

An R Lecture from Practice: Part I

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Contents

Numerical R

Data Analysis with R

Preparation

- Bring your laptop.
- Install R and R-studio
- Download the dataset “Rlecture_Diamonds.csv”
- Be ready to typing in code!



Our Goals

- Know what is R
- Learn basic operations on R vectors
- Use R to do scientific computation
- Learn different data types in R to simplify operations

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What is R?

- A language and environment for statistical computing and graphics
- A wide variety of statistical (linear and nonlinear modelling, classical statistical tests, time-series analysis, classification, clustering, ...) and graphical techniques, and is highly extensible.
- Free Software
- Polls, surveys of data miners, ... show that R's popularity has increased substantially in recent years. (Wikipedia)

What can R do?

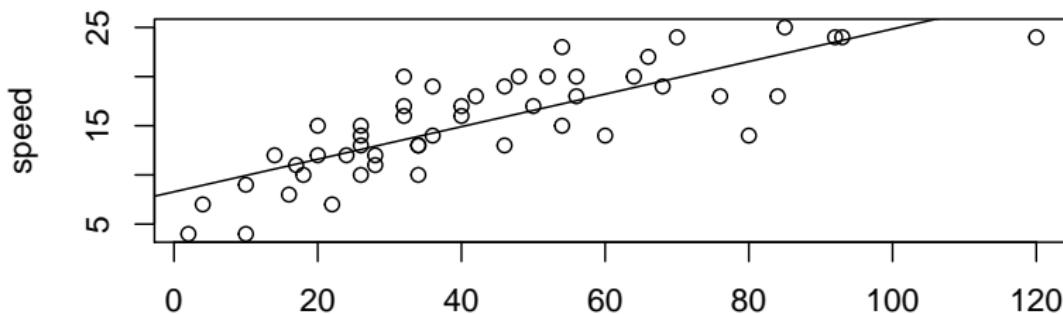
- Data: Input, output, cleaning, extracting, summarizing, ...
- Statistical models: random variables and distribution, linear regression, clustering, machine learning, social analysis, ..., nearly all statistical methods that you can think out of
- Scientific computing: vector and matrix operations, lots of mathematical functions, ...
- Programming: if, for, while, user-defined functions, ...
- Presentation: various kinds of plots, LaTeX reports with “knitr”
- And more ...

How to begin?

1. Open the RStudio
2. Create a new script from File → New File → R Scripture
3. Type the code in the upper-left area
4. Run each line with Ctrl+Enter after finishing it

Try the power of one-line R Code

```
## Scatter plot with an one-line code
plot(speed ~ dist, data = cars)
## Linear Regression with an one-line code!
model = lm(speed ~ dist, data = cars)
## Summry with an one-line code!
summary(model)
## Add a line with an one-line code
abline(model)
```



Interpretation

```
summary(model)

##
## Call:
## lm(formula = speed ~ dist, data = cars)
##
## Residuals:
##      Min      1Q  Median      3Q     Max 
## -7.5293 -2.1550  0.3615  2.4377  6.4179 
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)    
## (Intercept) 8.28391   0.87438   9.474 1.44e-12 ***
## dist        0.16557   0.01749   9.464 1.49e-12 ***
## ---      
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.156 on 48 degrees of freedom
## Multiple R-squared:  0.6511, Adjusted R-squared:  0.6438 
## F-statistic: 89.57 on 1 and 48 DF,  p-value: 1.49e-12
```

Distribution and Random Variables

- We can easily get critical values of given distribution from R

```
pnorm(2, mean = 0, sd = 1) # Distribution function (normal)  
## [1] 0.9772499  
  
dnorm(2, mean = 0, sd = 1) # Density function (normal)  
## [1] 0.05399097  
  
qnorm(0.975, mean = 0, sd = 1) # Quantile function (normal)  
## [1] 1.959964
```

- Generate random sample from a given distribution

```
set.seed(1234) # Set a random seed to repeat a random experiment  
rnorm(5, mean = 0, sd = 1) # Random sample (normal)  
  
## [1] -1.2070657 0.2774292 1.0844412 -2.3456977 0.4291247  
  
runif(5, min = 0, max = 1) # Random sample (uniform)  
  
## [1] 0.6935913 0.5449748 0.2827336 0.9234335 0.2923158  
  
rbinom(20, size = 5, prob = 0.3) # Random sample (binomial)  
  
## [1] 3 1 1 1 1 1 1 0 0 1 2 1 3 2 0 1 1 1 1 1
```

