IST 5535: Machine Learning Algorithms and Applications

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2. Getting Started with R

Reading

- Book Section 2.3 “Lab: Introduction to R”
- An Introduction to R (Chapters 1, 2, 3, 4, 5, 6, 9,10; pg 2-29, 40-50)
  - https://cran.r-project.org/doc/manuals/R-intro.pdf
- Data Wrangling with dplyr and tidyr Cheat Sheet
  - https://www.rstudio.com/wp-content/uploads/2015/02/data-wrangling-cheatsheet.pdf
- RStudio IDE Cheat Sheet
  - https://github.com/rstudio/cheatsheets/raw/master/rstudio-ide.pdf
- Base R Cheat Sheet
  - http://github.com/rstudio/cheatsheets/raw/master/base-r.pdf

Learning Objectives

- Learn basic R programming knowledge
- Get familiar with RStudio, be able to use it for BA and ML projects
- Be able to apply basic data structures in R
- Understand the concepts of control structures and be able to use them in R programming
- Be able to define functions for code reuse

Agenda

- What is R?
- Program with RStudio
- Introduction to R Markdown
- Data Structures in R
- R Functions
- Control Structures (Selection and Loop)

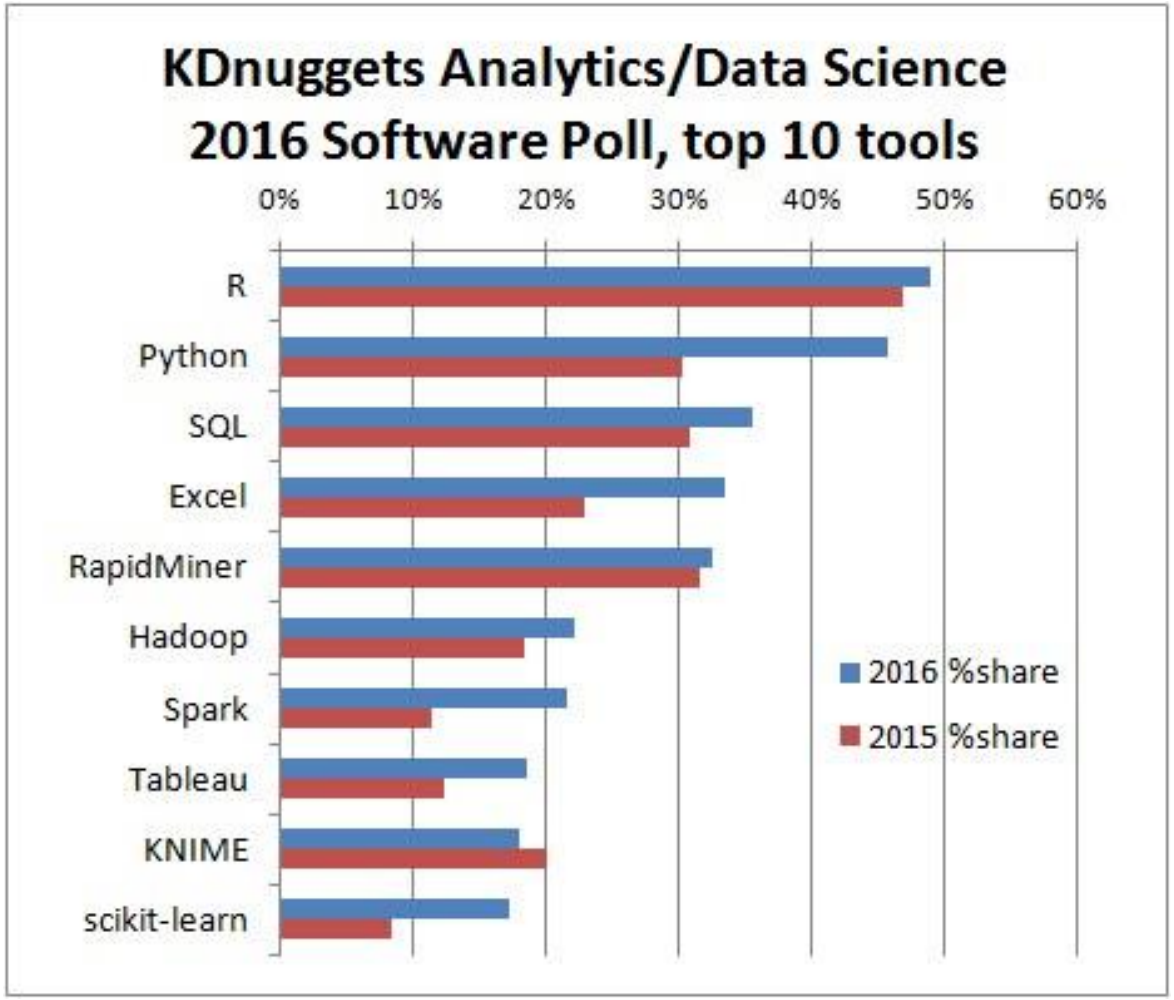
R

- A free, open-source programming language for statistical computing
- An interpreted language (executed directly, no compilation)
- R supports matrix arithmetic (like Matlab)
- R supports both procedural programming and object-oriented programming

CRAN: Comprehensive R Archive Network

- Capability extended through a packaging system on CRAN, the Comprehensive R Archive Network
  - http://cran.r-project.org/
- So many useful packages available on CRAN
- You can contribute to CRAN by uploading your own package!

R is popular; Don’t get left behind.



http://www.kdnuggets.com/2016/06/r-python-top-analytics-data-mining-data-science-software.html

Steep Learning Curve for R

- The “weird” syntax of R

“The best thing about R is that it was developed by statisticians. The worst thing about R is that ... it was developed by statisticians.”

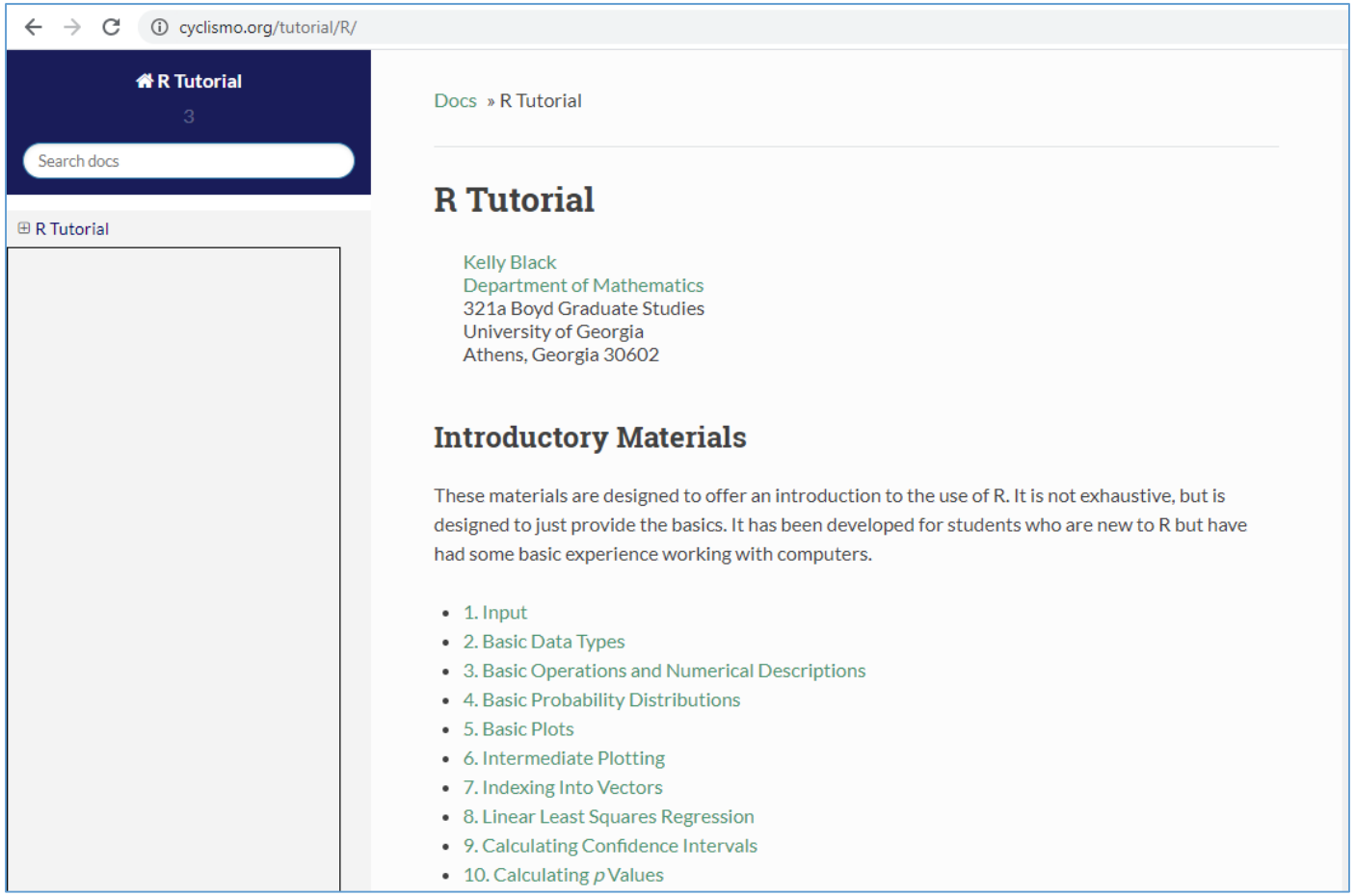
-- Bo Cowgill, Google

“Unlike other high-level scripting languages, such as Python or Ruby, R has a unique and somewhat prickly syntax and tends to have a steeper learning curve than other languages.”

