

# Chapter 02: Statistical Learning

## Solutions to Exercises

January 11, 2023

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### CONCEPTUAL

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#### EXERCISE 1:

##### **Part a)**

flexible learning method would perform **better** because sample size is large enough to fit more parameters and small number of predictors limits model variance

##### **Part b)**

flexible learning method would perform **worse** because it would be more likely to overfit

##### **Part c)**

flexible learning method would perform **better** because it is less restrictive on the shape of fit

##### **Part d)**

flexible learning method would perform **worse** because it would be more likely to overfit

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#### EXERCISE 2:

##### **Part a)**

- regression
- inference
- $n = 500$  observations
- $p = 3$  variables
  - profit
  - number of employees
  - industry

##### **Part b)**

- classification
- prediction
- $n = 20$  observations

- $p = 13$  variables
  - price charged
  - marketing budget
  - competition price
  - *ten other variables*

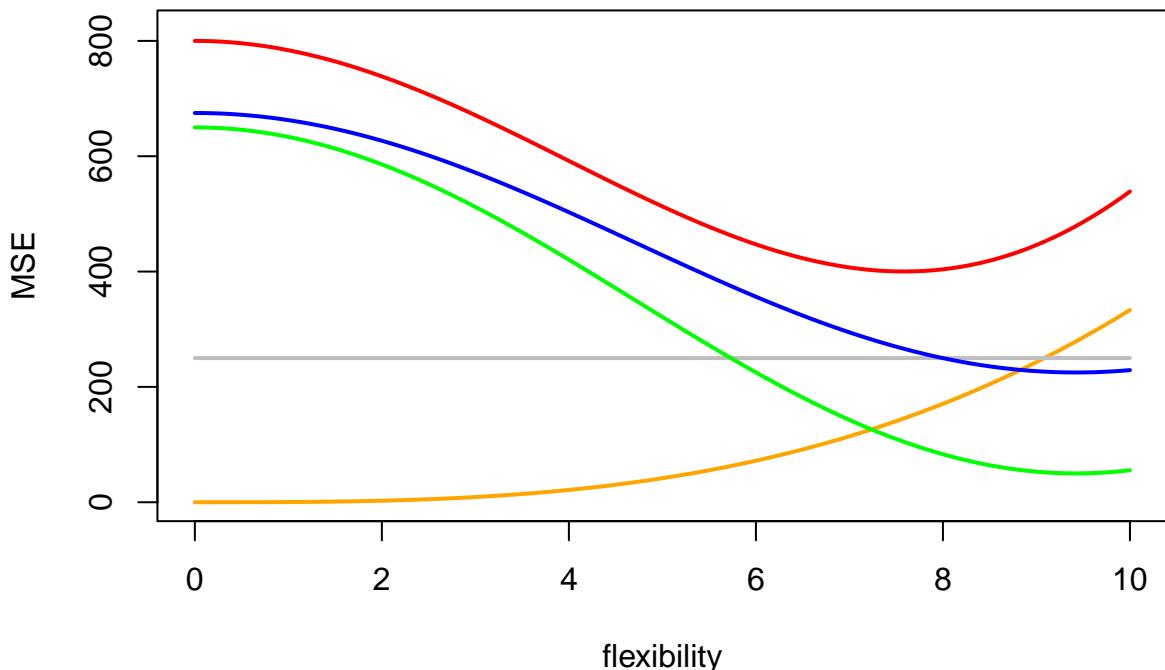
**Part c)**

- regression
  - prediction (predicting the quantitative value of the % change of USD)
  - $n = 52$  weekly observations
  - $p = 3$  variables
    - change in the US market
    - change in the British market
    - change in the German market
- 

EXERCISE 3:

**Part a)**

- red = test error
- orange = estimator variance
- green = model bias
- gray = irreducible error
- blue = train error



### Part b)

- **variance** will increase with higher flexibility because changing data points will have more effect on the parameter estimates
  - **bias** will decrease with higher flexibility because there are fewer assumptions made about the shape of the fit
  - **test error** will have a U-shaped curve because it reflects the interaction between **variance** and **bias**
  - **irreducible error** is the same regardless of model fit
  - **train error** will always decrease with more model flexibility because an overfit model will produce lower MSE on the training data
- 

### EXERCISE 4:

#### Part a)

- win/loss in basketball game
  - Response: team win or loss
  - Predictors: team strength/weakness, opponent strength/weakness, player injuries
  - Goal: both prediction to know win or loss and inference to understand what factors influence win/loss result
- renew/non-renew insurance policy
  - Response: policyholder renew or cancel
  - Predictors: price change, customer elasticity, competitor price
- type of particle
  - Response: particle type
  - Predictors: image, size, shape, time

#### Part b)

- fantasy points
  - Response: player fantasy points for next game
  - Predictors: past points, injuries, teammates, opponents
- salary for job posting
  - Response: salary
  - Predictors: position title, location, company/peer salaries
- insurance costs
  - Response: loss cost for policyholder
  - Predictors: experience losses, customer behavior stats

#### Part c)

- types of shoppers
  - commodity groups
  - personality styles
-

#### EXERCISE 5:

Advantages of a very flexible model include better fit to data and fewer prior assumptions. Disadvantages are hard to interpret and prone to overfitting.

A more flexible approach might be preferred if the underlying data is very complex (simple linear fit doesn't suffice) or if we mainly care about the result and not inference. A less flexible model is preferred if the underlying data has a simple shape or if inference is important.

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#### EXERCISE 6:

For parametric methods, we make an assumption about the shape of the underlying data, select a model form, and fit the data to our selected form. The advantage here is that we can incorporate any prior/expert knowledge and don't tend to have too many parameters that need to be fit. To the extent that our prior/expert assumptions are wrong, then that would be a disadvantage.

Non-parametric methods don't make explicit assumptions on the shape of the data. This can have the advantage of not needing to make an assumption on the form of the function and can more accurately fit a wider range of shapes for the underlying data. The key disadvantage is that they need a large number of observations to fit an accurate estimate.