Get help

- From R: ? + function
 - ?rnorm
 - ?runif
 - ?lm
 - ?plot
- From Books:
 - The Art of R Programming, Norman Matloff
 - An Introduction to Statistical Learning with Applications in R, Gareth James
- From Google: Your Question + R



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Vectors

- Generate 5 random variables of uniform distribution between 0 and 1

```
set.seed(12345)
x = runif(5, 0, 1)
x

## [1] 0.7209039 0.8757732 0.7609823 0.8861246 0.4564810

x + 1

## [1] 1.720904 1.875773 1.760982 1.886125 1.456481
```

- Generate continuous integers from 1 to 5

```
y = 1:5
y

## [1] 1 2 3 4 5

y * 2

## [1] 2 4 6 8 10
```

Mathematical Operations (1)

- Four arithmetic operations

```
x + y  
## [1] 1.720904 2.875773 3.760982 4.886125 5.456481  
  
x - y  
## [1] -0.2790961 -1.1242268 -2.2390177 -3.1138754 -4.5435190  
  
x * y  
## [1] 0.7209039 1.7515464 2.2829470 3.5444983 2.2824048  
  
x / y  
## [1] 0.72090390 0.43788660 0.25366078 0.22153114 0.09129619
```

- Power and square root

```
x ** 2  
## [1] 0.5197024 0.7669787 0.5790941 0.7852167 0.2083749  
  
sqrt(x)  
## [1] 0.8490606 0.9358275 0.8723430 0.9413419 0.6756337
```

Mathematical Operations (2)

- Exponential and logarithm

```
exp(x)

## [1] 2.056291 2.400731 2.140378 2.425711 1.578509

log(x)

## [1] -0.3272494 -0.1326481 -0.2731451 -0.1208977 -0.7842083

log10(x)

## [1] -0.14212263 -0.05760835 -0.11862543 -0.05250522 -0.34057733
```

- Statistics

```
sum(x)

## [1] 3.700265

c(sum(x), mean(x), var(x), sd(x)) # Combine values into a vector

## [1] 3.70026494 0.74005299 0.03024368 0.17390709

c(median = median(x), minimum = min(x), maximum = max(x)) # named vector

##      median      minimum      maximum
## 0.7609823 0.4564810 0.8861246
```

Mathematical Operations (3)

- Quantiles and ranks

```
quantile(x)

##          0%      25%      50%      75%     100%
## 0.4564810 0.7209039 0.7609823 0.8757732 0.8861246

rank(x)

## [1] 2 4 3 5 1
```

- Round

```
round(x, 3)

## [1] 0.721 0.876 0.761 0.886 0.456

floor(x)

## [1] 0 0 0 0 0

ceiling(x)

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

- Sort

```
sort(x)

## [1] 0.4564810 0.7209039 0.7609823 0.8757732 0.8861246

x

## [1] 0.7209039 0.8757732 0.7609823 0.8861246 0.4564810
```

Take Values by Position Index

- Assign the sorted value of x to z

```
z = sort(x)  
z  
  
## [1] 0.4564810 0.7209039 0.7609823 0.8757732 0.8861246
```

- Get the values of assigned positions from a vector

```
z[1] # the first value  
  
## [1] 0.456481  
  
z[2:4] # the values of positions from 2 to 4  
  
## [1] 0.7209039 0.7609823 0.8757732  
  
z[c(1,4,5)] # the values of positions in 1, 4 and 5  
  
## [1] 0.4564810 0.8757732 0.8861246  
  
z[-c(2,3)] # The other values except of the positions in 2 and 3  
  
## [1] 0.4564810 0.8757732 0.8861246
```

Logical Operations (1)

- Inequalities

```
1 == 0 # Whether they are equal
## [1] FALSE

z > 0.5 # Comparasion for each elements of a vector
## [1] FALSE TRUE TRUE TRUE TRUE

z == x # Pairwise comparasion between two vectors
## [1] FALSE FALSE TRUE FALSE FALSE

z != x # Unequal
## [1] TRUE TRUE FALSE TRUE TRUE

z > x # Greater than
## [1] FALSE FALSE FALSE FALSE TRUE

z <= x # Not greater than
## [1] TRUE TRUE TRUE TRUE FALSE
```

Logical Operations (2)

- And (`&`): true if both values are true

```
TRUE & FALSE  
  
## [1] FALSE  
  
(z > 0.5) & (z < 0.5)  
  