-- Drew Conway & John White, “Machine Learning for Hackers” P2.

To be familiar with R

https://www.cyclismo.org/tutorial/R/



Other Resources for Learning R

- Remember the Rseek (search engine for R language)!
  - http://rseek.org/
- “An Introduction to R”
  - https://cran.r-project.org/doc/manuals/R-intro.pdf
- R Language Definition
  - https://cran.r-project.org/doc/manuals/r-release/R-lang.pdf
- “R Reference Card” – quick reference for important tasks
  - https://cran.r-project.org/doc/contrib/Short-refcard.pdf
- A Step-by-Step R Tutorial
  - http://www.cyclismo.org/tutorial/R/
- Stack Overflow Q&A Site
  - http://stackoverflow.com/questions/tagged/r
- Commonly Used R Packages
  - https://support.rstudio.com/hc/en-us/articles/201057987-Quick-list-of-useful-R-packages

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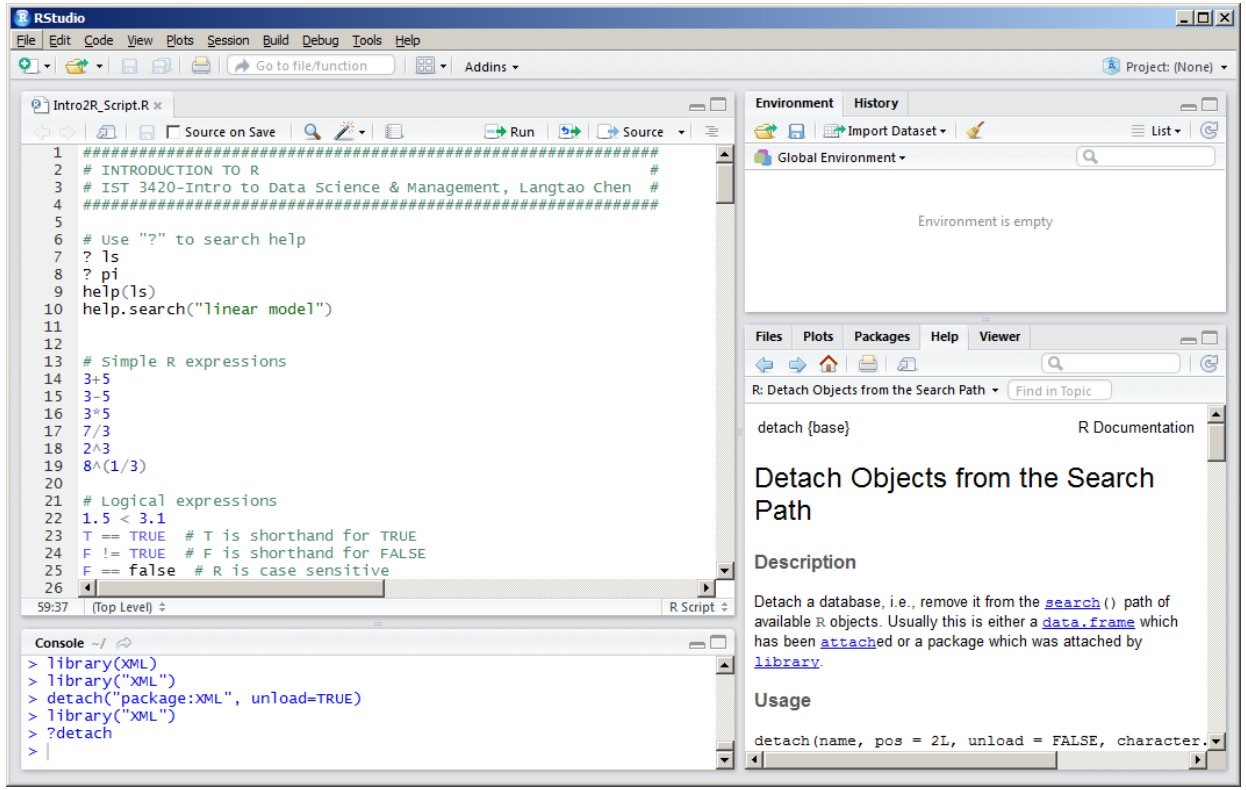
RStudio

- An open-source IDE for R
- Since version 1.2, RStudio started to support Python
- Install the RStudio Desktop (open source edition) from https://www.rstudio.com/products/rstudio/download/



Try RStudio

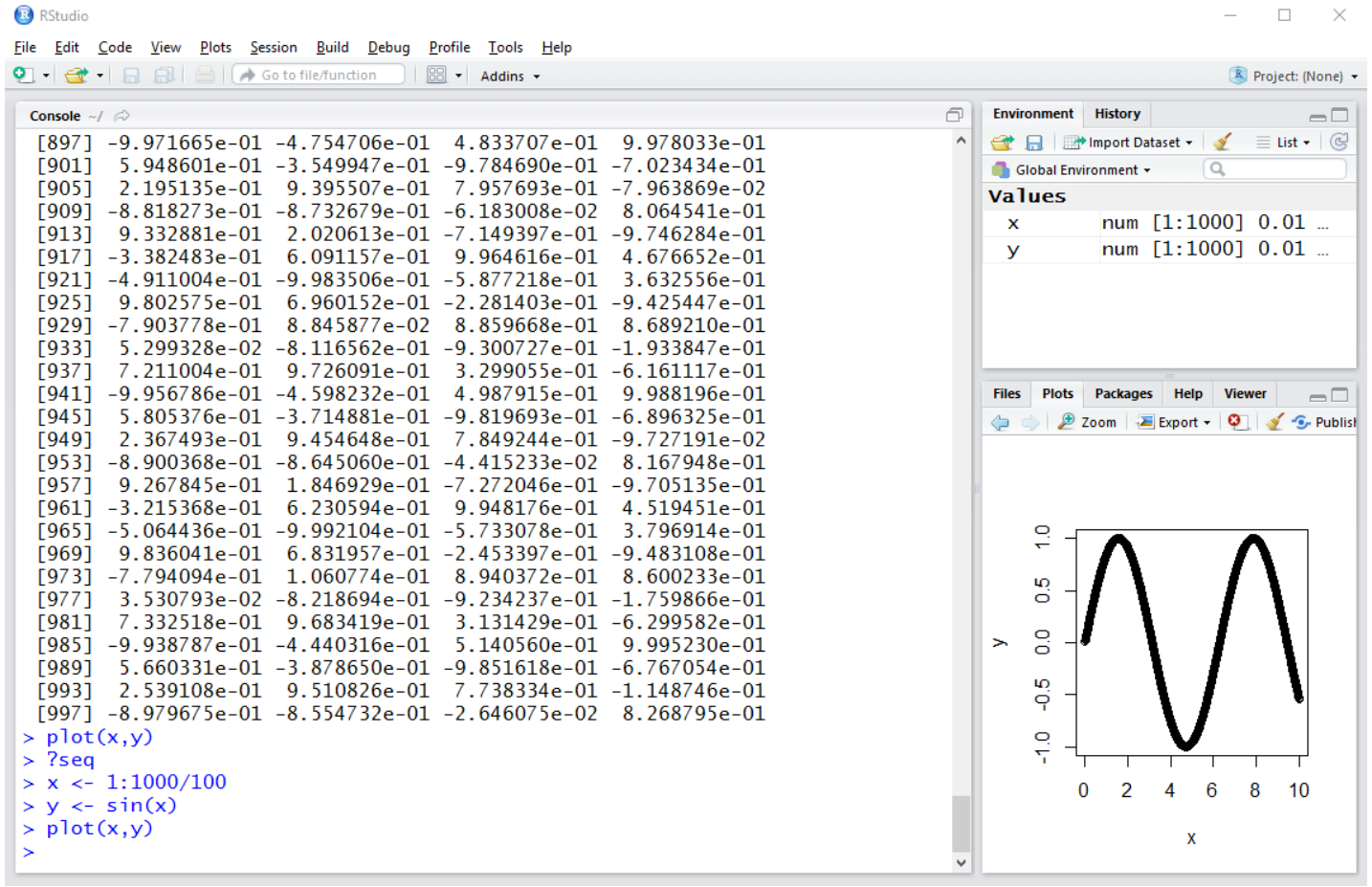
Use Shortcuts to Improve Coding Efficiency

- For a complete list, refer to https://support.rstudio.com/hc/en-us/articles/200711853-Keyboard-Shortcuts

Function	***Windows & Linux***	***Mac***
Move cursor to Source Editor	Ctrl + 1	Ctrl + 1
Move cursor to Console	Ctrl + 2	Ctrl + 2
Interrupt currently executing command	Esc	Esc
Navigate command history	Up/Down	Up/Down
Run current line/selection	Ctrl + Enter	Command + Enter
Save active document	Ctrl + S	Command + S

