R -PROGRAMMING

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LECTURE -1

Outline

- Why R, and R Paradigm
- References, Tutorials and links
- R Overview
- R Interface
- R Workspace
- Help
- R Packages
- Input/Output
- Reusing Results

Why R?

- It's free!
- It runs on a variety of platforms including Windows, Unix and MacOS.
- It provides an unparalleled platform for programming new statistical methods in an easy and straightforward manner.
- It contains advanced statistical routines not yet available in other packages.
- It has state-of-the-art graphics capabilities.

R has a Steep Learning Curve

First, while there are many introductory tutorials (covering data types, basic commands, the interface), none alone are comprehensive. In part, this is because much of the advanced functionality of **R** comes from hundreds of user contributed packages. Hunting for what you want can be time consuming, and it can be hard to get a clear overview of what procedures are available.

R has a Learning Curve

The **second** reason is more transient. As users of statistical packages, we tend to run one controlled procedure for each type of analysis. Think of PROC GLM in SAS. We can carefully set up the run with all the parameters and options that we need. When we run the procedure, the resulting output may be a hundred pages long. We then sift through this output pulling out what we need and discarding the rest.

R paradigm is different

Rather than setting up a complete analysis at once, the process is highly interactive. You run a command (say fit a model), take the results and process it through another command (say a set of diagnostic plots), take those results and process it through another command (say cross-validation), etc. The cycle may include transforming the data, and looping back through the whole process again. You stop when you feel that you have fully analyzed the data.

How to download?

- Google it using R or CRAN (Comprehensive R Archive Network)
- http://www.r-project.org

Tutorials

Each of the following tutorials are in PDF format.

- P. Kuhnert & B. Venables, An Introduction to R: Software for Statistical Modeling & Computing
- J.H. Maindonald, Using R for Data Analysis and Graphics
- B. Muenchen, R for SAS and SPSS Users
- W.J. Owen, The R Guide
- D. Rossiter, Introduction to the R Project for Statistical Computing for Use at the ITC
- W.N. Venebles & D. M. Smith, An Introduction to R

Web links

- Paul Geissler's excellent R tutorial
- Dave Robert's Excellent Labs on Ecological Analysis
- Excellent Tutorials by David Rossitier
- Excellent tutorial an nearly every aspect of R **MOST of these notes follow this web page format**
- Introduction to R by Vincent Zoonekynd
- R Cookbook
- Data Manipulation Reference

Web links

- R time series tutorial
- R Concepts and Data Types
- Interpreting Output From lm()
- The R Wiki
- An Introduction to R
- Import / Export Manual
- R Reference Cards

Web links

- KickStart
- Hints on plotting data in R
- Regression and ANOVA
- Appendices to Fox Book on Regression
- JGR a Java-based GUI for R [Mac|Windows|Linux]
- A Handbook of Statistical Analyses Using R(Brian S. Everitt and Torsten Hothorn)

R Overview

R is a comprehensive statistical and graphical programming language and is a dialect of the S language:

1988 - S2: RA Becker, JM Chambers, A Wilks
1992 - S3: JM Chambers, TJ Hastie
1998 - S4: JM Chambers

R: initially written by Ross Ihaka and Robert Gentleman at Dep. of Statistics of U of Auckland, New Zealand during 1990s.

Since 1997: international "R-core" team of 15 people with access to common CVS archive.

R Overview

You can enter commands one at a time at the command prompt (>) or run a set of commands from a source file.

There is a wide variety of data types, including vectors (numerical, character, logical), matrices, data frames, and lists.

To quit R, use

>q()

R Overview

- Most functionality is provided through built-in and user-created functions and all data objects are kept in memory during an interactive session.
- Basic functions are available by default. Other functions are contained in packages that can be attached to a current session as needed

R Overview

A key skill to using **R** effectively is learning how to use the built-in help system. Other sections describe the working environment, inputting programs and outputting results, installing new functionality through packages and etc.