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#### EXERCISE 7:

##### Part a)

```
obs1 <- c(0, 3, 0)
obs2 <- c(2, 0, 0)
obs3 <- c(0, 1, 3)
obs4 <- c(0, 1, 2)
obs5 <- c(-1, 0, 1)
obs6 <- c(1, 1, 1)
obs0 <- c(0, 0, 0)

(dist1 <- sqrt(sum((obs1-obs0)^2)) )
## [1] 3

(dist2 <- sqrt(sum((obs2-obs0)^2)) )
## [1] 2

(dist3 <- sqrt(sum((obs3-obs0)^2)) )
## [1] 3.162278

(dist4 <- sqrt(sum((obs4-obs0)^2)) )
## [1] 2.236068
```

```
(dist5 <- sqrt(sum((obs5-obs0)^2)) )
```

```
## [1] 1.414214
```

```
(dist6 <- sqrt(sum((obs6-obs0)^2)) )
```

```
## [1] 1.732051
```

### Part b)

- closest 1 neighbor is obs5
- prediction = **Green**

### Part c)

- closest 3 neighbors are obs5, obs6, obs2
- prediction = **Red**

### Part d)

best value of K should be smaller to be able to capture more of the non-linear decision boundary

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## APPLIED

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### EXERCISE 8:

#### Part a)

```
require(ISLR2)
data(College)
str(College)
```

```
## 'data.frame':    777 obs. of  18 variables:
##   $ Private     : Factor w/ 2 levels "No","Yes": 2 2 2 2 2 2 2 2 2 ...
##   $ Apps        : num  1660 2186 1428 417 193 ...
##   $ Accept      : num  1232 1924 1097 349 146 ...
##   $ Enroll      : num  721 512 336 137 55 158 103 489 227 172 ...
##   $ Top10perc   : num  23 16 22 60 16 38 17 37 30 21 ...
##   $ Top25perc   : num  52 29 50 89 44 62 45 68 63 44 ...
##   $ F.Undergrad: num  2885 2683 1036 510 249 ...
##   $ P.Undergrad: num  537 1227 99 63 869 ...
##   $ Outstate    : num  7440 12280 11250 12960 7560 ...
##   $ Room.Board  : num  3300 6450 3750 5450 4120 ...
##   $ Books       : num  450 750 400 450 800 500 500 450 300 660 ...
##   $ Personal    : num  2200 1500 1165 875 1500 ...
##   $ PhD         : num  70 29 53 92 76 67 90 89 79 40 ...
```

```

## $ Terminal    : num  78 30 66 97 72 73 93 100 84 41 ...
## $ S.F.Ratio   : num  18.1 12.2 12.9 7.7 11.9 9.4 11.5 13.7 11.3 11.5 ...
## $ perc.alumni : num  12 16 30 37 2 11 26 37 23 15 ...
## $ Expend      : num  7041 10527 8735 19016 10922 ...
## $ Grad.Rate   : num  60 56 54 59 15 55 63 73 80 52 ...

```

### Part b)

```

# these steps were already taken on College data in the ISLR2 package
fix(College) # pops up table in window
rownames(College) <- College[,1] # set row names
College <- College[,-1] # drop first col

```

### Part c)

```

# i.
summary(College)

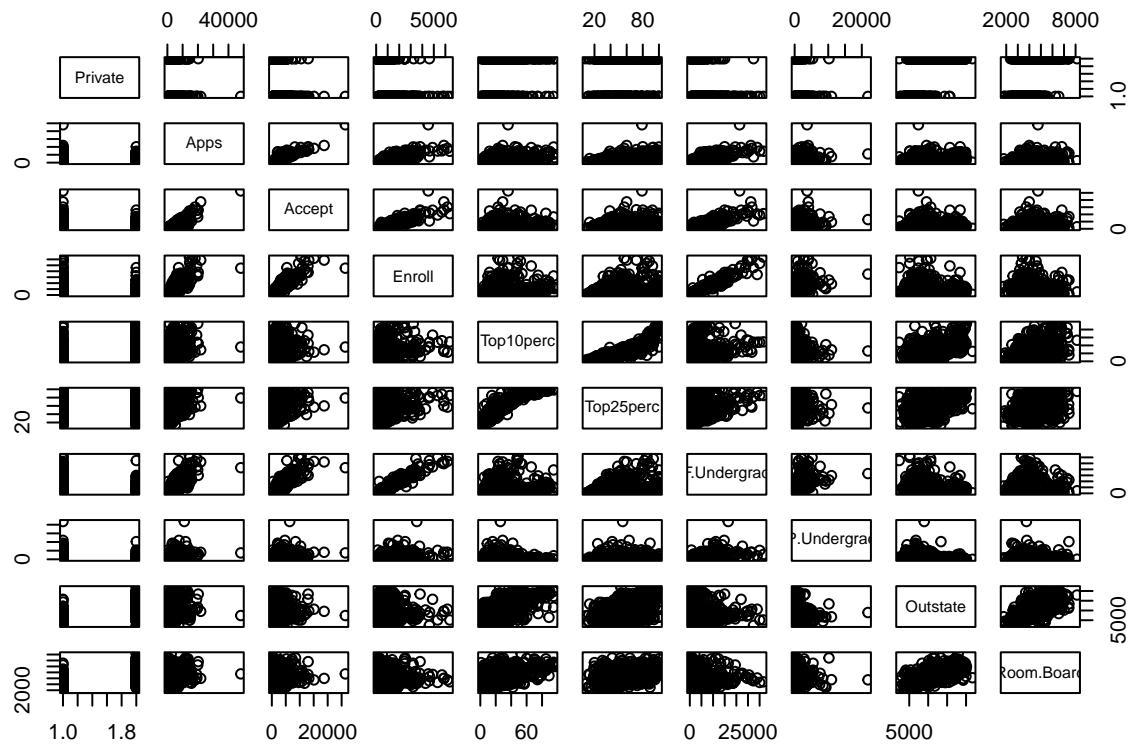
```

```

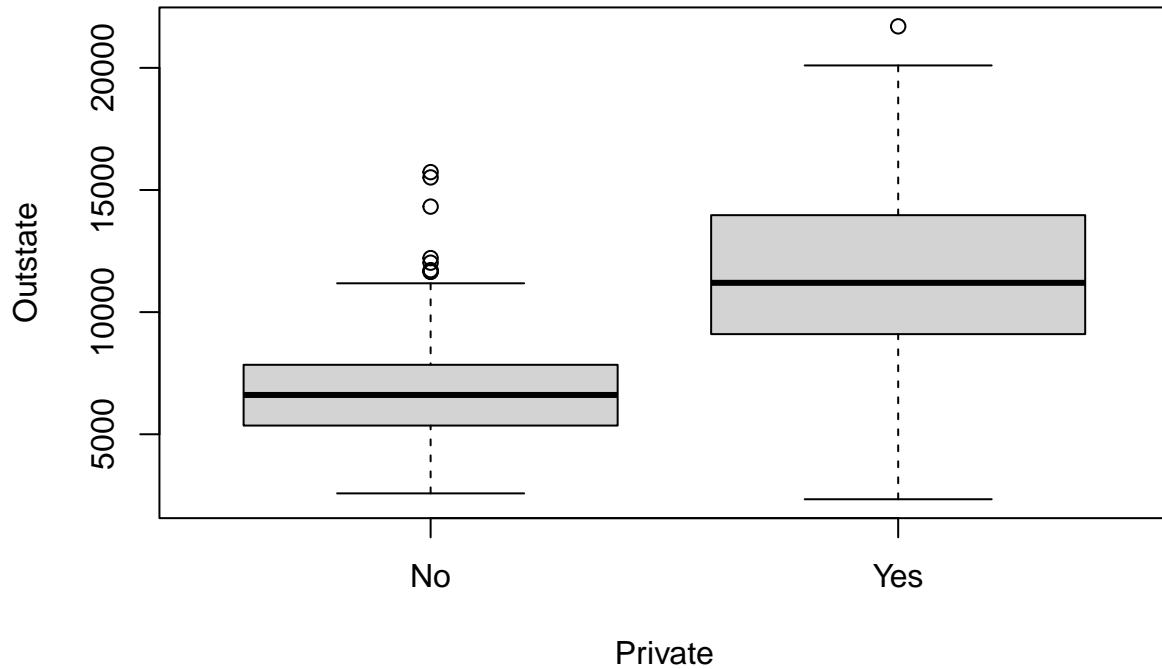
## Private          Apps          Accept          Enroll        Top10perc
## No :212    Min.   : 81   Min.   : 72   Min.   : 35   Min.   : 1.00
## Yes:565   1st Qu.: 776  1st Qu.: 604  1st Qu.: 242  1st Qu.:15.00
##                   Median :1558  Median :1110  Median :434   Median :23.00
##                   Mean   :3002  Mean   :2019  Mean   :780   Mean   :27.56
##                   3rd Qu.:3624  3rd Qu.:2424  3rd Qu.:902   3rd Qu.:35.00
##                   Max.  :48094 Max.  :26330 Max.  :6392   Max.  :96.00
## Top25perc       F.Undergrad    P.Undergrad     Outstate
## Min.   : 9.0   Min.   : 139  Min.   : 1.0   Min.   : 2340
## 1st Qu.: 41.0  1st Qu.: 992  1st Qu.: 95.0  1st Qu.: 7320
## Median : 54.0  Median :1707  Median :353.0  Median : 9990
## Mean   : 55.8  Mean   :3700  Mean   :855.3  Mean   :10441
## 3rd Qu.: 69.0  3rd Qu.:4005  3rd Qu.:967.0  3rd Qu.:12925
## Max.  :100.0   Max.  :31643  Max.  :21836.0 Max.  :21700
## Room.Board      Books          Personal        PhD
## Min.   :1780   Min.   : 96.0  Min.   : 250  Min.   :  8.00
## 1st Qu.:3597   1st Qu.: 470.0  1st Qu.: 850  1st Qu.: 62.00
## Median :4200   Median :500.0   Median :1200  Median : 75.00
## Mean   :4358   Mean   :549.4   Mean   :1341  Mean   : 72.66
## 3rd Qu.:5050   3rd Qu.:600.0   3rd Qu.:1700  3rd Qu.: 85.00
## Max.  :8124   Max.  :2340.0   Max.  :6800   Max.  :103.00
## Terminal        S.F.Ratio      perc.alumni     Expend
## Min.   : 24.0   Min.   : 2.50  Min.   : 0.00  Min.   : 3186
## 1st Qu.: 71.0   1st Qu.:11.50  1st Qu.:13.00  1st Qu.: 6751
## Median : 82.0   Median :13.60  Median :21.00  Median : 8377
## Mean   : 79.7   Mean   :14.09  Mean   :22.74  Mean   : 9660
## 3rd Qu.: 92.0   3rd Qu.:16.50  3rd Qu.:31.00  3rd Qu.:10830
## Max.  :100.0   Max.  :39.80  Max.  :64.00  Max.  :56233
## Grad.Rate
## Min.   : 10.00
## 1st Qu.: 53.00
## Median : 65.00
## Mean   : 65.46
## 3rd Qu.: 78.00
## Max.  :118.00