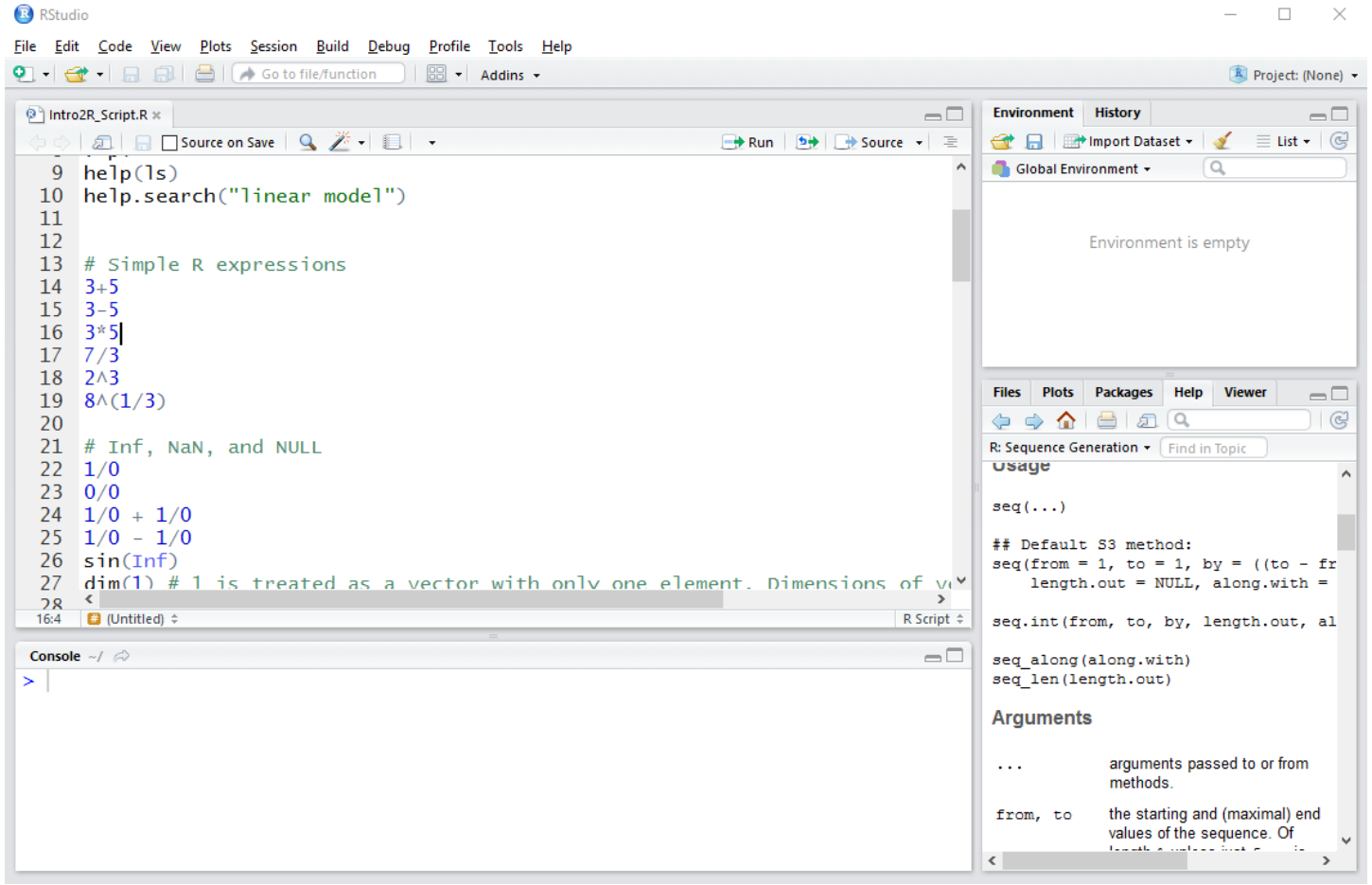
Three Ways of R Programming for Data Science

- 1: Type and execute R command in Console window line by line => Avoid



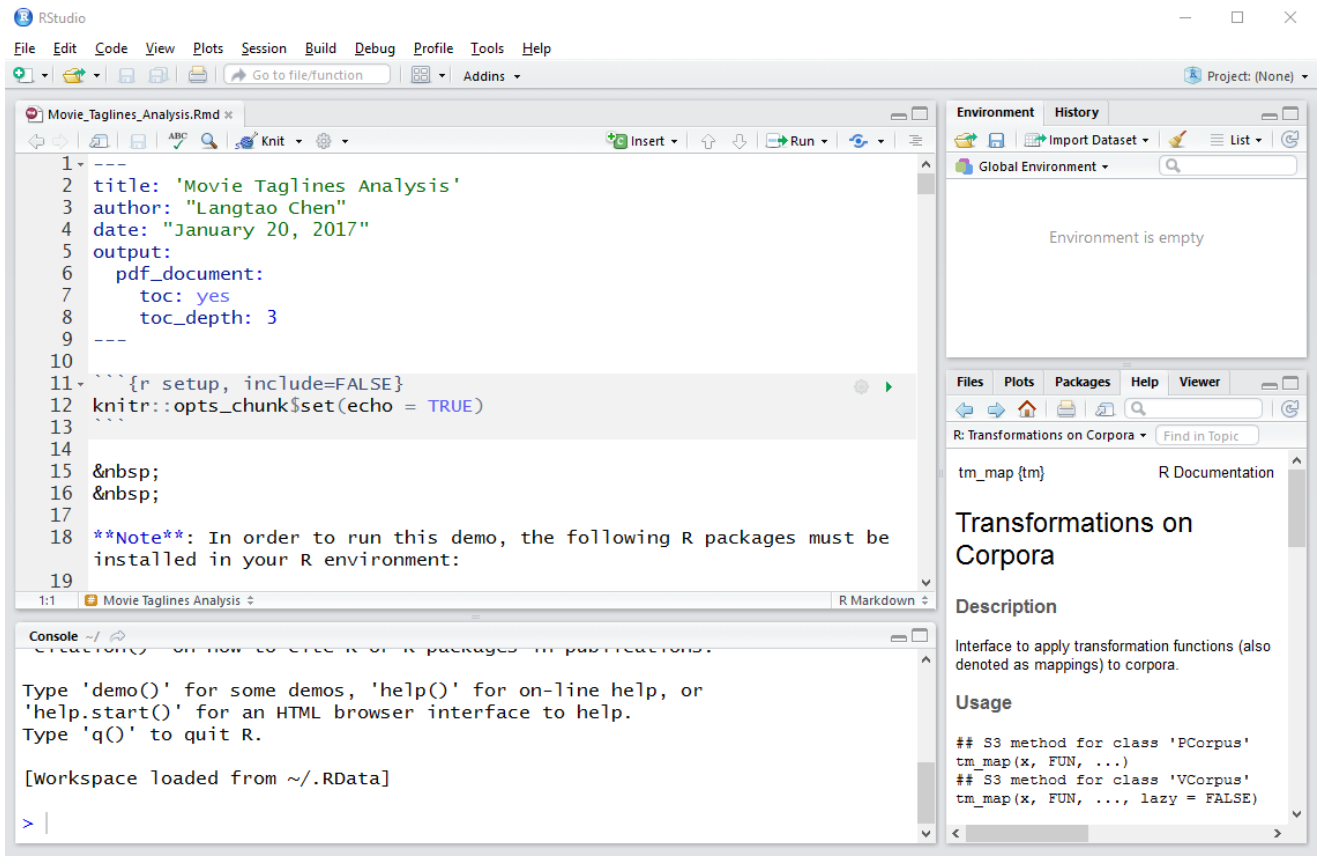
Three Ways of R Programming for Data Science

- 2: Program in R script => Acceptable



Three Ways of R Programming for Data Science

- 3: Program in R Markdown + Results + Full explanation => Preferred



Fundamental Principles

- Everything that exists in R is an object.
- Everything that happens in R is a function call.
- Interfaces to other software are part of R.

Source: Chambers, John M. *Extending R*. CRC Press, 2016.

Attributes of an Object

- names
- dimnames
- dim
- class
- attributes (contain metadata)
- length (works on vectors and lists)
- nchar (number of characters in a string)

Basic Operations

- R is case sensitive!
- Use “?” to search help
- Constants and symbols
  - Any number typed directly is a constant.
  - The name of a variable is a symbol.
- Two assignment operators
  - Left assignment <- (for example, a <- 4)
  - Right assignment -> (for example, 4 -> b)
- List indexing: $

Atomic Data Types

- Character
  - “a”, “hello”
- Logical
  - TRUE, FALSE
- Integer
  - x <- 5L # Must add L at the end to explicitly denote integer
- Double
  - 4, 13.48
- Complex
  - 2 + 3i

R Basic Operators

- Arithmetic Operators

Operator	Meaning	Unary or Binary
+	Plus	Both
-	Minus	Both
*	Multiplication	Binary
/	Division	Binary
^	Exponentiation	Binary
%%	Modulus	Binary
%/%	Integer division	Binary
%*%	Matrix product	Binary
%o%	Outer product	Binary

(cont.)

- Comparison Operators

Operator	Meaning	Unary or Binary	Example (a is 4)	Result
<	Less than	Binary	a < 0	FALSE
>	Greater than	Binary	a > 0	TRUE
==	Equal to	Binary	a == 3	FALSE
>=	Greater than or equal to	Binary	a >= 0	TRUE
<=	Less than or equal to	Binary	a <= 0	FALSE
!=	Not equal to	Binary	a !=3	TRUE

(cont.)