## [1] FALSE FALSE FALSE FALSE FALSE
```

- Or (`||`): true if either of them is true

```
TRUE | FALSE  
  
## [1] TRUE  
  
(z > 0.5) | (z < 0.5)  
  
## [1] TRUE TRUE TRUE TRUE TRUE
```

- Not (`!`): true if the origin value is false

```
!0 # in R, TRUE/FALSE can be also represented by 1/0  
  
## [1] TRUE  
  
!(z < 0.5)  
  
## [1] FALSE TRUE TRUE TRUE TRUE
```

Take Values by Logical Index

- Take the values greater than 0.5

```
z[z > 0.5]
## [1] 0.7209039 0.7609823 0.8757732 0.8861246
```

- Find people with specific pets

```
people = c("Annas", "Bob", "Charles", "Darrel", "Emma")
animals = c("cat", "dog", "fish")
set.seed(123)
pets = sample(animals, 5, replace = TRUE)
pets

## [1] "cat"  "fish" "dog"  "fish" "fish"

people[pets != "fish"] # Who have a pet on the land?

## [1] "Annas"   "Charles"
```



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Matrix (1)

- Construct a matrix

```
m = matrix(c(x, y), nrow = 5) # Construct a matrix from vector x and y
m

##          [,1] [,2]
## [1,] 0.7209039   1
## [2,] 0.8757732   2
## [3,] 0.7609823   3
## [4,] 0.8861246   4
## [5,] 0.4564810   5

dim(m) # Dimensions of a matrix

## [1] 5 2

t(m) # Transpose of a matrix

##          [,1]      [,2]      [,3]      [,4]      [,5]
## [1,] 0.7209039 0.8757732 0.7609823 0.8861246 0.456481
## [2,] 1.0000000 2.0000000 3.0000000 4.0000000 5.000000
```

Matrix (2)

- Matrix algebra

```
m2 = t(m) %*% m # Matrix multiplication
m2

##          [,1]      [,2]
## [1,]  2.859367 10.5823
## [2,] 10.582300 55.0000

det(m2) # Determinant
## [1] 45.2801

solve(m2) # Inverse of a matrix

##          [,1]      [,2]
## [1,]  1.2146618 -0.23370755
## [2,] -0.2337076  0.06314843

solve(m2, c(12, 16)) # Solve x from Ax = b
## [1] 10.836620 -1.794116
```

Matrix (3)

- Matrix selection

```
m[3,] # Take the 3rd row  
## [1] 0.7609823 3.0000000  
  
m[,2] # Take the 2nd column  
## [1] 1 2 3 4 5  
  
m[3,2] # Take the element at row = 3 and column = 2  
## [1] 3  
  
m[2:4,c(1,2)] # Take the submatrix from row 2 to 4 and column 1, 2  
## [,1] [,2]  
## [1,] 0.8757732 2  
## [2,] 0.7609823 3  
## [3,] 0.8861246 4
```

List

- A list: a set of pairs of key-value

```
a = list(index = 1:5, name = people)
a

## $index
## [1] 1 2 3 4 5
##
## $name
## [1] "Annas"    "Bob"       "Charles"   "Darrel"   "Emma"

a["name"] # A sub-list, not a vector!

## $name
## [1] "Annas"    "Bob"       "Charles"   "Darrel"   "Emma"

a[["name"]] # This is a right way to take a value.

## [1] "Annas"    "Bob"       "Charles"   "Darrel"   "Emma"

a$name # This is another right way to take a value.

## [1] "Annas"    "Bob"       "Charles"   "Darrel"   "Emma"
```

Data Frame (1)

- A Data Frame: A special list in a matrix form

```
a$animals = pets # Add a new element to a list
a

## $index
## [1] 1 2 3 4 5
##
## $name
## [1] "Annas"    "Bob"       "Charles"   "Darrel"   "Emma"
##
## $animals
## [1] "cat"      "fish"     "dog"      "fish"     "fish"

data = data.frame(a)
data

##   index     name animals
## 1      1 Annas      cat
## 2      2    Bob     fish
## 3      3 Charles     dog
## 4      4   Darrel     fish
## 5      5   Emma     fish
```

Data Frame (2)

- You can use both matrix and list operations on a data frame, and each column is a list element