```

```
# ii.  
pairs(College[,1:10])
```



```
# iii.  
boxplot(Outstate~Private, data=College, xlab="Private", ylab="Outstate")
```



```
# iv.
Elite <- rep("No", nrow(College))
Elite[College$Top10perc>50] <- "Yes"
College <- data.frame(College, Elite)
summary(College) # 78 Elite
```

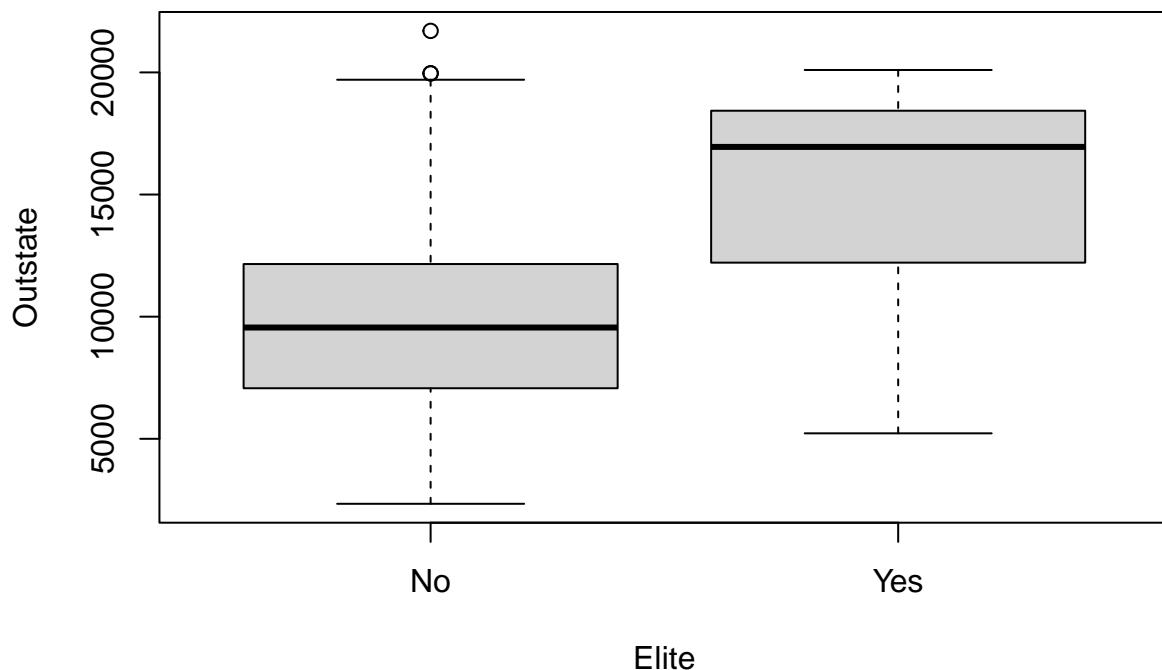
```
##   Private      Apps      Accept      Enroll      Top10perc
##   No :212    Min.   : 81    Min.   : 72    Min.   : 35    Min.   : 1.00
##   Yes:565   1st Qu.: 776   1st Qu.: 604   1st Qu.: 242   1st Qu.:15.00
##             Median :1558   Median :1110   Median :434    Median :23.00
##             Mean   :3002   Mean   :2019   Mean   :780    Mean   :27.56
##             3rd Qu.:3624   3rd Qu.:2424   3rd Qu.:902    3rd Qu.:35.00
##             Max.  :48094   Max.  :26330   Max.  :6392   Max.  :96.00
##   Top25perc    F.Undergrad    P.Undergrad      Outstate
##   Min.   : 9.0    Min.   : 139    Min.   : 1.0    Min.   : 2340
##   1st Qu.: 41.0   1st Qu.: 992    1st Qu.: 95.0   1st Qu.: 7320
##   Median : 54.0   Median :1707    Median :353.0   Median : 9990
##   Mean   : 55.8   Mean   :3700    Mean   :855.3   Mean   :10441
##   3rd Qu.: 69.0   3rd Qu.:4005    3rd Qu.:967.0   3rd Qu.:12925
##   Max.  :100.0   Max.  :31643    Max.  :21836.0  Max.  :21700
##   Room.Board     Books      Personal      PhD
##   Min.   :1780    Min.   : 96.0   Min.   :250    Min.   : 8.00
##   1st Qu.:3597    1st Qu.: 470.0  1st Qu.:850    1st Qu.: 62.00
##   Median :4200    Median : 500.0  Median :1200    Median : 75.00
##   Mean   :4358    Mean   : 549.4  Mean   :1341    Mean   : 72.66
##   3rd Qu.:5050    3rd Qu.: 600.0  3rd Qu.:1700    3rd Qu.: 85.00
```

```

##   Max.    :8124    Max.    :2340.0    Max.    :6800    Max.    :103.00
##   Terminal      S.F.Ratio     perc.alumni      Expend
##   Min.    : 24.0    Min.    : 2.50    Min.    : 0.00    Min.    : 3186
##   1st Qu.: 71.0    1st Qu.:11.50    1st Qu.:13.00    1st Qu.: 6751
##   Median  : 82.0    Median  :13.60    Median  :21.00    Median  : 8377
##   Mean    : 79.7    Mean    :14.09    Mean    :22.74    Mean    : 9660
##   3rd Qu.: 92.0    3rd Qu.:16.50    3rd Qu.:31.00    3rd Qu.:10830
##   Max.    :100.0    Max.    :39.80    Max.    :64.00    Max.    :56233
##   Grad.Rate       Elite
##   Min.    : 10.00   Length:777
##   1st Qu.: 53.00   Class :character
##   Median  : 65.00   Mode  :character
##   Mean    : 65.46
##   3rd Qu.: 78.00
##   Max.    :118.00

