl_tst$Deadlift,
          predicted = predict(lm_mod_final, pl_tst))
```

```
## [1] 22.29668
```

- TODO: Is this a good model?
- TODO: Is this model useful?

```r
william_biscarri = tibble(
  Name = "William Biscarri",
  Age = 28,
  Sex = "M",
  Bodyweight = 83,
  Squat = 130,
  Bench = 90
)
```

```r
predict(lm_mod_final, william_biscarri)
```

```
##       1
## 175.495
```

1.2 Classification: Handwritten Digits

1.2.1 Background

- TODO: https://en.wikipedia.org/wiki/MNIST_database
- TODO: http://yann.lecun.com/exdb/mnist/

1.2.2 Data

- TODO: How is this data pre-processed?
- TODO: https://gist.github.com/daviddalpiaz/ae62ae5ccd0bada4b9acd6dbc9008706
- TODO: https://github.com/itsrainingdata/mnistR
- TODO: https://pjreddie.com/projects/mnist-in-csv/
- TODO: http://varianceexplained.org/r/digit-eda/

```
mnist_trn = read_csv(file = "data/mnist_train_subest.csv")
mnist_tst = read_csv(file = "data/mnist_test.csv")
```

```
mnist_trn_y = as.factor(mnist_trn$X1)
mnist_tst_y = as.factor(mnist_tst$X1)

mnist_trn_x = mnist_trn[, -1]
mnist_tst_x = mnist_tst[, -1]
```

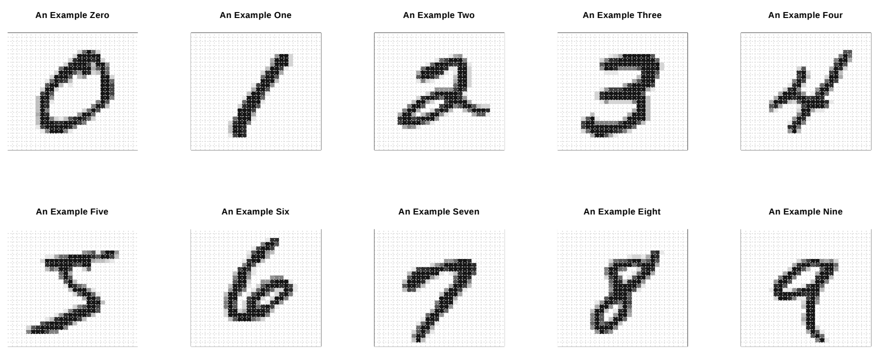
- TODO: If we were going to tune a model, we would need a validation split as well. We're going to be lazy and just fit a single random forest.
- TODO: This is an agreed upon split.

1.2.3 EDA

```
pixel_positions = expand.grid(j = sprintf("%02.0f", 1:28),
                              i = sprintf("%02.0f", 1:28))
pixel_names = paste("pixel", pixel_positions$i, pixel_positions$j, sep = "-")
```

```
colnames(mnist_trn_x) = pixel_names
colnames(mnist_tst_x) = pixel_names
```

```
show_digit = function(arr784, col = gray(12:1 / 12), ...) {
  image(matrix(as.matrix(arr784), nrow = 28)[, 28:1],
        col = col, xaxt = "n", yaxt = "n", ...)
  grid(nx = 28, ny = 28)
}
```



1.2.4 Modeling

```r
set.seed(42)
mnist_rf = randomForest(x = mnist_trn_x, y = mnist_trn_y, ntree = 100)
```

1.2.5 Model Evaluation