```
data[c("index", "animals")] # Subset columns by name

##   index animals
## 1     1     cat
## 2     2    fish
## 3     3     dog
## 4     4    fish
## 5     5    fish

data$index # Select a column as a list

## [1] 1 2 3 4 5

data[2:4, 1:2] # Select rows and columns as a matrix

##   index   name
## 2     2    Bob
## 3     3 Charles
## 4     4 Darrel
```

Marginal Apply

- **apply:** apply a function to a matrix by row/column

```
sum(m)

## [1] 18.70026

apply(m, 1, sum) # Apply a function by row

## [1] 1.720904 2.875773 3.760982 4.886125 5.456481

apply(m, 2, sum) # Apply a function by column

## [1] 3.700265 15.000000
```

- **sapply:** apply a function to a vector/list by element

```
sapply(a, length) # Apply a function by list element

##   index     name animals
##       5       5       5

sapply(data, length) # Apply a function by column of data frame

##   index     name animals
##       5       5       5
```

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Data Analysis with R

Preparation

- Download the dataset “[Rlecture_Diamonds.csv](#)”

Our Goals

- Read real data from files
- Analyze data with R Data Frame

Data

- Information of over 50000 diamonds
- Analyze data with R Data Frame

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Read Data

Before reading data, we must set the working directory to find the data file:

1. open the “files” tag in the bottom-right area
 2. Find the button “...” on the right
 3. Select the folder where our data files are
 4. Find the “More” button and choose “Set as working directory”
 5. Then read data by `read.csv()`

```
data = read.csv("Rlecture_Diamonds.csv")
dim(data) # check the dimension of data
```

Summarize Data

- We can summarize the data with `str()` and `summary()`

```
str(data) # Structure of data
```

```
## 'data.frame': ^I53940 obs. of 11 variables:  
## $ n      : int 1 2 3 4 5 6 7 8 9 10 ...  
## $ carat   : num 0.23 0.21 0.23 0.29 0.31 0.24 0.24 0.26 0.22 0.23 ...  
## $ cut     : Factor w/ 5 levels "Fair","Good",...: 3 4 2 4 2 5 5 5 1 5 ...  
## $ color   : Factor w/ 7 levels "D","E","F","G",...: 2 2 2 6 7 7 6 5 2 5 ...  
## $ clarity: Factor w/ 8 levels "I1","IF","SI1",...: 4 3 5 6 4 8 7 3 6 5 ...  
## $ depth   : num 61.5 59.8 56.9 62.4 63.3 62.8 62.3 61.9 65.1 59.4 ...  
## $ table   : num 55 61 65 58 58 57 57 55 61 61 ...  
## $ price   : int NA 326 NA 334 335 NA NA 337 337 338 ...  
## $ x       : num 3.95 3.89 4.05 4.2 4.34 3.94 3.95 4.07 3.87 4 ...  
## $ y       : num 3.98 3.84 4.07 4.23 4.35 3.96 3.98 4.11 3.78 4.05 ...  
## $ z       : num 2.43 2.31 2.31 2.63 2.75 2.48 2.47 2.53 2.49 2.39 ...
```

```
summary(data) # Summary of data
```

	n	carat	cut	color
## Min.	: 1	Min. :0.2000	Fair : 1610	D: 6775
## 1st Qu.	:13486	1st Qu.:0.4000	Good : 4906	E: 9797
## Median	:26971	Median :0.7000	Ideal :21551	F: 9542
## Mean	:26971	Mean :0.7979	Premium :13791	G:11292
## 3rd Qu.	:40455	3rd Qu.:1.0400	Very Good:12082	H: 8304
## Max.	:53940	Max. :5.0100		I: 5422
				J: 2808
	clarity	depth	table	price
## SI1	:13065	Min. :43.00	Min. :43.00	Min. : 326
## VS2	:12258	1st Qu.:61.00	1st Qu.:56.00	1st Qu.: 949
## SI2	: 9194	Median :61.80	Median :57.00	Median : 2397
## VS1	: 271	Mean :61.75	Mean :57.46	Mean : 2000



Summarize Discrete Variables

- We can summarize discrete variables by frequency with `table()`

```
table(data$color) # Univariate frequency table

##
##      D      E      F      G      H      I      J
##  6775  9797  9542 11292  8304  5422  2808

table(data$color, data$cut) # Cross frequency table

##
##      Fair Good Ideal Premium Very Good
##      D   163   662   2834    1603    1513
##      E   224   933   3903    2337    2400
##      F   312   909   3826    2331    2164
##      G   314   871   4884    2924    2299
##      H   303   702   3115    2360    1824
##      I   175   522   2093    1428    1204
##      J   119   307   896     808     678
```

Summarize Continuous Variables

- We can summarize continuous variables by statistics and `cut()`