```

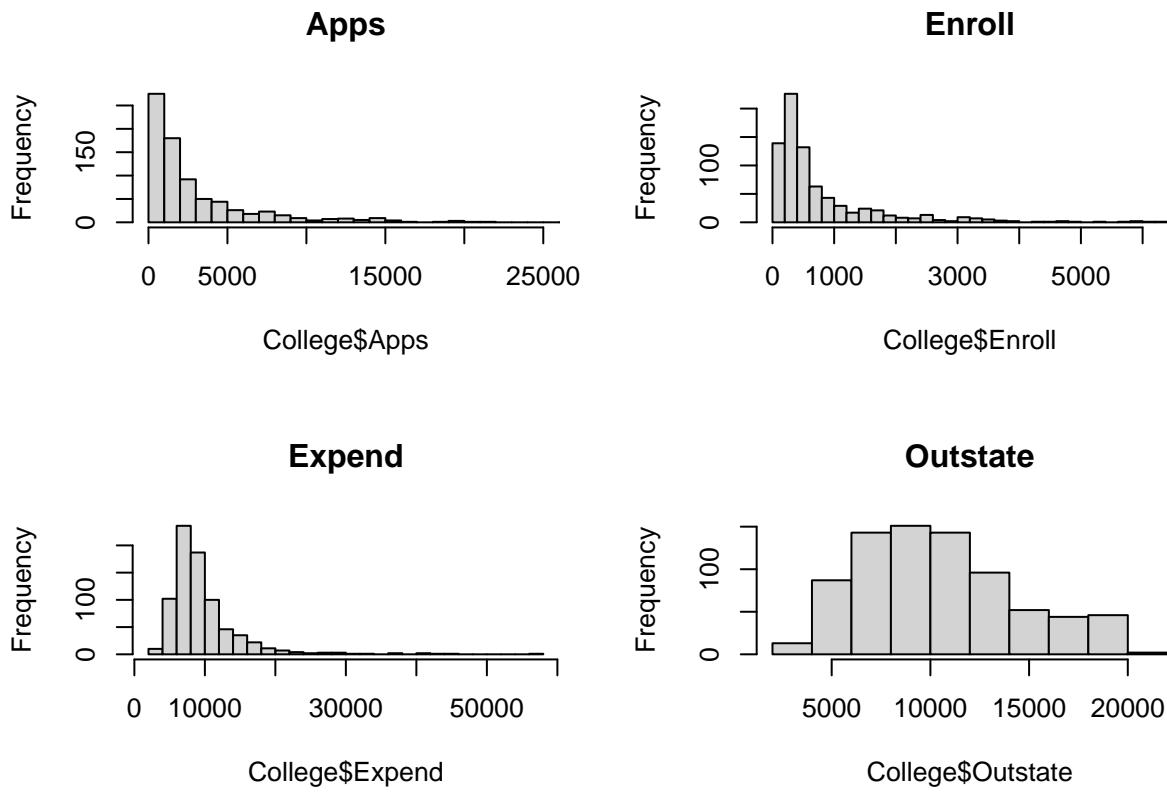
```
boxplot(Outstate~Elite, data=College, xlab="Elite", ylab="Outstate")
```



```

# v.
par(mfrow=c(2,2))
hist(College$Apps, breaks=50, xlim=c(0,25000), main="Apps")
hist(College$Enroll, breaks=25, main="Enroll")
hist(College$Expend, breaks=25, main="Expend")
hist(College$Outstate, main="Outstate")

```



```
# vi.
```

---

### EXERCISE 9:

Part a)

```
require(ISLR2)
data(Auto)
str(Auto)

## 'data.frame': 392 obs. of 9 variables:
## $ mpg          : num  18 15 18 16 17 15 14 14 14 15 ...
## $ cylinders    : int  8 8 8 8 8 8 8 8 8 ...
## $ displacement: num  307 350 318 304 302 429 454 440 455 390 ...
## $ horsepower   : int  130 165 150 150 140 198 220 215 225 190 ...
## $ weight       : int  3504 3693 3436 3433 3449 4341 4354 4312 4425 3850 ...
## $ acceleration: num  12 11.5 11 12 10.5 10 9 8.5 10 8.5 ...
## $ year         : int  70 70 70 70 70 70 70 70 70 70 ...
## $ origin       : int  1 1 1 1 1 1 1 1 1 ...
## $ name         : Factor w/ 304 levels "amc ambassador brougham",...: 49 36 231 14 161 141 54 223 241 ...
## - attr(*, "na.action")= 'omit' Named int [1:5] 33 127 331 337 355
## ..- attr(*, "names")= chr [1:5] "33" "127" "331" "337" ...
```