```r
mnist_tst_pred = predict(mnist_rf, mnist_tst_x)
mean(mnist_tst_pred == mnist_tst_y)
```

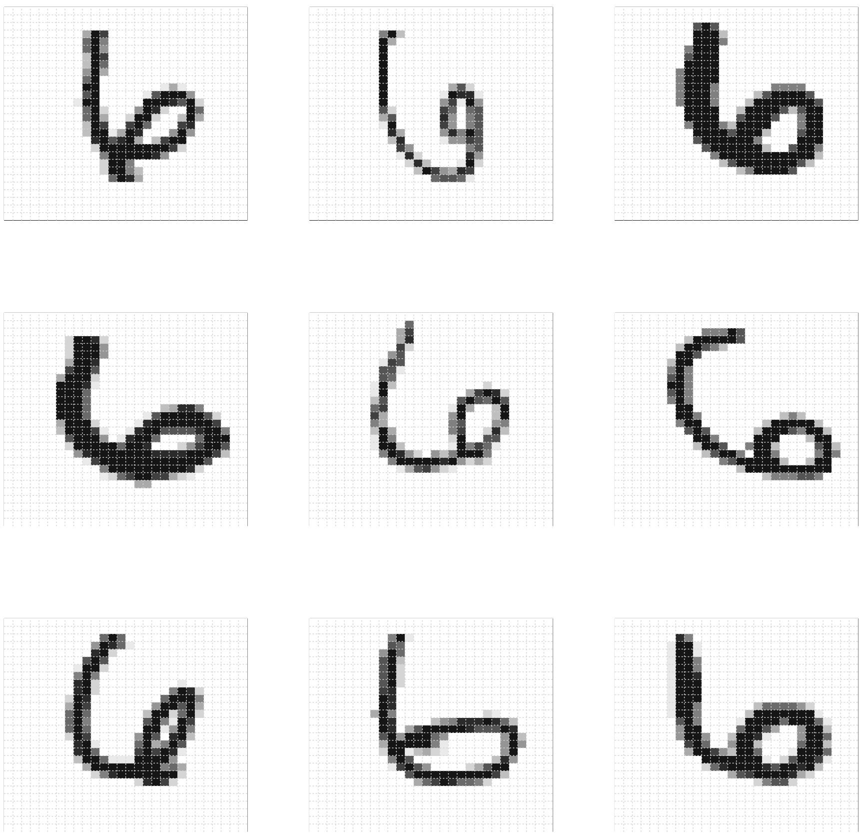
```
## [1] 0.8839
```

```r
table(predicted = mnist_tst_pred, actual = mnist_tst_y)
```

```
##          actual
## predicted    0    1    2    3    4    5    6    7    8    9
##         0  959    0   14    6    1   15   22    1   10   10
##         1    0 1112    5    5    1   16    5    9    5    6
##         2    1    2  928   31    3    5   19   24   17    8
##         3    0    2   11  820    1   24    0    1   13   13
##         4    4    0   13    1  839   21   39   11   18   40
##         5    3    1    1   88    3  720   18    1   25    9
##         6    7    2   15    3   25   15  848    0   18    2
##         7    2    1   29   24    1   14    2  928   15   30
##         8    4   14   13   22    5   19    5    4  797    3
##         9    0    1    3   10  103   43    0   49   56  888
```

1.2.6 Discussion

```
par(mfrow = c(3, 3))
plot_mistake(actual = 6, predicted = 4)
```



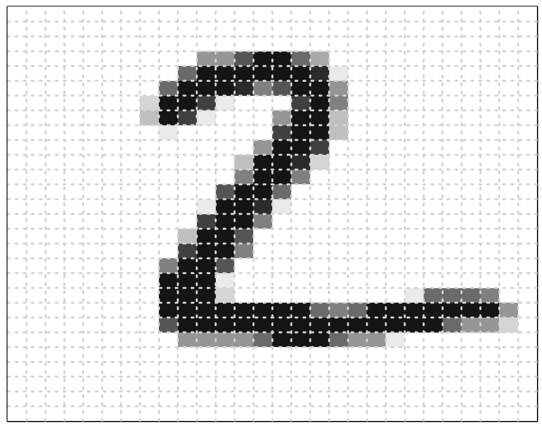
```
mnist_obs_to_check = 2
predict(mnist_rf, mnist_tst_x[mnist_obs_to_check, ], type = "prob")[1, ]
```

```
##    0    1    2    3    4    5    6    7    8    9
## 0.09 0.03 0.25 0.14 0.02 0.14 0.25 0.01 0.05 0.02
```