```
mean(data$carat) # Mean value  
  
## [1] 0.7979397  
  
sd(data$carat) # Standard error  
  
## [1] 0.4740112  
  
quantile(data$carat) # Quantiles  
  
##    0%   25%   50%   75% 100%  
## 0.20 0.40 0.70 1.04 5.01  
  
table(cut(data$carat, breaks = 10)) # Frequency counts of equal-length cut  
  
##  
## (0.195,0.681]  (0.681,1.16]   (1.16,1.64]   (1.64,2.12]   (2.12,2.6]  
##      25155       18626        7129        2349        614  
##  (2.6,3.09]  (3.09,3.57]  (3.57,4.05]  (4.05,4.53]  (4.53,5.01]  
##      53           6            5            2            1
```

Summarize by Group

- We can summarize data by groups with `aggregate()` and `xtabs()`

```
aggregate(carat ~ cut, data, mean) # summarize by groups

##          cut      carat
## 1      Fair 1.0461366
## 2     Good 0.8491847
## 3    Ideal 0.7028370
## 4 Premium 0.8919549
## 5 Very Good 0.8063814

group = aggregate(carat ~ color + cut, data, mean) # group by multi-index with "+" in formula
xtabs(carat ~ color + cut, data = group) # expand a 2-D multi-index to a matrix

##          cut
## color      Fair      Good      Ideal      Premium Very Good
##       D 0.9201227 0.7445166 0.5657657 0.7215471 0.6964243
##       E 0.8566071 0.7451340 0.5784012 0.7177450 0.6763167
##       F 0.9047115 0.7759296 0.6558285 0.8270356 0.7409612
##       G 1.0238217 0.8508955 0.7007146 0.8414877 0.7667986
##       H 1.2191749 0.9147293 0.7995249 1.0164492 0.9159485
##       I 1.1980571 1.0572222 0.9130291 1.1449370 1.0469518
##       J 1.3411765 1.0995440 1.0635937 1.2930941 1.1332153
```

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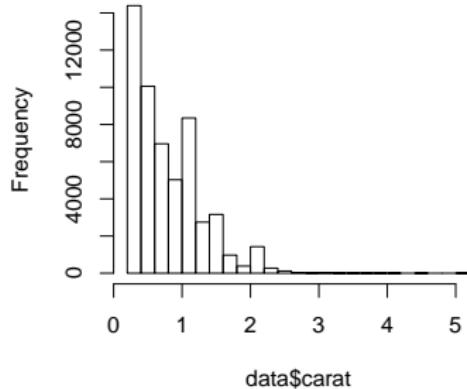
Linear Regression

Univariate Plot (1)

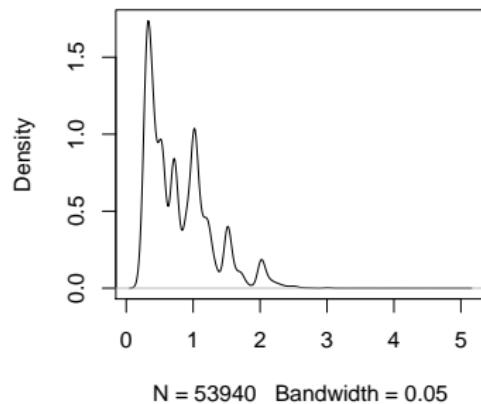
- Visualize the distribution of numeric variables by histogram and density