- quantitative: *mpg*, *cylinders* (can treat as qual too), *displacement*, *horsepower*, *weight*, *acceleration*, *year*
- qualitative: *origin*, *name*

#### Part b)

```
range(Auto$mpg)

## [1] 9.0 46.6

range(Auto$cylinders)

## [1] 3 8

range(Auto$displacement)

## [1] 68 455

range(Auto$horsepower)

## [1] 46 230

range(Auto$weight)

## [1] 1613 5140

range(Auto$acceleration)

## [1] 8.0 24.8

range(Auto$year)

## [1] 70 82
```

#### Part c)

```
sapply(Auto[,1:7], mean)

##          mpg      cylinders displacement horsepower      weight acceleration
##     23.445918      5.471939    194.411990   104.469388  2977.584184    15.541327
##          year
##    75.979592

sapply(Auto[,1:7], sd)

##          mpg      cylinders displacement horsepower      weight acceleration
##     7.805007      1.705783    104.644004   38.491160   849.402560    2.758864
##          year
##    3.683737
```

#### Part d)

```

# create temp matrix for numeric columns
tmp <- Auto[,-(8:9)] # drop origin, name
tmp <- tmp[-(10:85),] # drop rows
sapply(tmp, range)

##      mpg cylinders displacement horsepower weight acceleration year
## [1,] 11.0          3           68          46    1649         8.5    70
## [2,] 46.6          8           455         230    4997        24.8    82

sapply(tmp, mean)

##      mpg      cylinders      displacement      horsepower      weight      acceleration
## 24.404430  5.373418  187.240506  100.721519  2935.971519  15.726899
##      year
## 77.145570

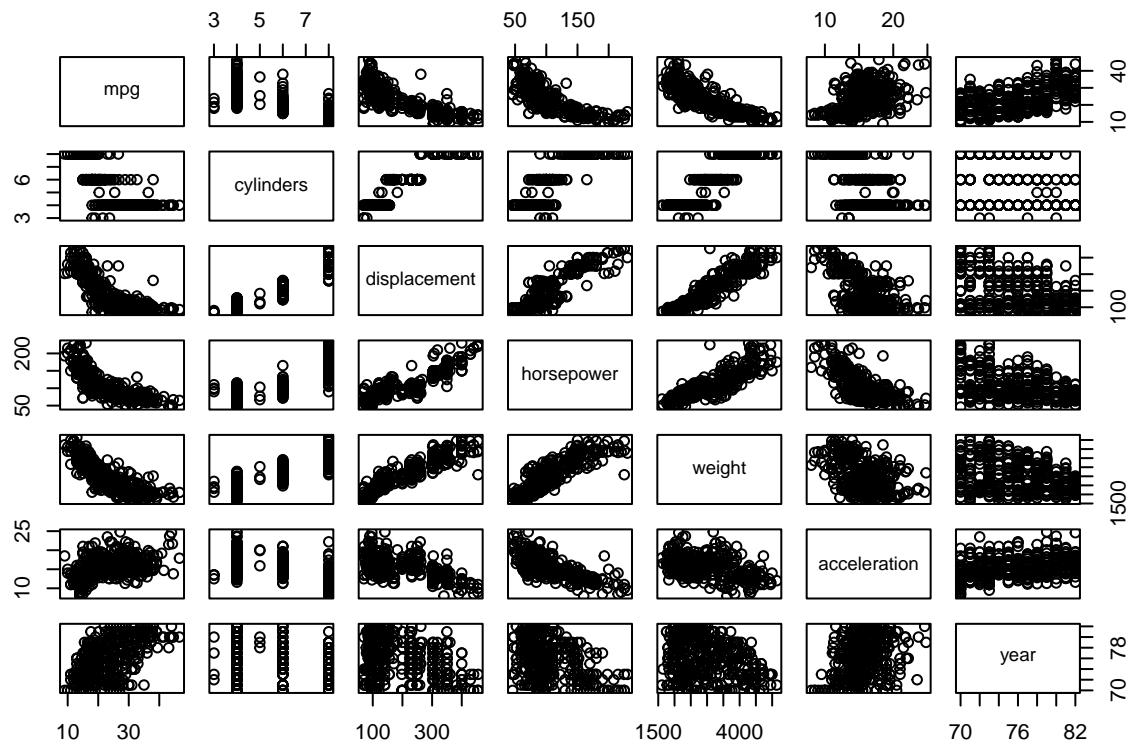
sapply(tmp, sd)

##      mpg      cylinders      displacement      horsepower      weight      acceleration
## 7.867283  1.654179   99.678367   35.708853  811.300208   2.693721
##      year
## 3.106217

```

Part e)

```
pairs(Auto[,1:7])
```



- mpg is negatively correlated with cylinders, displacement, horsepower, and weight
- horsepower is negatively correlated with weight
- mpg mostly increases for newer model years

### Part f)

yes, the plots show that there are relationships between mpg and other variables in the data set