- Logic Operators

Operator	Meaning	Unary or Binary	Example (a is TRUE, b is FALSE)	Result
&	And, vectorized	Binary	a & b	FALSE
|	Or, vectorized	Binary	a | b	TRUE
&&	And, not vectorized	Binary	a && b	FALSE
||	Or, not vectorized	Binary	a || b	TRUE
!	Not	Unary	!a	TRUE
xor	Exclusive or	Binary	xor(a,b)	TRUE
isTrue()	Test if true	Unary	isTRUE(a)	FALSE

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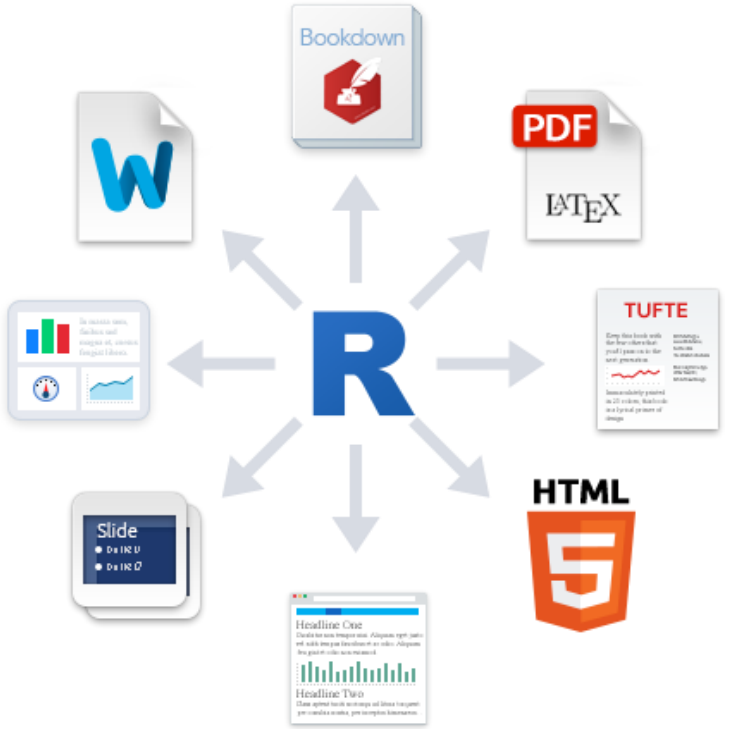
Dynamic Documents in R

- "R Markdown is an authoring format that enables easy creation of dynamic documents, presentations, and reports from R".

- R code embedded in text
  - You can write R code in plain text and generate data analysis reports in various formats such as HTML, PDF, Word, HTML5 slides.

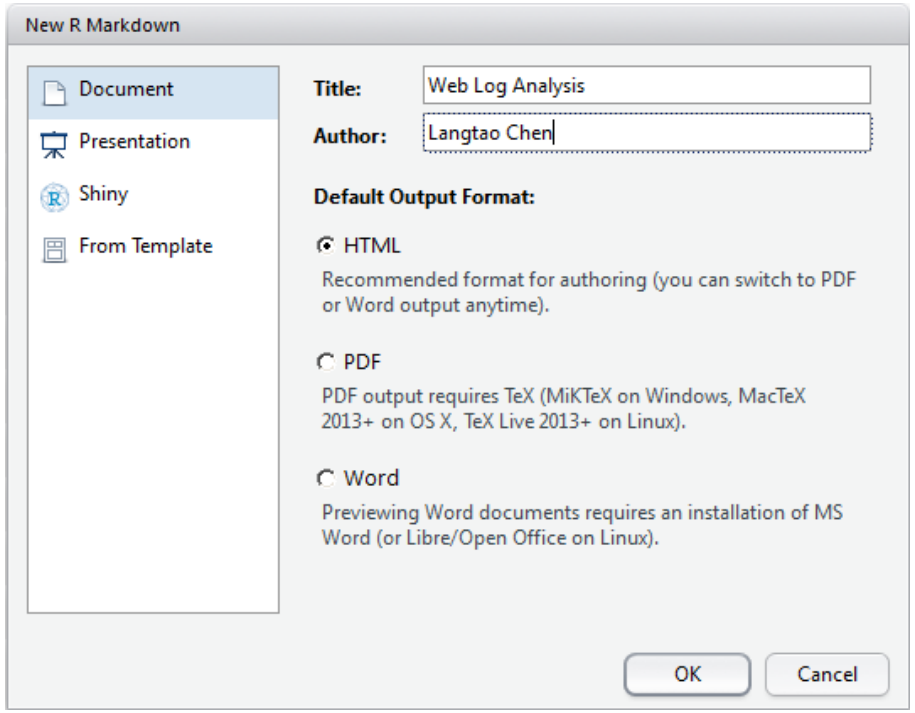
- Reproducible analysis
  - You can easily reproduce the data analysis results after the data and/or code change.



Source: http://rmarkdown.rstudio.com/

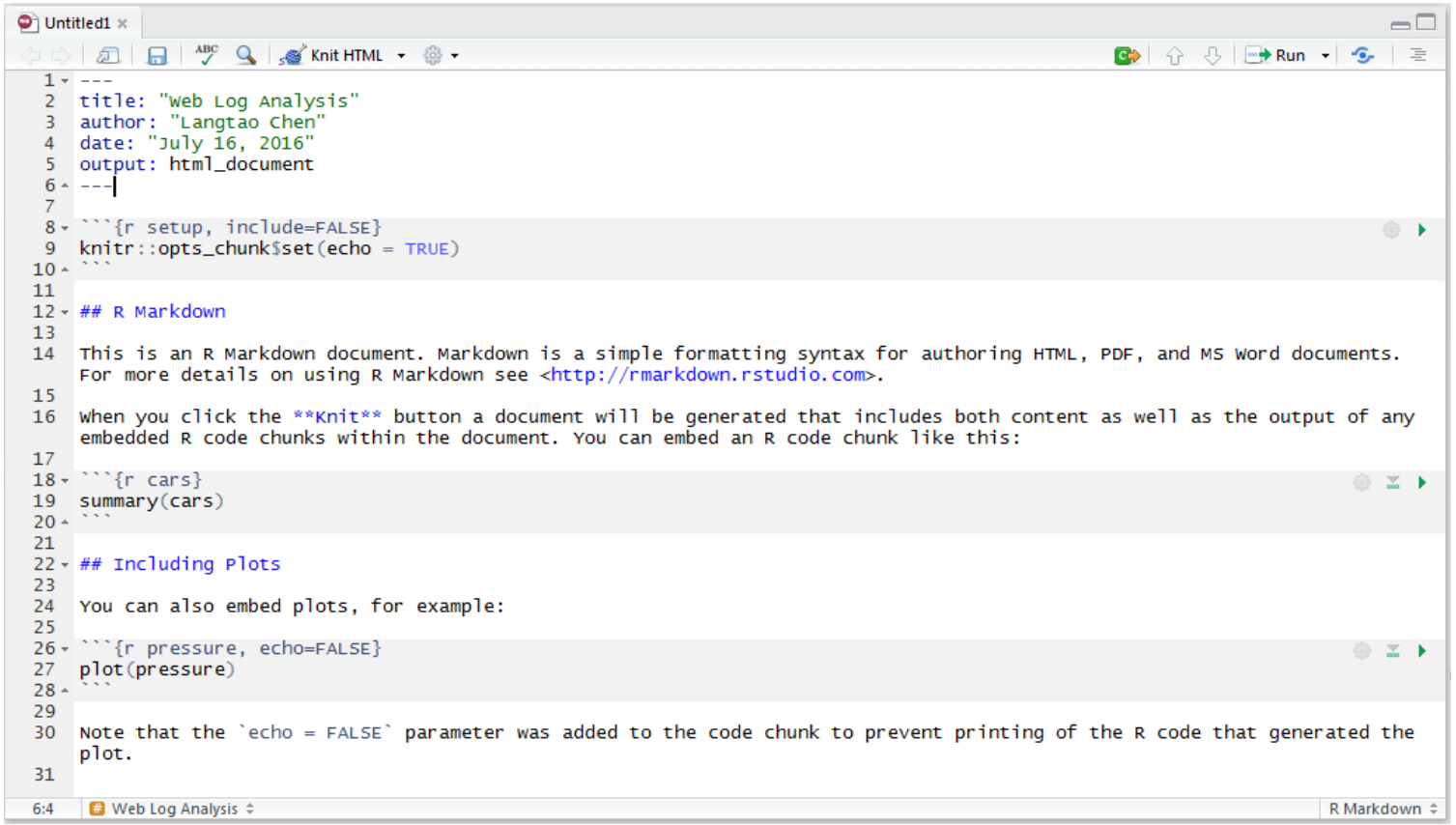
Use R Markdown

- Install R markdown package
  - install.packages("rmarkdown")
- In Rstudio, click “File -> New File -> R Markdown...” menu
- In the popup window, input header information, then click “OK” button



(cont.)