```
hist(data$carat, breaks = 30)
plot(density(data$carat, width = 0.2), main = "Density Distribution of Carat")
```

Histogram of data\$carat



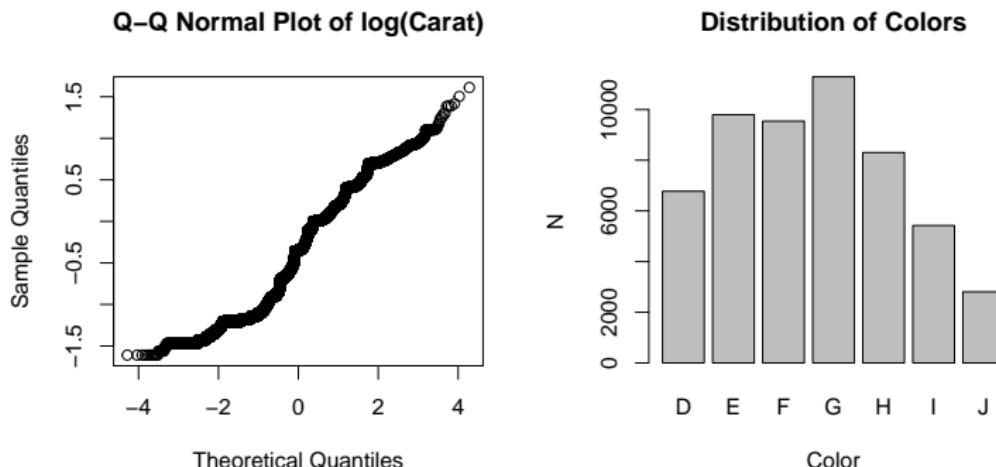
Density Distribution of Carat



Univariate Plot (2)

- Visualize the distribution of categorical variables by bar-plot

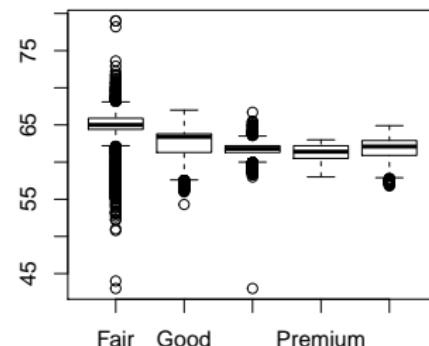
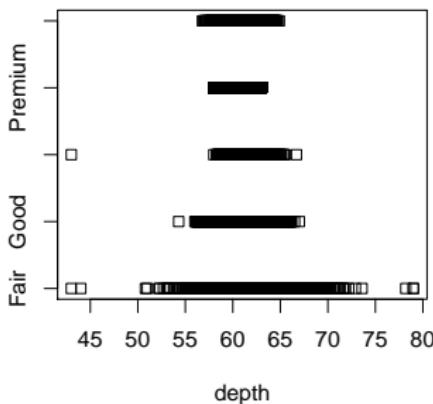
```
qqnorm(log(data$carat), main = "Q-Q Normal Plot of log(Carat)")  
plot(data$color, xlab = "Color", ylab = "N", main = "Distribution of Colors")
```



Bivariate Plot (1)

- Plot when a numerical variable is grouped by a categorical variable

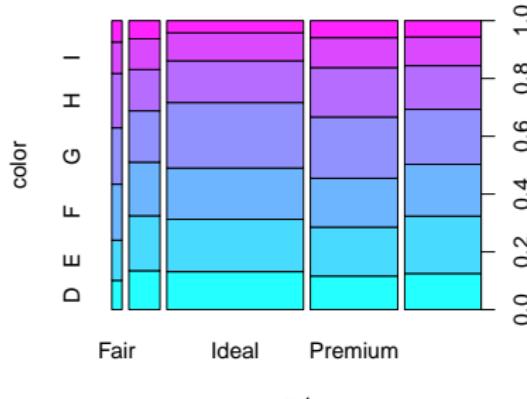
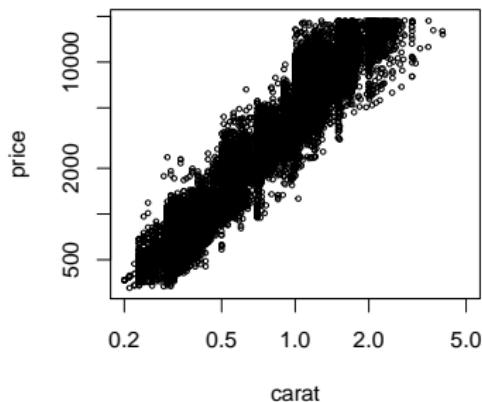
```
stripchart(depth ~ cut, data = data) # stripchart for small sample size  
boxplot(depth ~ cut, data = data) # boxplot
```



Bivariate Plot (2)

- Function `plot()` can treat different types of variables automatically

```
plot(price ~ carat, data = data, cex = 0.5, log = "xy") # scatter plot for both numerical  
plot(color ~ cut, data = data, col = rgbs((1:7)/7, (7:1)/7, 1)) # area plot for both categorical
```



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Define a function: find NA values

- We learn to define a function to find NA values in variables

```
is.na(c(NA, 0, "a", "", NA))
## [1] TRUE FALSE FALSE FALSE TRUE

countNA = function(x){
  return(sum(is.na(x)))
}
countNA(c(NA, 0, "a", "", NA))