---

### EXERCISE 10:

#### Part a)

```
require(ISLR2)
require(MASS)
data(Boston)
str(Boston) # 506 rows, 14 cols

## 'data.frame': 506 obs. of 14 variables:
## $ crim    : num 0.00632 0.02731 0.02729 0.03237 0.06905 ...
## $ zn      : num 18 0 0 0 0 12.5 12.5 12.5 12.5 ...
## $ indus   : num 2.31 7.07 7.07 2.18 2.18 2.18 7.87 7.87 7.87 ...
## $ chas    : int 0 0 0 0 0 0 0 0 0 ...
## $ nox    : num 0.538 0.469 0.469 0.458 0.458 0.458 0.524 0.524 0.524 ...
```

```

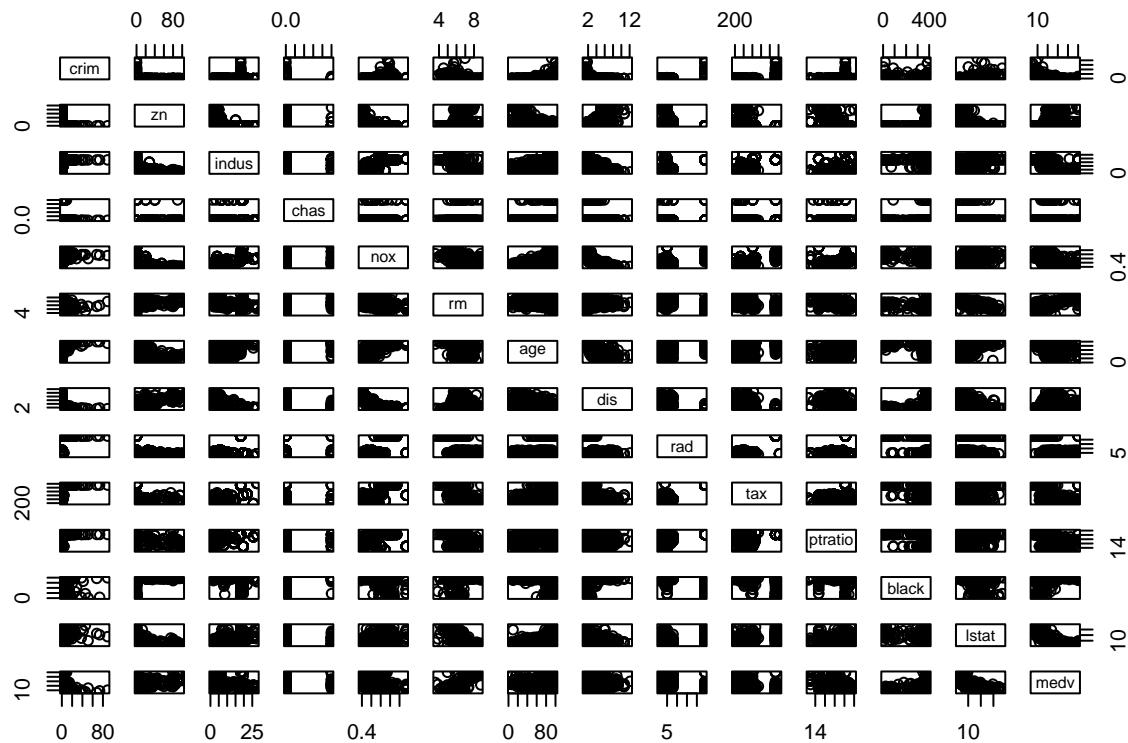
## $ rm      : num  6.58 6.42 7.18 7 7.15 ...
## $ age     : num  65.2 78.9 61.1 45.8 54.2 58.7 66.6 96.1 100 85.9 ...
## $ dis     : num  4.09 4.97 4.97 6.06 6.06 ...
## $ rad     : int  1 2 2 3 3 3 5 5 5 5 ...
## $ tax     : num  296 242 242 222 222 311 311 311 311 ...
## $ ptratio: num  15.3 17.8 17.8 18.7 18.7 18.7 15.2 15.2 15.2 15.2 ...
## $ black   : num  397 397 393 395 397 ...
## $ lstat   : num  4.98 9.14 4.03 2.94 5.33 ...
## $ medv    : num  24 21.6 34.7 33.4 36.2 28.7 22.9 27.1 16.5 18.9 ...

```

- data set includes 506 rows and 14 columns
  - rows represent observations for each town
  - columns represent features

### Part b)

```
pairs(Boston)
```



relationship between crime rate per capita and other variables don't seem to be linear

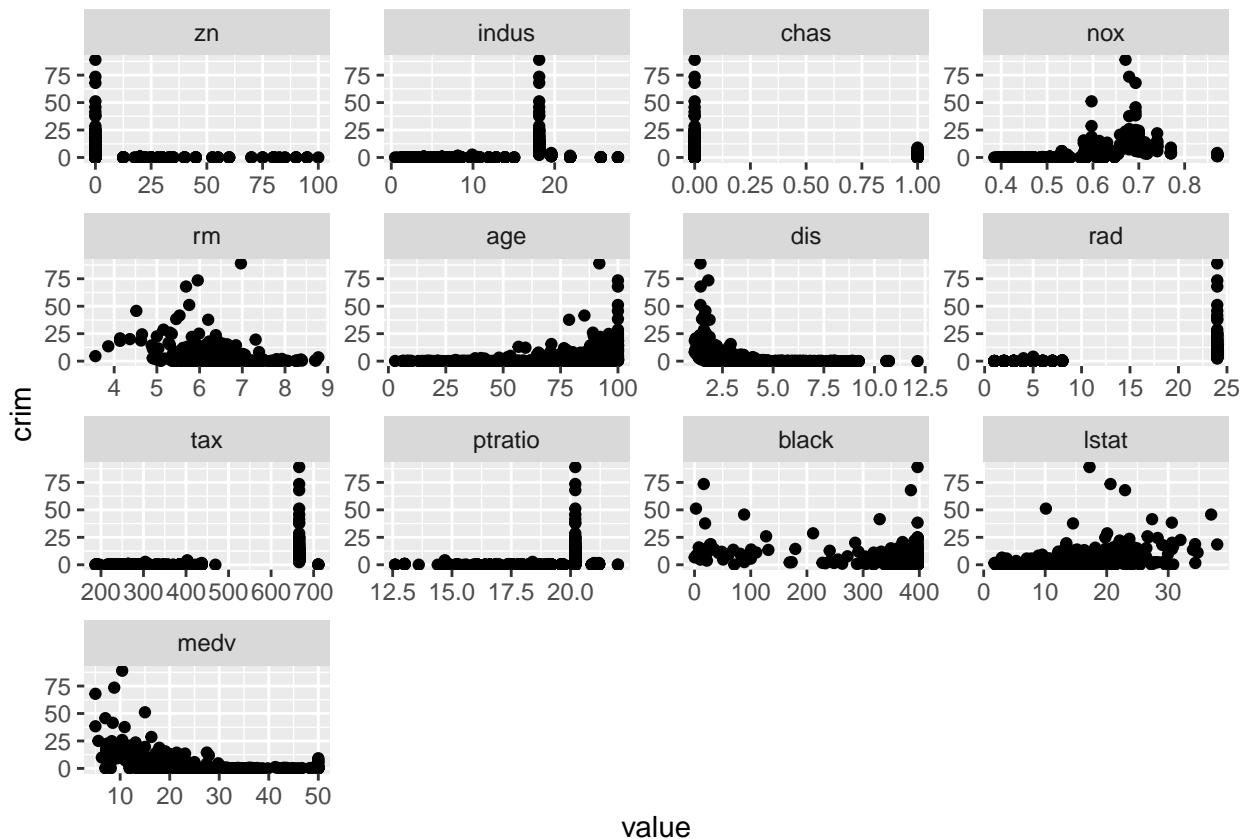
### Part c)

```

require(ggplot2)
require(reshape2)

```

```
# plot each feature against crim rate
bosmelt <- melt(Boston, id="crim")
ggplot(bosmelt, aes(x=value, y=crim)) +
  facet_wrap(~variable, scales="free") +
  geom_point()
```



```
(corrmatrix <- cor(Boston, use="complete.obs")[1,])
```

```
##      crim      zn     indus      chas      nox       rm
## 1.0000000 -0.20046922  0.40658341 -0.05589158  0.42097171 -0.21924670
##      age      dis      rad      tax      ptratio    black
## 0.35273425 -0.37967009  0.62550515  0.58276431  0.28994558 -0.38506394
##      lstat     medv
## 0.45562148 -0.38830461
```

```
corrmatrix[corrmatrix > 0.5 | corrmatrix < -0.5][-1]
```