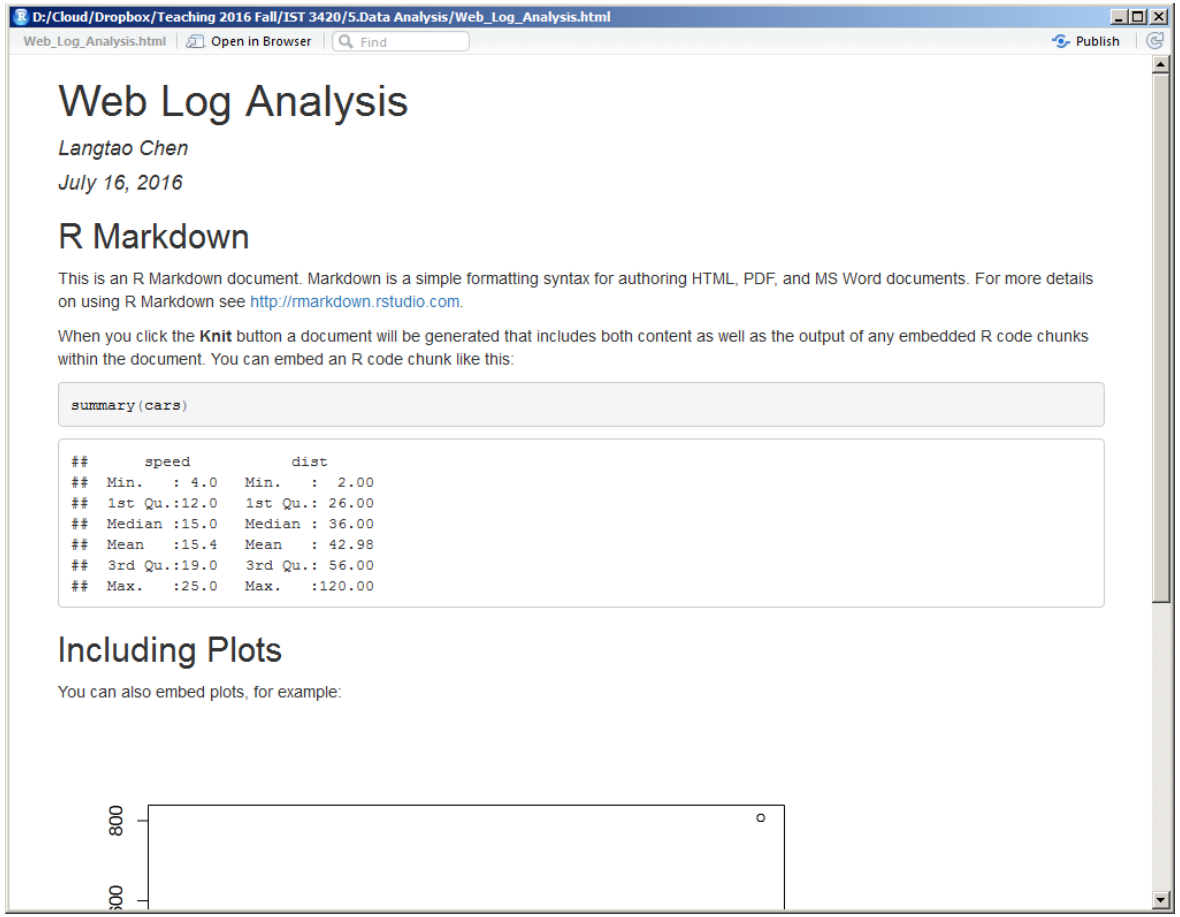
- RStudio generates a sample R markdown (.Rmd) file for you



(cont.)

- Click the “Knit HTML” button 

on the toolbar to generate the HTML report



(cont.)

- Follow the R markdown syntax demonstrated in the sample file, write your own data analysis by editing the Rmd template.

R Markdown Syntax Summary

- YAML Header (key: value pairs)
  - At the beginning of Rmd file
  - Between lines of ---
- Plain Text Format
  - Headers: Begin with #
  - Lists: Begin with -
  - LaTex or MathML equations: Enclosed within $
- Embedded R Code
  - R Code Chunks: Begin with ```{r} and end with ```
  - Inline R Code: Begin with `r and end with `

An Example

- R Markdown File

Manage_Weblog_Data.Rmd

- PDF Output

Manage_Weblog_Data.pdf

Reference

- R Markdown Cheat Sheet
  - http://www.rstudio.com/wp-content/uploads/2016/03/rmarkdown-cheatsheet-2.0.pdf
- R Markdown Reference Guide
  - http://www.rstudio.com/wp-content/uploads/2015/03/rmarkdown-reference.pdf

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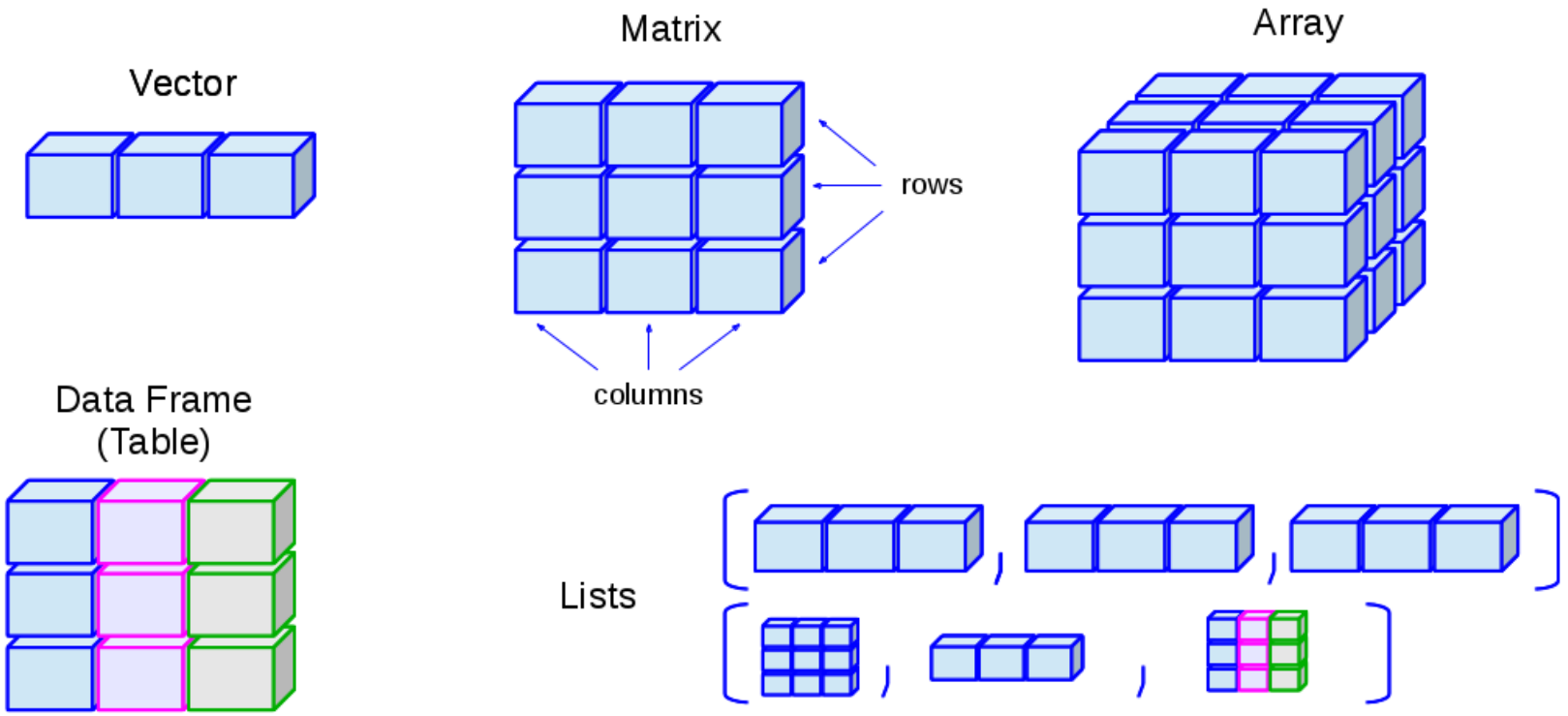
R Data Structures

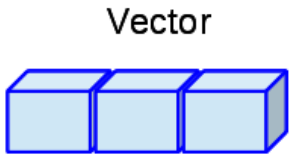
- Vectors, matrices, arrays, data frames (like tables in a RDBMS), and lists



There is no scalar data structure in R. We simply use a vector of length 1 to represent scalar.

Image source: http://venus.ifca.unican.es/Rintro/dataStruct.html

Vectors



- An ordered collection of elements
- Create a vector of numbers
  - v1 <- c(1,2,3,4)
- Use [] to access vector elements
- Create a vector of strings
  - v2 <- c("a","b","c")
- Elements in a vector should be of the same type
  - v3 <- c(1, "a")
  - mode(v3) # Check the type of storage mode
    [1] "character"

c function: c means “combine”

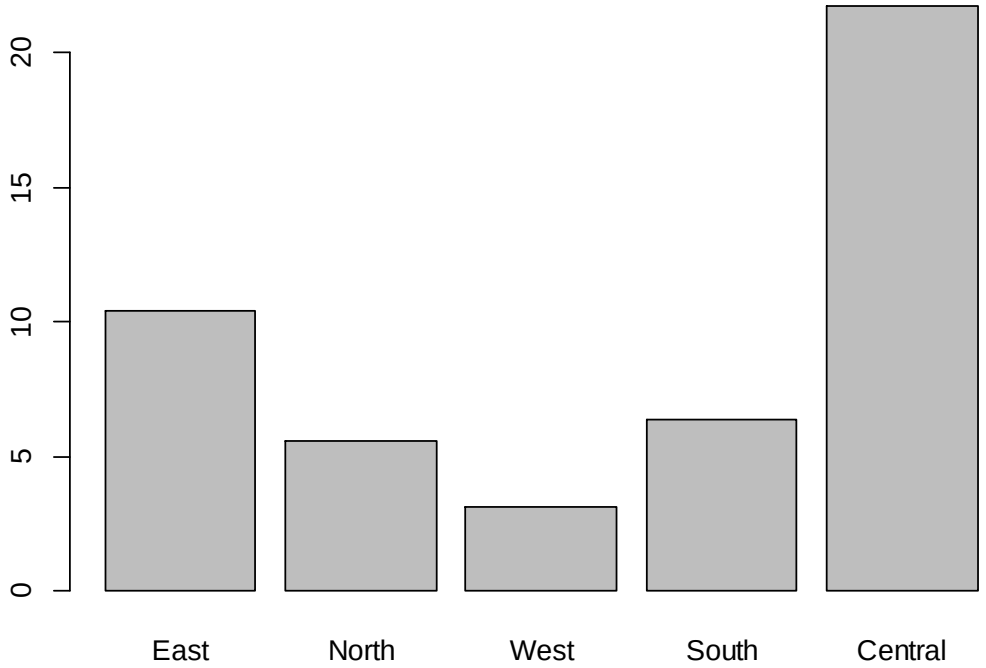
Names of Vectors

- Use names() to set or get names of an object

```
> v4
[1] 10.4 5.6 3.1 6.4 21.7
> names(v4) <- c("East","North","West","South","Central")
# To set vector name
> v4
  East North West South Central
  10.4 5.6 3.1 6.4 21.7
> names(v4) # To get vector name
[1] "East" "North" "West" "South" "Central"
```