A fundamental design feature of **R** is that the output from most functions can be used as input to other functions. This is described in reusing results.

R Interface

Start the R system, the main window (RGui) with a sub window (R Console) will appear

In the `Console' window the cursor is waiting for you to type in some R commands.

Your First R Session

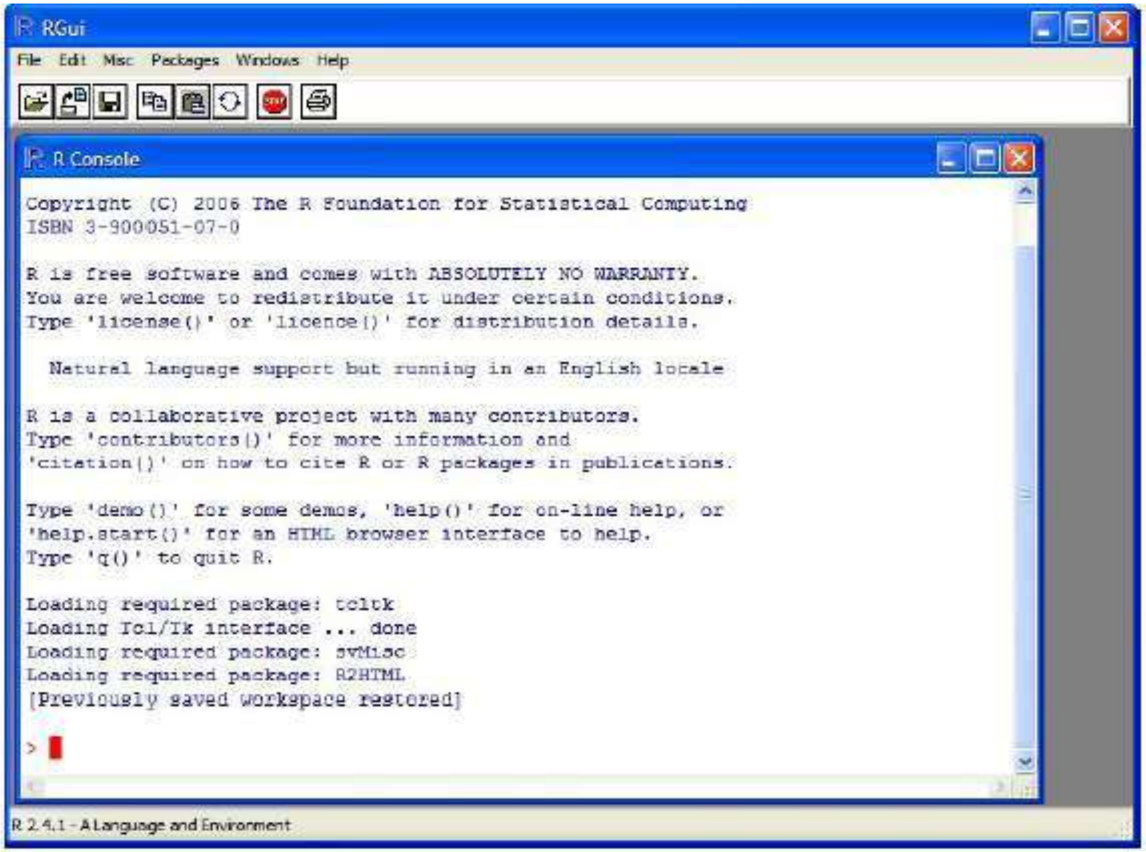


Figure 1.1: The R system on Windows

R Introduction

- Results of calculations can be stored in objects using the assignment operators:
  - An arrow (<-) formed by a smaller than character and a hyphen without a space!
  - The equal character (=).

R Introduction

- These objects can then be used in other calculations. To print the object just enter the name of the object. There are some restrictions when giving an object a name:
  - Object names cannot contain `strange' symbols like !, +, -, #.
  - A dot (.) and an underscore ( ) are allowed, also a name starting with a dot.
  - Object names can contain a number but cannot start with a number.
  - R is case sensitive, X and x are two different objects, as well as temp and temP.