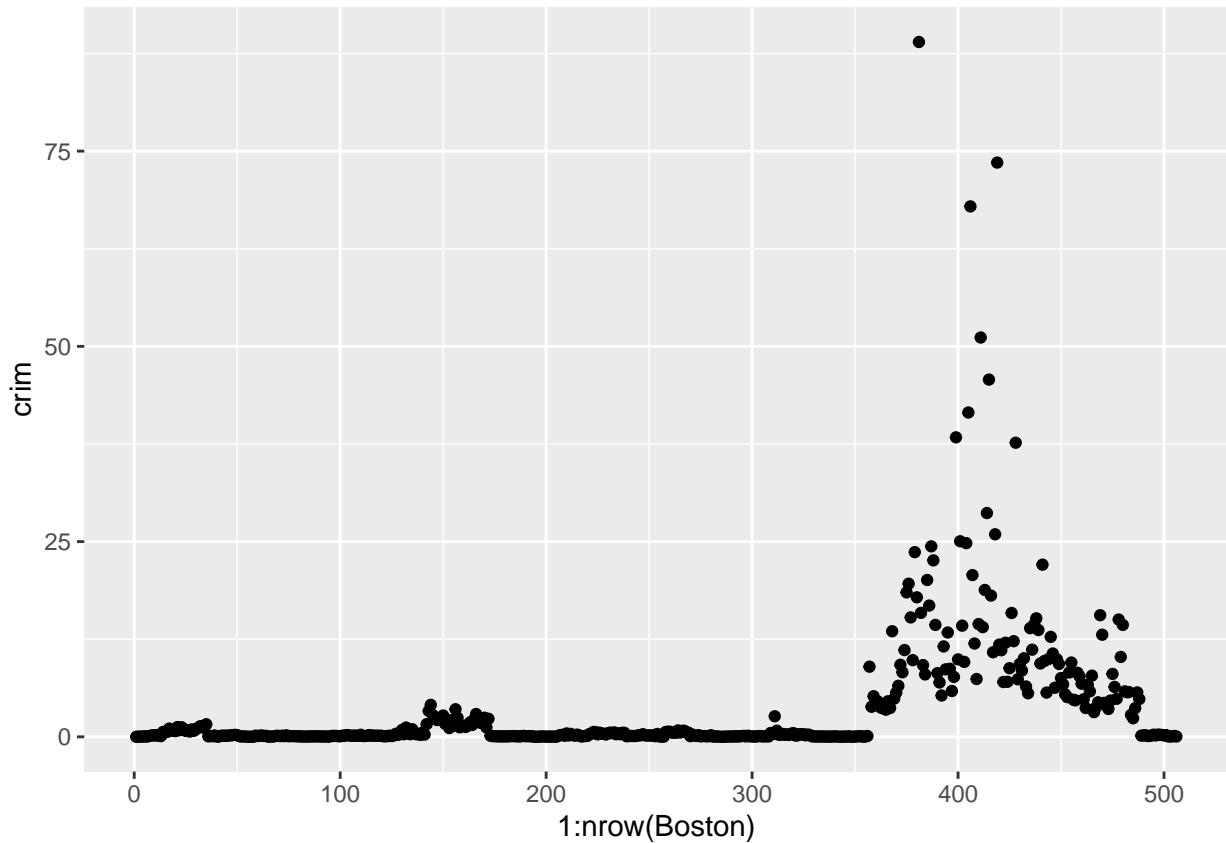
```
##      rad      tax
## 0.6255051 0.5827643
```

- some correlations with each variable, except chas
- crim rates seem to spike within certain zones
  - when rad is > 20

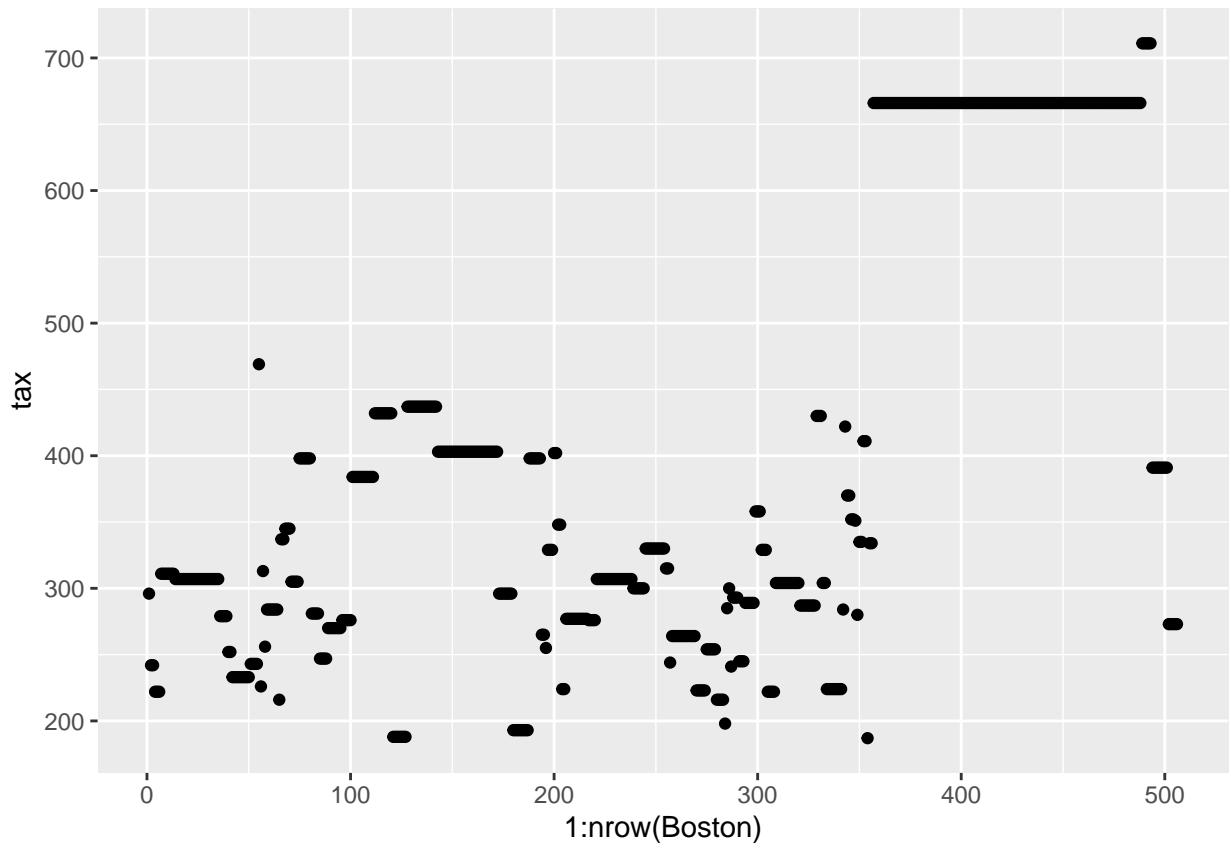
- when `tax` is between 600 and 700
- when `zn` is close to 0
- etc.
- negative correlations with `dis`, `medv` and maybe `black`