Bar Plot

- barplot(v4)



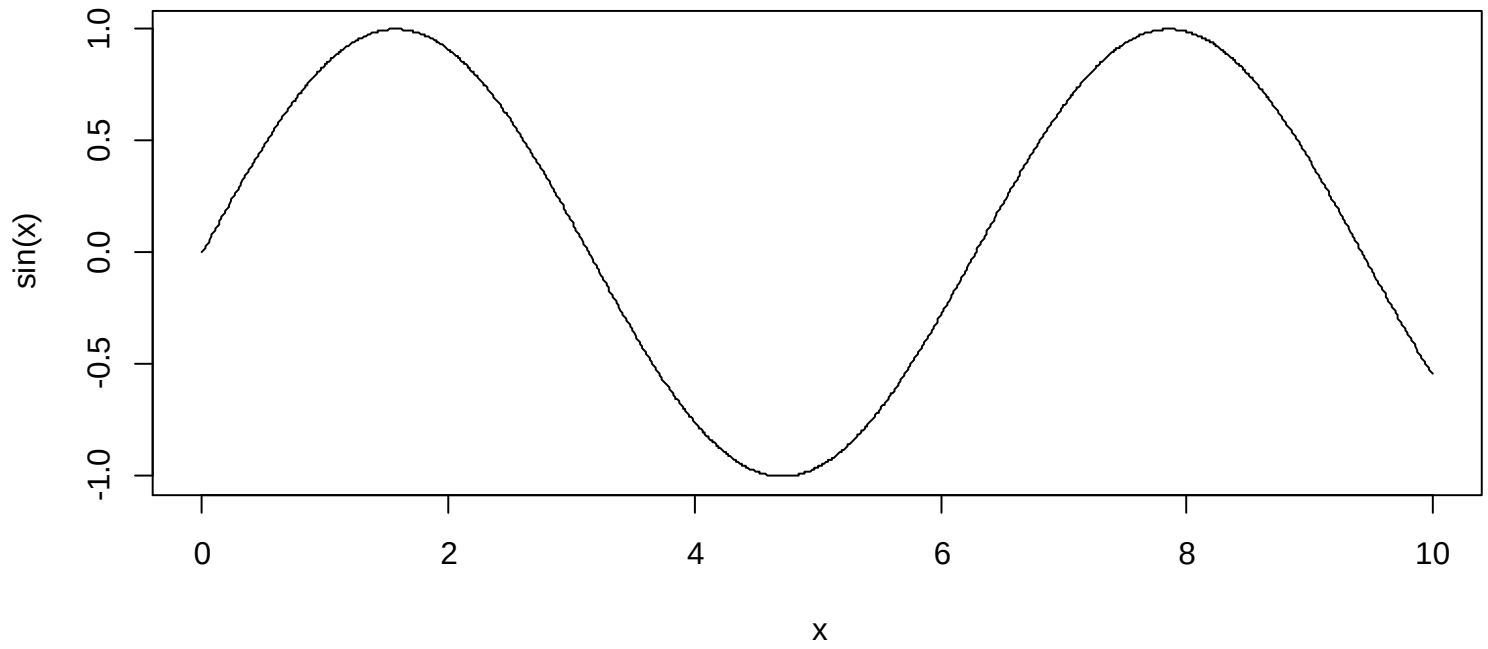
Sequences

- Use colon :
- Use seq() function

```
> 5:9
[1] 5 6 7 8 9
> seq(5,9)
[1] 5 6 7 8 9
> seq(5,9,by = 1)
[1] 5 6 7 8 9
> seq(5,9,by = 0.5)
[1] 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0
> seq(from = 5, to = 9, by = 0.4)
[1] 5.0 5.4 5.8 6.2 6.6 7.0 7.4 7.8 8.2 8.6 9.0
> seq(0, 1, length.out = 11)
[1] 0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
```

Plot

```
> x <- seq(0,10, by=0.01)
> plot(x,sin(x),type ="l")
```



Repetitions

- Use rep( ) function

```
> rep(1:4, 3)
[1] 1 2 3 4 1 2 3 4 1 2 3 4
> rep(1:4, each = 3)
[1] 1 1 1 2 2 2 3 3 3 4 4 4
> rep(1:4, c(3,3,3,3))
[1] 1 1 1 2 2 2 3 3 3 4 4 4
> rep(1:4, c(1,2,3,4))
[1] 1 2 2 3 3 3 4 4 4 4
```

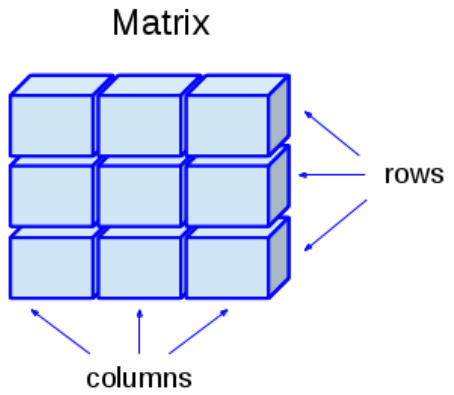
Vector Math

- Most arithmetic operations work as well

```
> a <- c(1,2,3,4)
> b <- a + 2
> a*2
[1] 2 4 6 8
> a/3
[1] 0.3333333 0.6666667 1.0000000 1.3333333
> a^2
[1] 1 4 9 16
> a<b
[1] TRUE TRUE TRUE TRUE
> sin(b)
[1] 0.1411200 -0.7568025 -0.9589243 -0.2794155
```

Matrices

- A matrix is a bi-dimensional array
  - Rows
  - Columns



Colum Names and Row Names

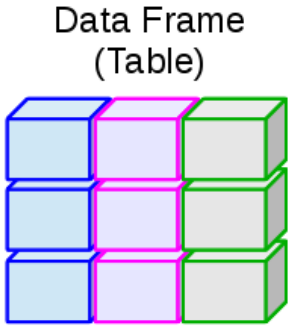
- Use colnames and rownames to retrieve or set the row and column names of a matrix-like object.

```
> m2 <- matrix(1:12,ncol = 4, byrow = TRUE)
> m2
     [,1] [,2] [,3] [,4]
[1,]    1    2    3    4
[2,]    5    6    7    8
[3,]    9   10   11   12
> colnames(m2) <- c("a","b","c","d")
> rownames(m2) <- c("i","j","k")
> m2
  a  b  c  d
i 1  2  3  4
j 5  6  7  8
k 9 10 11 12
> colnames(m2)
[1] "a" "b" "c" "d"
> rownames(m2)
[1] "i" "j" "k"
```

Data Frames

- Data frame is a list of vectors of equal length.
- Each column should be of the same type.
- Similar to tables in RDBMS, or data set in SAS or SPSS, i.e. a “cases by variables” matrix of data.

```
> id <- c(11,12,13)
> name <- c("Lily","Jim","Tom")
> credit <- c(710,700,680)
> df <- data.frame(id,name,credit)
> df
  id name credit
1 11 Lily    710
2 12  Jim    700
3 13  Tom    680
> df["name"]  # Show the name column
  name
1 Lily
2  Jim
3  Tom
> df[["name"]]
[1] Lily Jim  Tom
Levels: Jim Lily Tom
```



Motor Trend Data Built in R

- The mtcars is a built-in data frame which comprises fuel consumption and 10 aspects of automobile design and performance for 32 automobiles (1973–74 models).

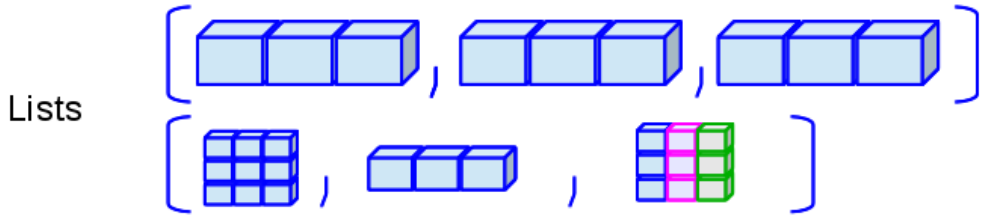
```
> head(mtcars)
                   mpg cyl disp  hp drat    wt  qsec vs am gear carb
Mazda RX4         21.0   6  160 110 3.90 2.620 16.46  0  1    4    4
Mazda RX4 Wag     21.0   6  160 110 3.90 2.875 17.02  0  1    4    4
Datsun 710        22.8   4  108  93 3.85 2.320 18.61  1  1    4    1
Hornet 4 Drive    21.4   6  258 110 3.08 3.215 19.44  1  0    3    1
Hornet Sportabout 18.7   8  360 175 3.15 3.440 17.02  0  0    3    2
Valiant           18.1   6  225 105 2.76 3.460 20.22  1  0    3    1
> head(mtcars,n=3)
               mpg cyl disp  hp drat    wt  qsec vs am gear carb
Mazda RX4     21.0   6  160 110 3.90 2.620 16.46  0  1    4    4
Mazda RX4 Wag 21.0   6  160 110 3.90 2.875 17.02  0  1    4    4
Datsun 710    22.8   4  108  93 3.85 2.320 18.61  1  1    4    1
> tail(mtcars)
                 mpg cyl  disp  hp drat    wt qsec vs am gear carb
Porsche 914-2   26.0   4 120.3  91 4.43 2.140 16.7  0  1    5    2
Lotus Europa    30.4   4  95.1 113 3.77 1.513 16.9  1  1    5    2
Ford Pantera L  15.8   8 351.0 264 4.22 3.170 14.5  0  1    5    4
Ferrari Dino    19.7   6 145.0 175 3.62 2.770 15.5  0  1    5    6
Maserati Bora   15.0   8 301.0 335 3.54 3.570 14.6  0  1    5    8
Volvo 142E      21.4   4 121.0 109 4.11 2.780 18.6  1  1    4    2
```