```
mnist_tst_y[mnist_obs_to_check]
```

```
## [1] 2
## Levels: 0 1 2 3 4 5 6 7 8 9
```

```
show_digit(mnist_tst_x[mnist_obs_to_check, ])
```



1.3 Clustering: NBA Players

1.3.1 Background

- https://www.youtube.com/watch?v=cuLprHh_BRg
- https://www.youtube.com/watch?v=1FBwSO_1Mb8
- https://www.basketball-reference.com/leagues/NBA_2019.html

1.3.2 Data

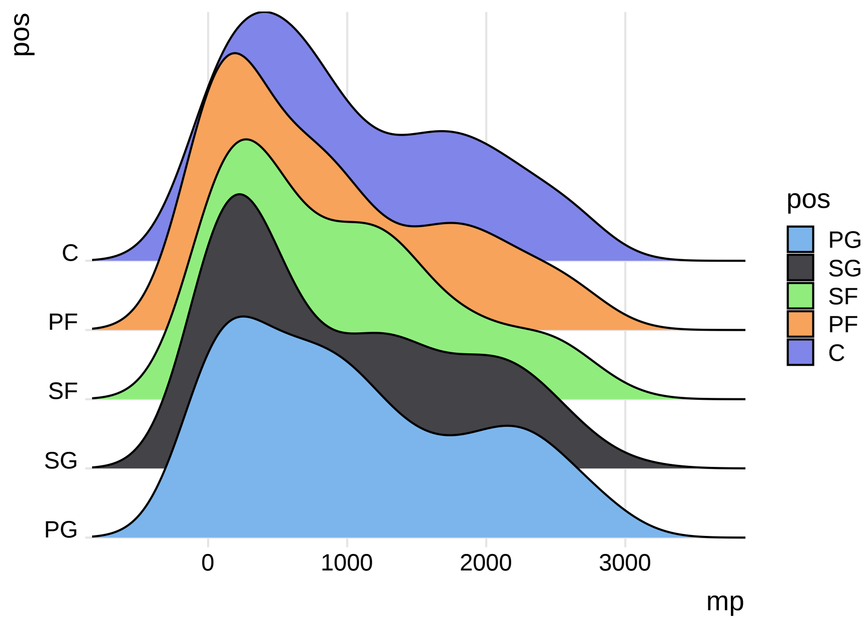
- https://www.basketball-reference.com/leagues/NBA_2019_totals.html
- https://www.basketball-reference.com/leagues/NBA_2019_per_minute.html

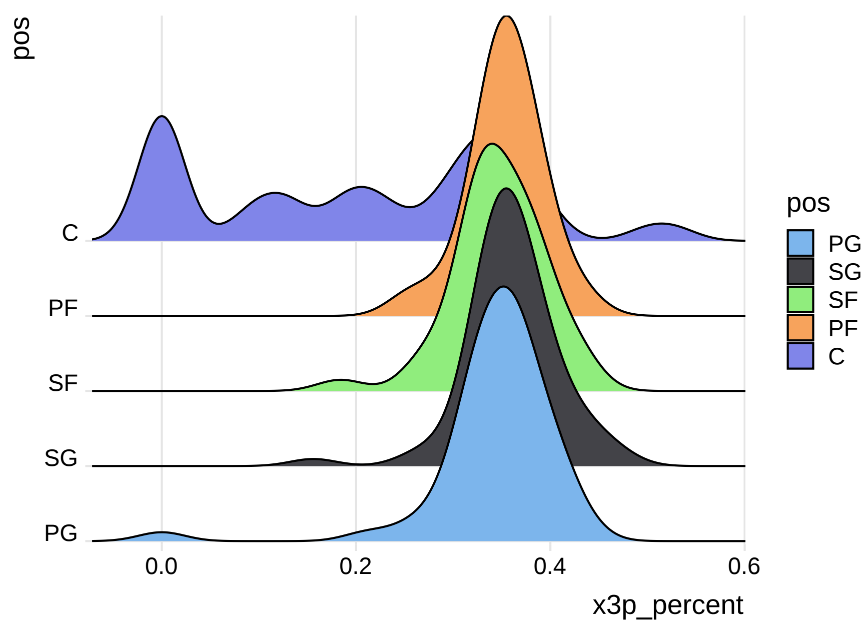
- https://www.basketball-reference.com/leagues/NBA_2019_per_poss.html
- https://www.basketball-reference.com/leagues/NBA_2019_advanced.html

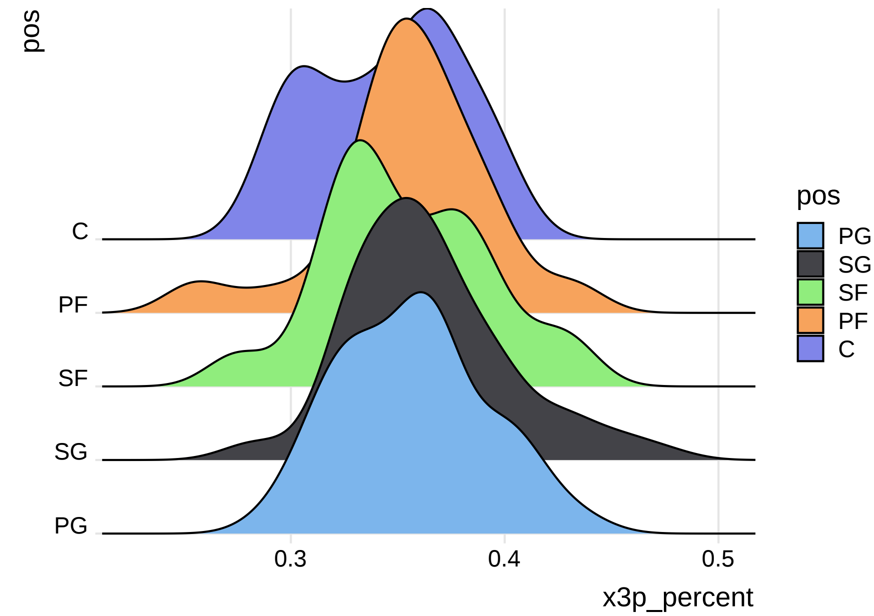
```r
nba = scrape_nba_season_player_stats()
nba$pos = factor(nba$pos, levels = c("PG", "SG", "SF", "PF", "C"))
```

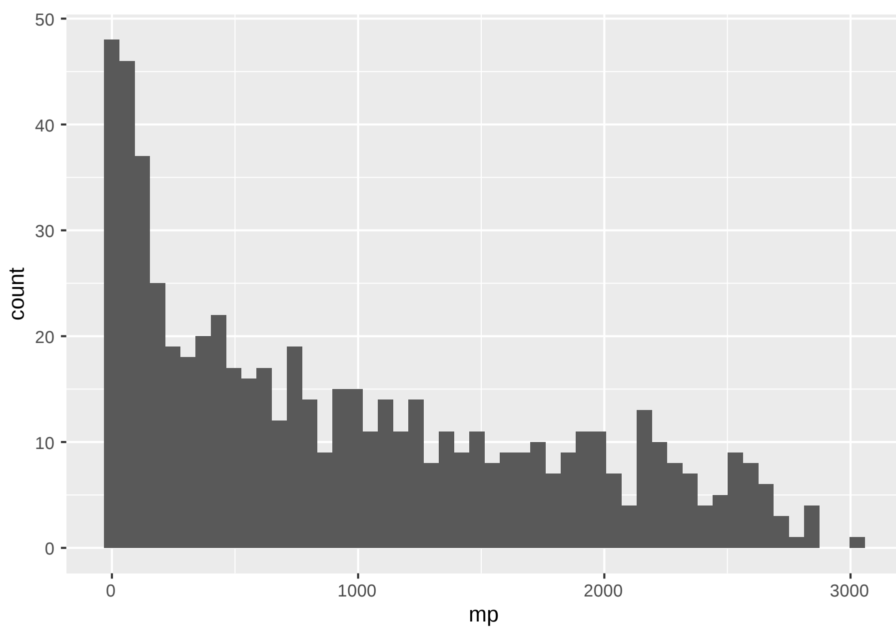
```
## # A tibble: 100 x 93
##    player_team pos     age tm        g    gs    mp    fg   fga fg_percent
##    <chr>       <fct> <dbl> <chr> <dbl> <dbl> <dbl> <dbl> <dbl>      <dbl>
##  1 Álex Abrin~ SG       25 OKC      31     2   