#### Part d)

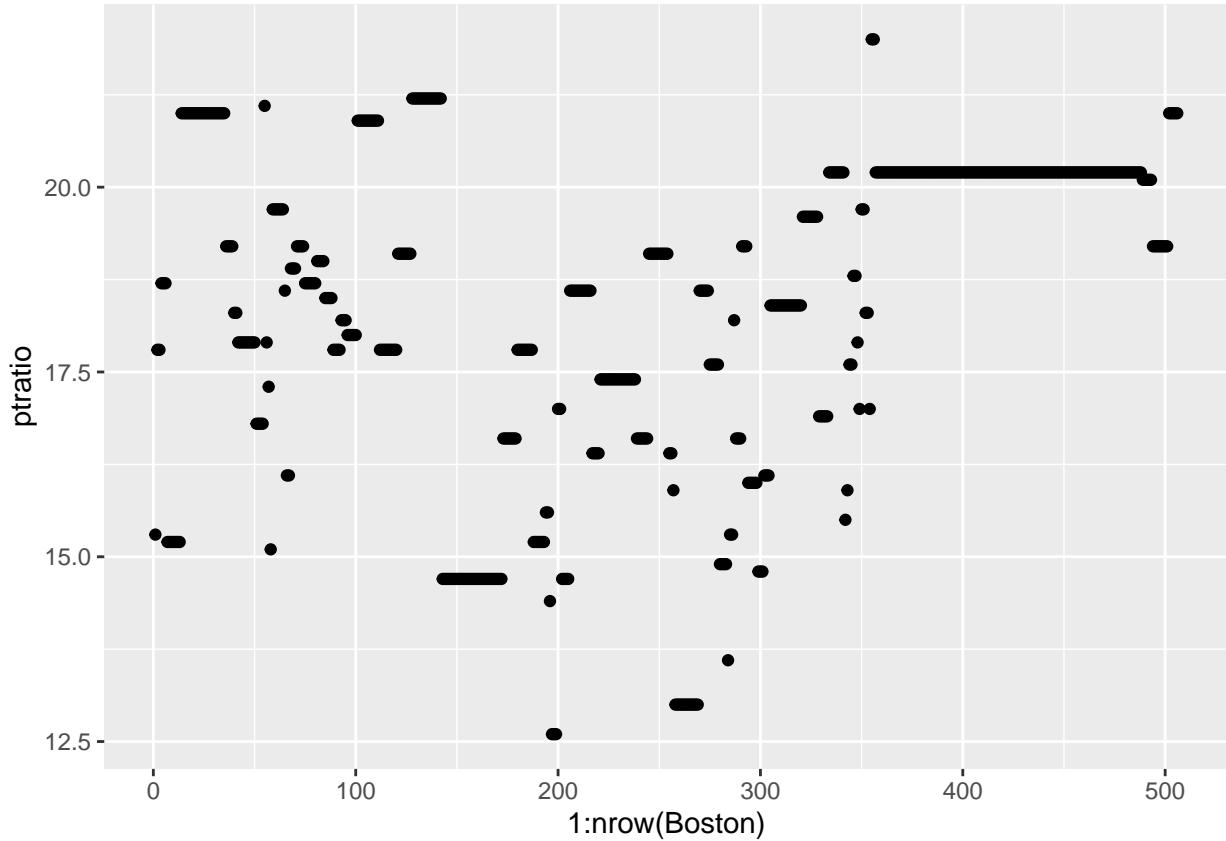
```
require(ggplot2)
g <- ggplot(Boston, aes(x=1:nrow(Boston), y=crim))
g + geom_point()
```



```
g <- ggplot(Boston, aes(x=1:nrow(Boston), y=tax))
g + geom_point()
```



```
g <- ggplot(Boston, aes(x=1:nrow(Boston), y=ptratio))
g + geom_point()
```



- definitely outliers for crim and tax
- no clear outlier for pptratio

Part e)

```
table(Boston$chas) # 35 towns
```

```
##  
## 0 1  
## 471 35
```

Part f)

```
median(Boston$ptratio) # 19.05
```

```
## [1] 19.05
```

Part g)

```
# there are two towns with lowest medv value of 5  
(seltown <- Boston[Boston$medv == min(Boston$medv),])
```

```

##      crim zn indus chas   nox     rm age     dis rad tax ptratio black lstat
## 399 38.3518 0 18.1    0 0.693 5.453 100 1.4896 24 666    20.2 396.90 30.59
## 406 67.9208 0 18.1    0 0.693 5.683 100 1.4254 24 666    20.2 384.97 22.98
##      medv
## 399    5
## 406    5

```

```

# overall quartiles and range of predictors
sapply(Boston, quantile)

```

```

##      crim     zn indus chas   nox     rm    age     dis rad tax ptratio
## 0% 0.006320 0.0 0.46    0 0.385 3.5610 2.900 1.129600 1 187 12.60
## 25% 0.082045 0.0 5.19    0 0.449 5.8855 45.025 2.100175 4 279 17.40
## 50% 0.256510 0.0 9.69    0 0.538 6.2085 77.500 3.207450 5 330 19.05
## 75% 3.677083 12.5 18.10    0 0.624 6.6235 94.075 5.188425 24 666 20.20
## 100% 88.976200 100.0 27.74    1 0.871 8.7800 100.000 12.126500 24 711 22.00
##      black lstat medv
## 0% 0.3200 1.730 5.000
## 25% 375.3775 6.950 17.025
## 50% 391.4400 11.360 21.200
## 75% 396.2250 16.955 25.000
## 100% 396.9000 37.970 50.000

```

- age, rad at max
- crim, indus, nox, tax, ptratio, lstat at or above 75th percentile
- low for zn, rm, dis

### Part h)

```

# count of towns
nrow(Boston[Boston$rm > 7,]) # 64 with > 7 rooms

```

```

## [1] 64

```

```

nrow(Boston[Boston$rm > 8,]) # 13 with > 8 rooms

```

```

## [1] 13

```

```

# row 1: mean for towns with > 8 rooms per dwelling
# row 2: median for all towns
rbind(sapply(Boston[Boston$rm > 8,], mean), sapply(Boston, median))

```

```

##      crim     zn indus chas   nox     rm    age     dis
## [1,] 0.7187954 13.61538 7.078462 0.1538462 0.5392385 8.348538 71.53846 3.430192
## [2,] 0.2565100 0.00000 9.690000 0.0000000 0.5380000 6.208500 77.50000 3.207450
##      rad     tax ptratio black lstat medv
## [1,] 7.461538 325.0769 16.36154 385.2108 4.31 44.2
## [2,] 5.000000 330.0000 19.05000 391.4400 11.36 21.2

```

- crim rates are higher (almost 3X)
- higher proportion of 25K sq ft lots
- much lower lstat value
- higher medv value