Summary of All Variables(Columns)

```
> summary(mtcars)  # Summary of all variables(columns)
      mpg             cyl             disp             hp             drat      
 Min.   :10.40   Min.   :4.000   Min.   : 71.1   Min.   : 52.0   Min.   :2.760  
 1st Qu.:15.43   1st Qu.:4.000   1st Qu.:120.8   1st Qu.: 96.5   1st Qu.:3.080  
 Median :19.20   Median :6.000   Median :196.3   Median :123.0   Median :3.695  
 Mean   :20.09   Mean   :6.188   Mean   :230.7   Mean   :146.7   Mean   :3.597  
 3rd Qu.:22.80   3rd Qu.:8.000   3rd Qu.:326.0   3rd Qu.:180.0   3rd Qu.:3.920  
 Max.   :33.90   Max.   :8.000   Max.   :472.0   Max.   :335.0   Max.   :4.930  
       wt             qsec             vs              am       
 Min.   :1.513   Min.   :14.50   Min.   :0.0000   Min.   :0.0000  
 1st Qu.:2.581   1st Qu.:16.89   1st Qu.:0.0000   1st Qu.:0.0000  
 Median :3.325   Median :17.71   Median :0.0000   Median :0.0000  
 Mean   :3.217   Mean   :17.85   Mean   :0.4375   Mean   :0.4062  
 3rd Qu.:3.610   3rd Qu.:18.90   3rd Qu.:1.0000   3rd Qu.:1.0000  
 Max.   :5.424   Max.   :22.90   Max.   :1.0000   Max.   :1.0000  
      gear            carb      
 Min.   :3.000   Min.   :1.000  
 1st Qu.:3.000   1st Qu.:2.000  
 Median :4.000   Median :2.000  
 Mean   :3.688   Mean   :2.812  
 3rd Qu.:4.000   3rd Qu.:4.000  
 Max.   :5.000   Max.   :8.000  
```

Lists

- A list is a special type of vector. Elements can be of different types.
- Use lists act as containers.



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Functions as Building Blocks of Software

- Functions are reusable pieces of programs.
- They allow you to give a name to a block of statements, then run that block using the specified name anywhere in your program and any number of times.
- R has a rich set of built-in functions such as length(), summary().
- You can define your own function and call it in other places.

Functions: Closure Type Objects

- So many built-in functions available
- You can define your own functions
  - Function name
  - Input (argument list)
  - Output

```
> f2c <- function(f){
+ # Fahrenheit to Celsius conversion
+ c <- (f-32)*5/9
+ return(c)
+ }
> f2c(90)
[1] 32.22222
> f2c(32)
[1] 0
> typeof(f2c)
[1] "closure"
```

Writing Your Own Functions

- Syntax

  function (arglist) body

  - The keyword function indicates that you want to create a function.
  - An argument list is a comma separated list of formal arguments. A formal argument can be a symbol, a statement of the form 'symbol = expression', or the special formal argument '...'.
  - The body can be any valid R expression. Generally, the body is a group of expressions contained in curly braces ('{' and '}') called block.
  - Generally functions are assigned to symbols but they don't need to be (anonymous functions).

Source: https://cran.r-project.org/doc/manuals/r-release/R-lang.html

(cont.)

- Formal arguments define the variables whose values will be supplied at the time the function is invoked. The names of these arguments can be used within the function body.

- Default values for arguments can be specified using the special form ‘name = expression’. In this case, if the user does not specify a value for the argument when the function is invoked the expression will be associated with the corresponding symbol.

Source: https://cran.r-project.org/doc/manuals/r-release/R-lang.html

Programming Style and Documentation

- Programming style is important
  - Good programming style makes a program more readable
  - Good programming style helps reduce programming errors

- Several guidelines
  - Appropriate Comments
  - Naming Conventions
  - Proper Indentation and Spacing Lines

Google's R Style Guide

- https://google.github.io/styleguide/Rguide.xml

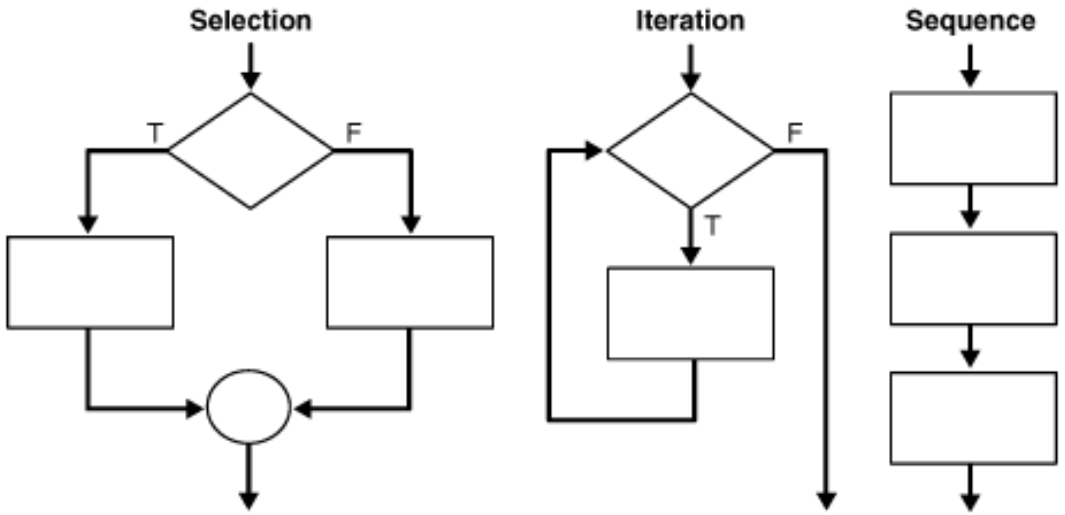
1. File Names: end in `.R`
2. Identifiers: `variable.name` (or `variableName`), `FunctionName`, `kConstantName`
3. Line Length: maximum 80 characters
4. Indentation: two spaces, no tabs
5. Spacing
6. Curly Braces: first on same line, last on own line
7. else: Surround else with braces
8. Assignment: use `<-`, not `=`
9. Semicolons: don't use them
10. General Layout and Ordering
11. Commenting Guidelines: all comments begin with `#` followed by a space; inline comments need two spaces before the `#`
12. Function Definitions and Calls
13. Function Documentation
14. Example Function
15. TODO Style: `TODO(username)`

Agenda

- What is R?
- Program with RStudio
- Introduction to R Markdown
- Data Structures in R
- R Functions
- Control Structures (Selection and Loop)

Structure Theorem

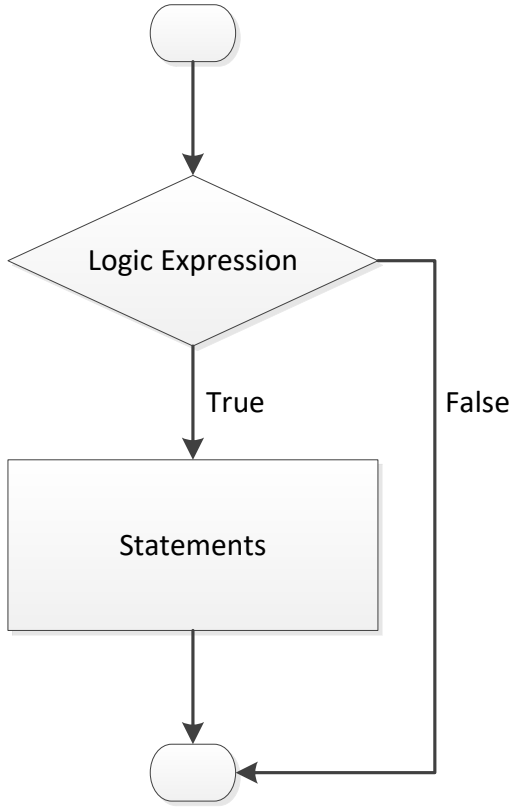
- According to the *structure theorem*, any computable program can be written using three basic control structures:
  - Sequence: executing one subprogram, and then another subprogram
  - Selection: executing one of two subprograms according to the value of a boolean expression
  - Iteration (loop): executing a subprogram until a boolean expression is true