## [1] 2

sapply(data, countNA)

##      n    carat      cut    color clarity depth table price      x
##      0        0        0        0        0      0      0   14232      0
##      y        z
##      0        0
```

Two ways to deal with NA values

- Delete the NA rows

```
data_clean = na.omit(data)
dim(data_clean)

## [1] 39708     11

sapply(data_clean, countNA)

##      n    carat      cut    color clarity   depth   table   price      x
##      0        0        0        0        0        0        0        0        0
##      y        z
##      0        0
```

- Fill NA values with the median/mean/... of the column

```
fillNA = function(x){
  a = median(x, na.rm = TRUE)
  x[is.na(x) == TRUE] = a
  return(x)
}
data$price = fillNA(data$price)
sapply(data, countNA)

##      n    carat      cut    color clarity   depth   table   price      x
##      0        0        0        0        0        0        0        0        0
##      y        z
##      0        0
```

For the earth shall be full of the knowledge of the LORD as the waters cover the sea.(Isaiah 11:9)

Select a subset from data

- Select where carat > 1 and column (carat, color, price) from data by subset()

```
data_sub_1 = subset(data, carat > 1, select = c(carat, color, price))
str(data_sub_1)

## 'data.frame': ^^I17502 obs. of  3 variables:
## $ carat: num  1.17 1.01 1.01 1.01 1.05 1.05 1.01 1.04 1.2 1.02 ...
## $ color: Factor w/ 7 levels "D","E","F","G",...: 7 3 2 5 7 7 2 4 3 4 ...
## $ price: num  2774 2781 2788 2788 2397 ...
```

- Select the same by row and column of data frame

```
data_sub_2 = data[data$carat > 1, c("carat", "color", "price")]
str(data_sub_2)

## 'data.frame': ^^I17502 obs. of  3 variables:
## $ carat: num  1.17 1.01 1.01 1.01 1.05 1.05 1.01 1.04 1.2 1.02 ...
## $ color: Factor w/ 7 levels "D","E","F","G",...: 7 3 2 5 7 7 2 4 3 4 ...
## $ price: num  2774 2781 2788 2788 2397 ...
```

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Linear Regression

Theory: Linear Regression

Model: $Y_{n \times 1} = \beta_0 + X_{n \times p} \beta_{p \times 1} + \varepsilon_{n \times 1}$

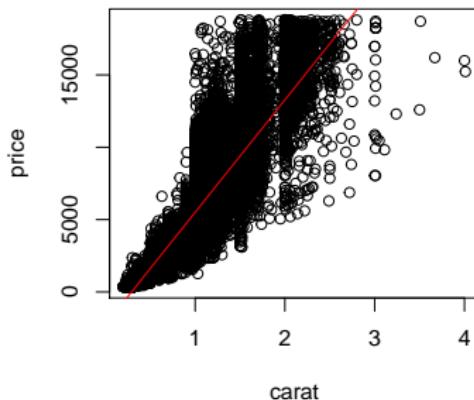
- $\varepsilon_{n \times 1} = (\varepsilon_1, \varepsilon_2, \dots, \varepsilon_n)^T \sim iid N(0, \sigma^2)$, $\sigma^2 > 0$
- Given $Y_{n \times 1} = (y_1, y_2, \dots, y_n)^T$ and $X_{n \times p} = (X_1, X_2, \dots, X_p)$
- Use least squares method to solve β_0 and
 $\beta_{p \times 1} = (\beta_1, \beta_2, \dots, \beta_p)^T$

Single Variable Regression

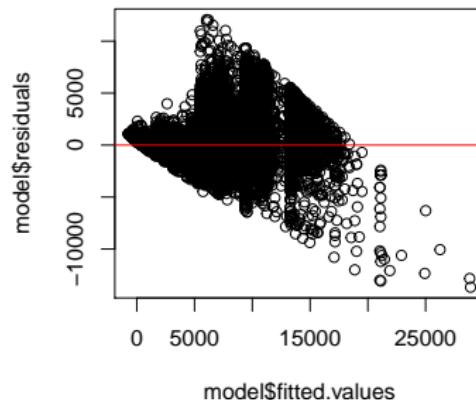
- Let Y: price, X: carat

```
model = lm(price ~ carat, data = data_clean)
plot(price ~ carat, data = data_clean, main = "Regression Plot")
abline(model, col = "red")
plot(model$residuals ~ model$fitted.values, main = "Residual Plot")
abline(0,0, col = "red")
```

Regression Plot



Residual Plot



Summary of Linear Regression

- Let Y: price, X: carat, cut(factor variable) and interaction (":")