588    56   157      0.357
##  2 Quincy Acy~ PF       28 PHO      10     0   123     4    18      0.222
##  3 Jaylen Ada~ PG       22 ATL      34     1   428    38   110      0.345
##  4 Steven Ada~ C        25 OKC      80    80  2669   481   809      0.595
##  5 Bam Adebay~ C        21 MIA      82    28  1913   280   486      0.576
##  6 Deng Adel ~ SF       21 CLE      19     3   194    11    36      0.306
##  7 DeVaughn A~ SG       25 DEN       7     0    22     3    10      0.3
##  8 LaMarcus A~ C        33 SAS      81    81  2687   684  1319      0.519
##  9 Rawle Alki~ SG       21 CHI      10     1   120    13    39      0.333
## 10 Grayson Al~ SG       23 UTA      38     2   416    67   178      0.376
## # ... with 90 more rows, and 83 more variables: x3p <dbl>, x3pa <dbl>,
## #   x3p_percent <dbl>, x2p <dbl>, x2pa <dbl>, x2p_percent <dbl>,
## #   e_fg_percent <dbl>, ft <dbl>, fta <dbl>, ft_percent <dbl>, orb <dbl>,
## #   drb <dbl>, trb <dbl>, ast <dbl>, stl <dbl>, blk <dbl>, tov <dbl>,
## #   pf <dbl>, pts <dbl>, fg_pm <dbl>, fga_pm <dbl>, fg_percent_pm <dbl>,
## #   x3p_pm <dbl>, x3pa_pm <dbl>, x3p_percent_pm <dbl>, x2p_pm <dbl>,
## #   x2pa_pm <dbl>, x2p_percent_pm <dbl>, ft_pm <dbl>, fta_pm <dbl>,
## #   ft_percent_pm <dbl>, orb_pm <dbl>, drb_pm <dbl>, trb_pm <dbl>,
## #   ast_pm <dbl>, stl_pm <dbl>, blk_pm <dbl>, tov_pm <dbl>, pf_pm <dbl>,
## #   pts_pm <dbl>, fg_pp <dbl>, fga_pp <dbl>, fg_percent_pp <dbl>,
## #   x3p_pp <dbl>, x3pa_pp <dbl>, x3p_percent_pp <dbl>, x2p_pp <dbl>,
## #   x2pa_pp <dbl>, x2p_percent_pp <dbl>, ft_pp <dbl>, fta_pp <dbl>,
## #   ft_percent_pp <dbl>, orb_pp <dbl>, drb_pp <dbl>, trb_pp <dbl>,
## #   ast_pp <dbl>, stl_pp <dbl>, blk_pp <dbl>, tov_pp <dbl>, pf_pp <dbl>,
## #   pts_pp <dbl>, o_rtg_pp <dbl>, d_rtg_pp <dbl>, per <dbl>,
## #   ts_percent <dbl>, x3p_ar <dbl>, f_tr <dbl>, orb_percent <dbl>,
## #   drb_percent <dbl>, trb_percent <dbl>, ast_percent <dbl>,
## #   stl_percent <dbl>, blk_percent <dbl>, tov_percent <dbl>,
## #   usg_percent <dbl>, ows <dbl>, dws <dbl>, ws <dbl>, ws_48 <dbl>,
## #   obpm <dbl>, dbpm <dbl>, bpm <dbl>, vorp <dbl>
```

1.3.3 EDA


pos
C
PF
SF
SG
PG
0
1000
2000
3000
mp
pos
PG
SG
SF
PF
C


pos
C
PF
SF
SG
PG
0.0
0.2
0.4
0.6
x3p_percent
pos
PG
SG
SF
PF
C

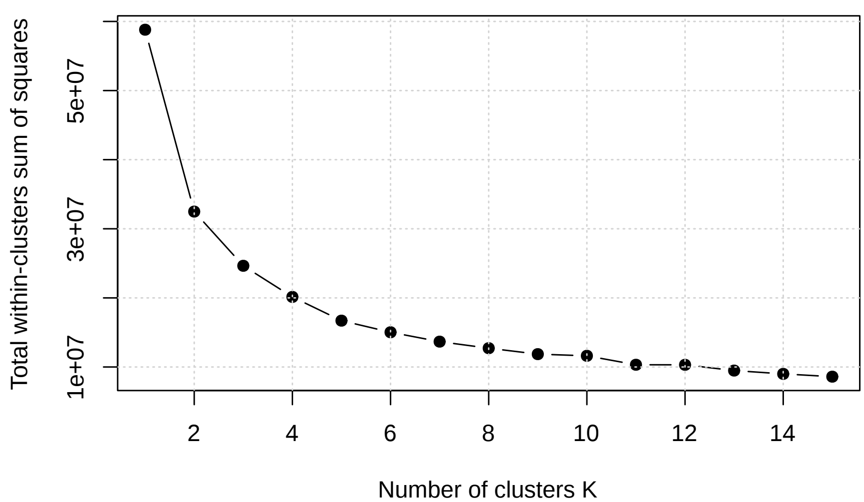