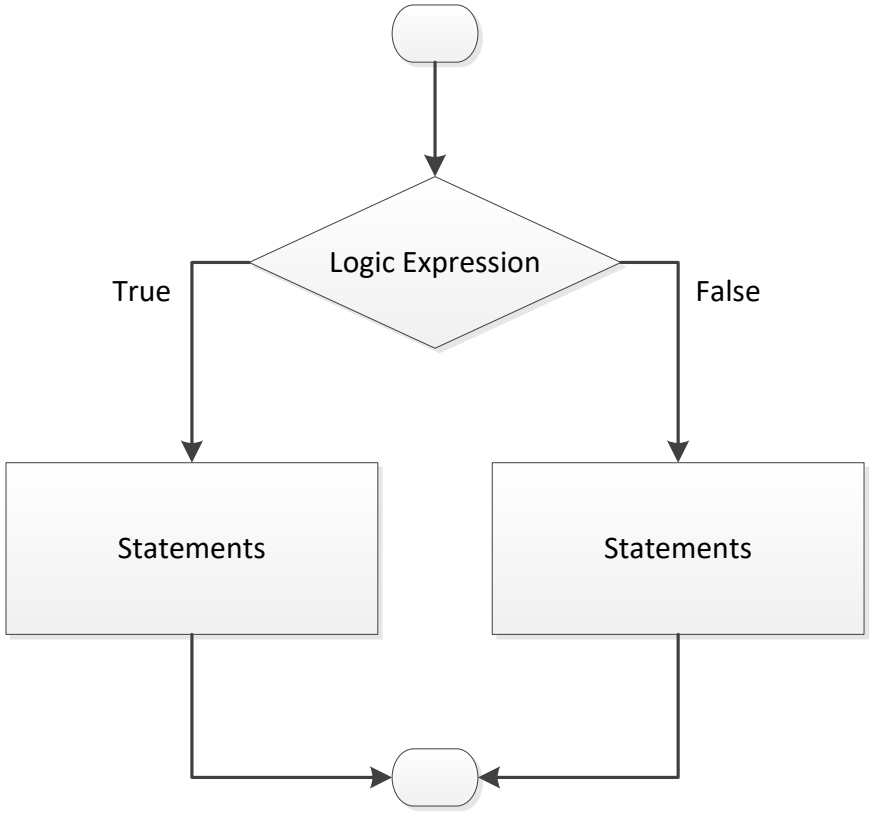
Reading: http://en.wikipedia.org/wiki/Structured_program_theorem

Selection Structure

One-way selection structure



Two-way selection structure



One-Way Selection Structure in R

- Syntax

  if(logic expression) {...}

Function

```
is.even <- function(x){
  if(x%%2==0){
    return(TRUE)
  }
}
```

Test

```
> is.even(24)
[1] TRUE
> is.even(23)
> is.even(10.5)
```

Two-Way Selection Structure in R

- Syntax

if(logic expression) {...} else {...}

Function

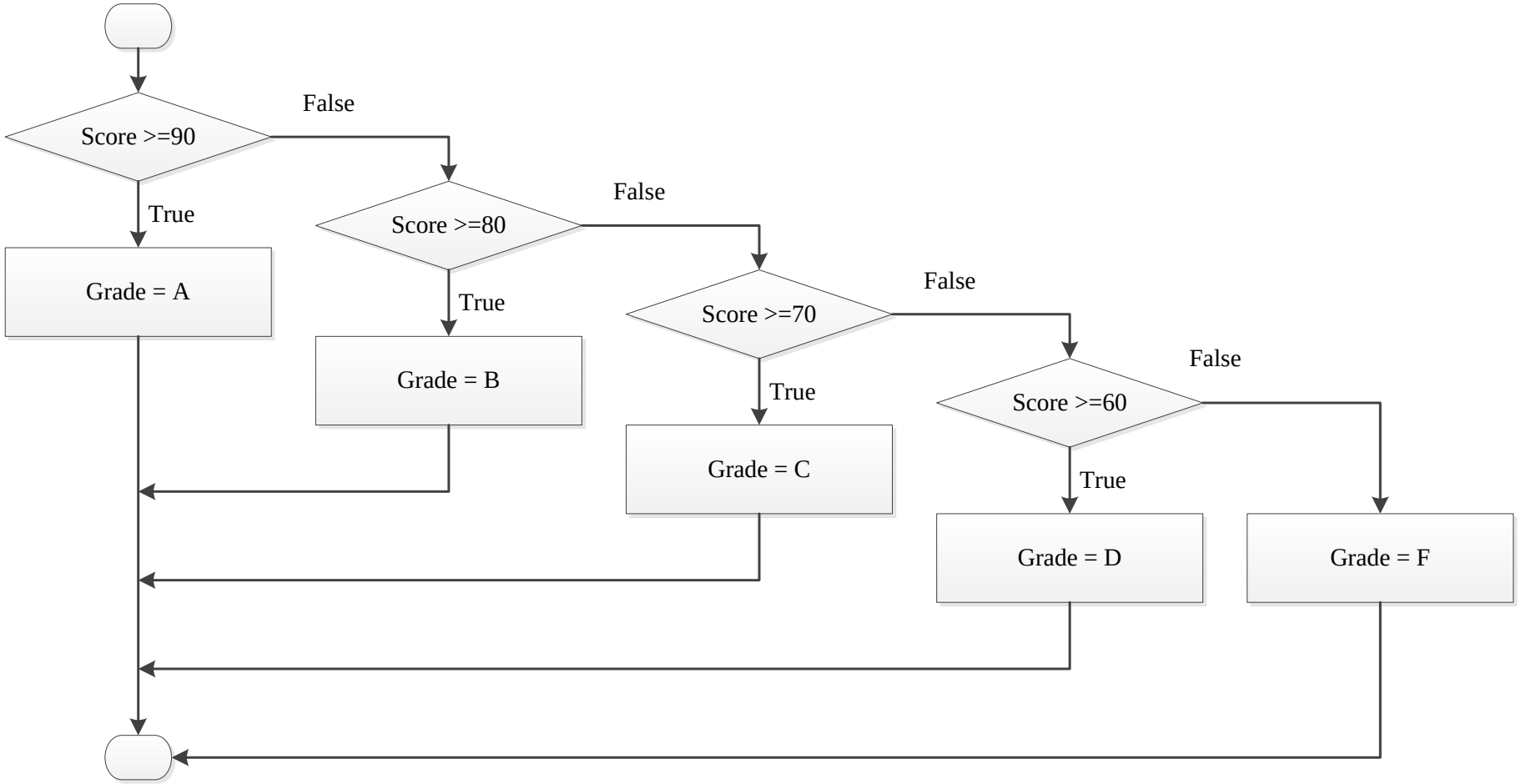
```
is.even2 <- function(x){
  if(x%%2==0){
    return(TRUE)
  } else{
    return(FALSE)
  }
}
```

Test

```
> is.even2(24)
[1] TRUE
> is.even2(23)
[1] FALSE
> is.even2(10.5)
[1] FALSE
```

Multi-Way Selection Structure

- Example: convert score to letter grade



Multi-Way Selection Structure in R

Function

```
score2grade <- function(score){
  if(score >= 90) return("A")
  else if (score >=80) return("B")
        else if (score >= 70) return("C")
              else if (score >= 60) return("D")
                    else return("F")
}
```

Test

```
> score2grade(99)
[1] "A“
> score2grade(90.1)
[1] "A“
> score2grade(89.9)
[1] "B“
> score2grade(70.1)
[1] "C“
> score2grade(68.6)
[1] "D“
> score2grade(57)
[1] "F"
```

The Nearest Rule (if else ambiguity)

The else clause matches the nearest preceding if clause in the same block.

Loop Structure in R

- R provides three statements to support looping
  - for statement
  - while statement
  - repeat statement
- Two statements used to explicitly control looping
  - break statement
  - next statement

for Loop

- Syntax

for (*name* in *vector*)
    statement

```
# Generate random scores for 100 students
score_v <- sample(50:100, 100, replace=T)
print(score_v)

# Use for loop
grade_v <- NULL  # Initiate a grade vector
for (i in 1:100)
    grade_v[i] = score2grade(score_v[i])
print(grade_v)  # Show the grades calculated
```

while Loop

- Syntax

```
while (logic expression)
    statement
```

```
# Use while loop
grade_v <- NULL
i <- 1
while (i <= 100){
  grade_v[i] = score2grade(score_v[i])
  i <- i + 1
}
print(grade_v)  # Show the grades calculated
```

repeat Loop

- Syntax

repeat statement

```
# Use repeat loop
grade_v <- NULL
i <- 1
repeat {
  grade_v[i] = score2grade(score_v[i])
  i <- i + 1
  if (i == 101) break
}
print(grade_v)  # Show the grades calculated
```

Which Loop to Use?

- The three forms of loop statements, for, while, and repeat, are expressively equivalent.
- You can write a loop in any of these three forms.

Guidelines for Choosing Loop Structures

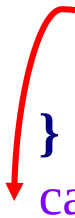
- Use the one that is most intuitive and comfortable for you.
- In general, a for loop may be used if the number of repetitions is known, as, for example, when you need to print a message 100 times.
- A while loop may be used if the number of repetitions is not known, as in the case of reading the numbers until the input is 0.
- A repeat loop can be used to replace a while loop if the loop body has to be executed before testing the continuation condition.

Using break and next

- The break and next keywords provide additional controls in a loop.
- break statement breaks out of the loop.
- continue statement bypasses the current iteration.

break Statement

```
sum <- 0
 i <- 0
 while(i < 20){
    i <- i +1
    if (sum >= 100)
       break
    sum <- sum + i
 }
 cat("The i is",i,"\n")
 cat("The sum is",sum,"\n")
```



break statement breaks out of the loop.

sum = 1 + 2 + 3 + ...+14 = 105

next Statement

```
sum <- 0
    i <- 0
    while(i < 20){
       i <- i + 1
       if (i == 10 | i ==11 )
          next
       sum <- sum + i
    }
    cat("The i is",i,"\n")
    cat("The sum is",sum,"\n")
```

next statement bypasses the current iteration.

sum = 1 + 2 + ...+ 8 + 9 + 12 + 13 + ... + 20 = 189

Q & A