```
model = lm(price ~ carat + cut + carat:cut, data = data_clean)
summary(model)

##
## Call:
## lm(formula = price ~ carat + cut + carat:cut, data = data_clean)
##
## Residuals:
##    Min      1Q  Median      3Q     Max 
## -13802.3   -794.5    -21.7    545.7  12043.6 
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)    
## (Intercept) -2056.50    101.18 -20.325 < 2e-16 ***
## carat        6174.20     88.06  70.110 < 2e-16 ***
## cutGood      -387.22    114.00  -3.397 0.000683 ***
## cutIdeal     -249.57    103.65  -2.408 0.016053 *  
## cutPremium   -312.43    105.39  -2.965 0.003033 ** 
## cutVery Good -363.72    106.09  -3.428 0.000608 *** 
## carat:cutGood 1315.59    103.53  12.708 < 2e-16 ***
## carat:cutIdeal 2024.48     92.17  21.964 < 2e-16 ***
## carat:cutPremium 1617.86    92.57  17.476 < 2e-16 ***
## carat:cutVery Good 1760.99    94.59  18.616 < 2e-16 *** 
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 1489 on 39698 degrees of freedom
## Multiple R-squared:  0.2699, Adjusted R-squared:  0.2699
```



ANOVA Table

- ANOVA table

```
anova(model)

## Analysis of Variance Table
##
## Response: price
##           Df   Sum Sq   Mean Sq   F value   Pr(>F)
## carat       1 5.3925e+11 5.3925e+11 243069.75 < 2.2e-16 ***
## cut          4 4.3910e+09 1.0977e+09   494.82 < 2.2e-16 ***
## carat:cut    4 1.2771e+09 3.1927e+08   143.91 < 2.2e-16 ***
## Residuals 39698 8.8070e+10 2.2185e+06
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

- Add source to the model ("." indicates all source in the data/model)

```
add1(model, ~ . + clarity, test = "F")

## Single term additions
##
## Model:
## price ~ carat + cut + carat:cut
##           Df   Sum of Sq      RSS      AIC F value   Pr(>F)
## <none>            8.8070e+10 580237
## clarity    7 2.5146e+10 6.2924e+10 566901     2266 < 2.2e-16 ***
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Stepwise Selection

- Stepwise selection from all variables from both forward and backward directions

```
model = lm(price ~ ., data = data_clean)
model_step = step(model, direction = "both", trace = 0)
anova(model_step)

## Analysis of Variance Table
##
## Response: price
##              Df    Sum Sq   Mean Sq   F value   Pr(>F)
## n            1 5.9563e+10 5.9563e+10 4.7941e+04 < 2.2e-16 ***
## carat        1 4.8098e+11 4.8098e+11 3.8712e+05 < 2.2e-16 ***
## cut           4 4.2296e+09 1.0574e+09 8.5106e+02 < 2.2e-16 ***
## color         6 9.3278e+09 1.5546e+09 1.2513e+03 < 2.2e-16 ***
## clarity       7 2.7198e+10 3.8855e+09 3.1273e+03 < 2.2e-16 ***
## depth          1 5.1445e+05 5.1445e+05 4.1410e-01    0.5199
## table          1 5.8029e+07 5.8029e+07 4.6706e+01 8.367e-12 ***
## x              1 2.3279e+09 2.3279e+09 1.8737e+03 < 2.2e-16 ***
## Residuals 39685 4.9306e+10 1.2424e+06
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

More Transformations of Linear Model Variables

- Use "*" in formula for both main effect ("+") and interaction effect (":")

```
model_interact = lm(price ~ carat * cut * color, data = data_clean)
summary(model_interact)
```

- Use "-" for deleting source (1 indicates intercept)

```
model_reduced = lm(price ~ . - 1 - cut, data = data_clean)
summary(model_reduced)
```

- More transformation of numerical variables: cut, log, polynomial, ...

```
model_cut = lm(price ~ cut(carat, breaks = 5) + cut, data = data_clean)
summary(model_cut)
model_log = lm(log(price) ~ log(carat) + cut, data = data_clean)
summary(model_log)
model_poly = lm(price ~ poly(carat, 3) + cut, data = data_clean)
summary(model_poly)
model_poly_raw = lm(price ~ poly(carat, 3, raw = TRUE) + cut, data = data_clean)
summary(model_poly_raw)
```