```
nba_for_clustering = nba %>%
  filter(mp > 2000) %>%
  column_to_rownames("player_team") %>%
  select(-pos, -tm)
```

1.3.4 Modeling

```
set.seed(42)

# function to compute total within-cluster sum of square
wss = function(k, data) {
  kmeans(x = data, centers = k, nstart = 10)$tot.withinss
}

# Compute and plot wss for k = 1 to k = 15
k_values = 1:15

# extract wss for 2-15 clusters
wss_values = map_dbl(k_values, wss, data = nba_for_clustering)

plot(k_values, wss_values,
       type="b", pch = 19, frame = TRUE,
       xlab="Number of clusters K",
       ylab="Total within-clusters sum of squares")
grid()
```

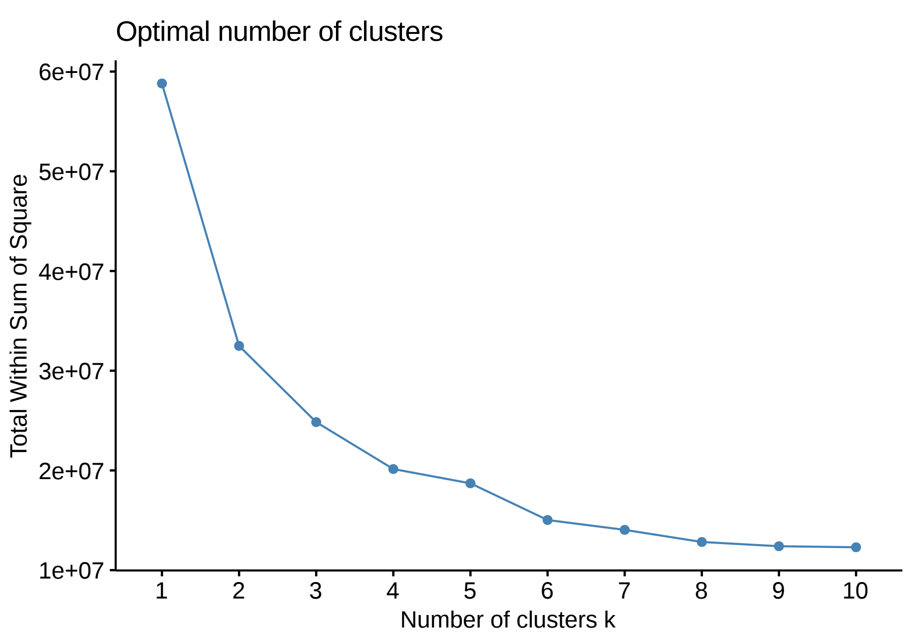


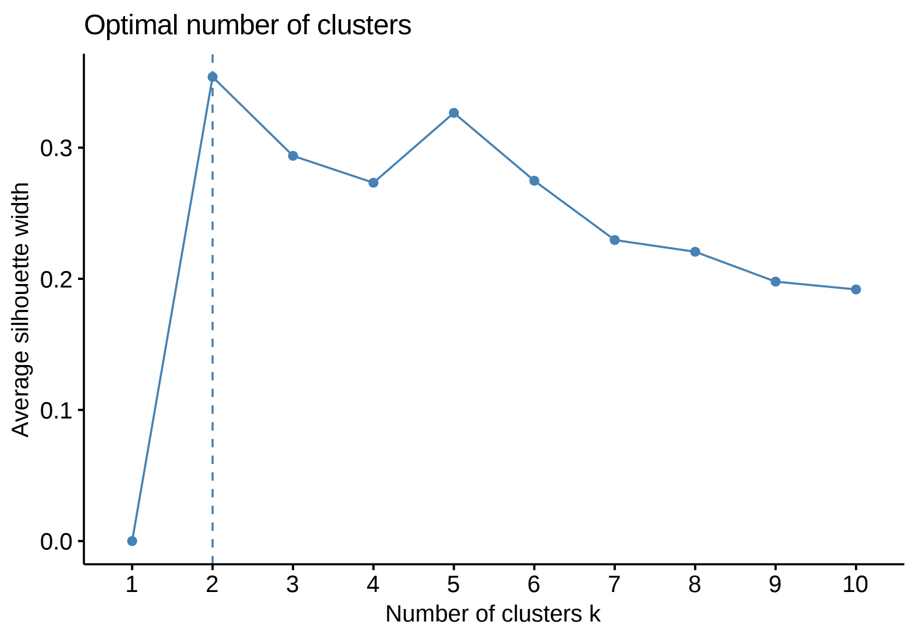
- TODO: K-Means likes clusters of roughly equal size.
- TODO: http://varianceexplained.org/r/kmeans-free-lunch/

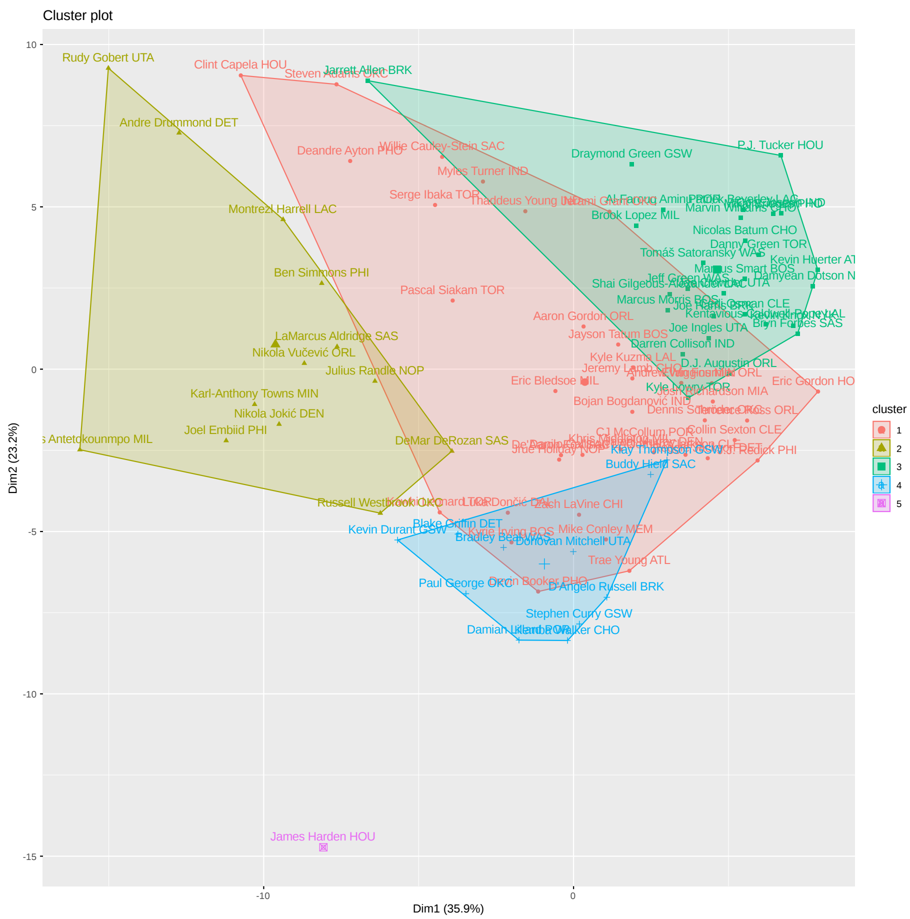
```r
nba_hc = hclust(dist(nba_for_clustering))
nba_hc_clust = cutree(nba_hc, k = 5)
table(nba_hc_clust)
```

```
## nba_hc_clust
##  1  2  3  4  5
## 38 13 28 11  1
```

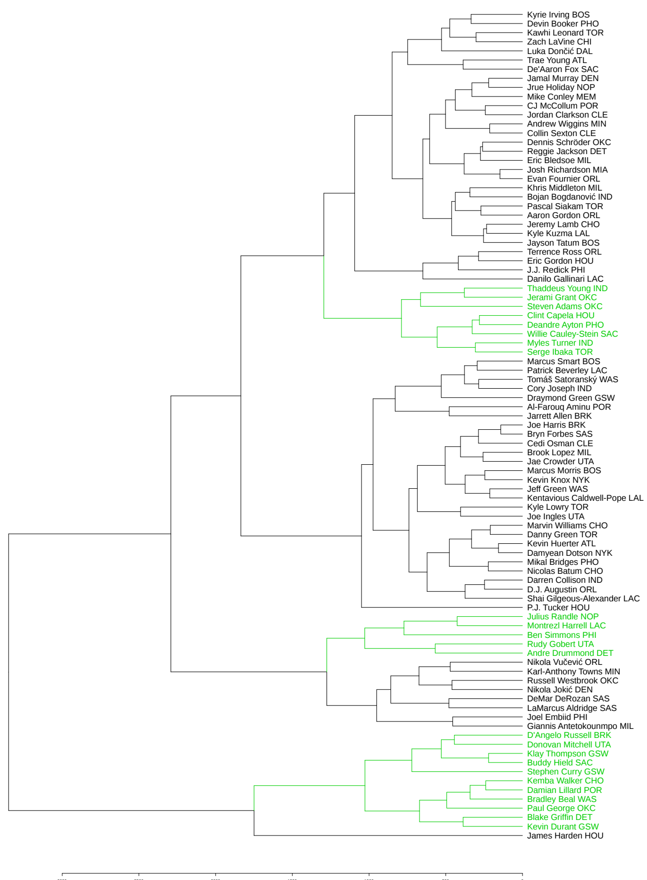
1.3.5 Model Evaluation




Optimal number of clusters
Average silhouette width
0.0
0.1
0.2
0.3
1
2
3
4
5
6
7
8
9
10
Number of clusters k


Cluster plot
Rudy Gobert UTA
Clint Capela HOU
Jarrett Allen BRK
Andre Drummond DET
Deandre Ayton PHO
Willie Cauley-Stein SAC
Draymond Green GSW
P.J. Tucker HOU
Myles Turner IND
Serge Ibaka TOR
Montrezl Harrell LAC
Brook Lopez MIL
Marvin Williams CHO
Nicolas Batum CHO
Danny Green TOR
Tomáš Satoranský WAS
Ben Simmons PHI
Marcus Smart BOS
Pascal Siakam TOR
Jeff Green WAS
Aaron Gordon ORL
Jayson Tatum BOS
Joe Ingles UTA
Darren Collison IND
LaMarcus Aldridge SAS
Nikola Vučević ORL
Julius Randle NOP
Kyle Kuzma LAL
D.J. Augustin ORL
Eric Bledsoe MIL
Kyle Lowry TOR
Karl-Anthony Towns MIN
Bojan Bogdanović IND
Nikola Jokić DEN
Joel Embiid PHI
Collin Sexton CLE
CJ McCollum POR
DeMar DeRozan SAS
Buddy Hield SAC
Russell Westbrook OKC
Zach LaVine CHI
Kevin Durant GSW
Blake Griffin DET
Mike Conley MEM
Donovan Mitchell UTA
Trae Young ATL
Paul George OKC
D'Angelo Russell BRK
Stephen Curry GSW
James Harden HOU
Dim1 (35.9%)
Dim2 (23.2%)
10
5
0
-5
-10
-15
-10
0
cluster
1
2
3
4
5

1.3.6 Discussion



Chapter 2

Computing

This is not a book about R.

- TODO: Set of readings to do. (R4DS, ADVR, ?)
- Applied Statistics with R
- R for Data Science
- Advanced R
- Hands-On Programming with R

2.1 Resources

2.1.1 R

- Efficient R programming
- R Programming for Data Science
- R Graphics Cookbook
- Modern Dive
- ? The `tidyverse` Website
  - ? `dplyr` Website
  - ? `readr` Website
  - ? `tibble` Website
  - ? `forcats` Website

2.1.2 RStudio

- https://resources.rstudio.com/rstudio-cheatsheets/rstudio-ide-cheat-sheet

- https://resources.rstudio.com/

2.1.3 R Markdown

- https://resources.rstudio.com/rstudio-cheatsheets/rmarkdown-2-0-cheat-sheet
- https://bookdown.org/yihui/rmarkdown/
- https://daringfireball.net/projects/markdown/basics
- https://guides.github.com/features/mastering-markdown/
- https://commonmark.org/

2.2 BSL Idioms

Things here supercede everythign above.

2.2.1 Style

- https://style.tidyverse.org/