An example

```
> # An example
> x <- c(1:10)
> x[(x>8) | (x<5)]
> # yields 1 2 3 4 9 10
> # How it works
> x <- c(1:10)
> x
>1 2 3 4 5 6 7 8 9 10
> x > 8
> F F F F F F F F T T
> x < 5
> T T T T F F F F F F
> x > 8 | x < 5
> T T T T F F F F T T
> x[c(T,T,T,T,F,F,F,F,T,T)]
> 1 2 3 4 9 10
```

R Introduction

- To list the objects that you have in your current R session use the function ls or the function objects.

```
> ls()
[1] "x" "y"
```

- So to run the function ls we need to enter the name followed by an opening (and a closing). Entering only ls will just print the object, you will see the underlying R code of the the function ls. Most functions in R accept certain arguments. For example, one of the arguments of the function ls is pattern. To list all objects starting with the letter x:

```
> x2 = 9
> y2 = 10
> ls(pattern="x")
[1] "x" "x2"
```

R Introduction

- If you assign a value to an object that already exists then the contents of the object will be overwritten with the new value (without a warning!). Use the function rm to remove one or more objects from your session.

```
> rm(x, x2)
```

- Lets create two small vectors with data and a scatterplot.

```
z2 <- c(1,2,3,4,5,6)
z3 <- c(6,8,3,5,7,1)
plot(z2,z3)
title("My first scatterplot")
```

R Warning !

- R is a case sensitive language.
- FOO, Foo, and foo are three different objects

R Introduction

```
> x = sin(9)/75
> y = log(x) + x^2
> x
[1] 0.005494913
> y
[1] -5.203902
> m <- matrix(c(1,2,4,1), ncol=2)
> m
> [,1] [,2]
[1,] 1 4
[2,] 2 1
> solve(m)
[,1] [,2]
[1,] -0.1428571 0.5714286
[2,] 0.2857143 -0.1428571
```

R Workspace

Objects that you create during an R session are hold in memory, the collection of objects that you currently have is called the workspace. This workspace is not saved on disk unless you tell R to do so. This means that your objects are lost when you close R and not save the objects, or worse when R or your system crashes on you during a session.

R Workspace

When you close the RGui or the R console window, the system will ask if you want to save the workspace image. If you select to save the workspace image then all the objects in your current R session are saved in a file .RData. This is a binary file located in the working directory of R, which is by default the installation directory of R.

R Workspace

- During your R session you can also explicitly save the workspace image. Go to the `File` menu and then select `Save Workspace...', or use the save.image function.

```
## save to the current working directory
save.image()
## just checking what the current working directory is
getwd()
## save to a specific file and location
save.image("C:\\Program Files\\R\\R-
   2.5.0\\bin\\.RData")
```

R Workspace

If you have saved a workspace image and you start R the next time, it will restore the workspace. So all your previously saved objects are available again. You can also explicitly load a saved workspace, that could be the workspace image of someone else. Go the `File' menu and select `Load workspace...'.

R Workspace

Commands are entered interactively at the **R** user prompt. **Up** and **down arrow keys** scroll through your command history.

You will probably want to keep different projects in different physical directories.

R Workspace

R gets confused if you use a path in your code like

c:|mydocuments|myfile.txt

This is because R sees "\" as an escape character. Instead, use

c:||my documents||myfile.txt

or

c:/mydocuments/myfile.txt

R Workspace

```
getwd() # print the current working directory

ls()  # list the objects in the current workspace
setwd(mydirectory)   # change to mydirectory
setwd("c:/docs/mydir")
```

R Workspace

#view and set options for the session

```
help(options) # learn about available options
options() # view current option settings
options(digits=3) # number of digits to print on output
```

work with your previous commands

```
history() # display last 25 commands
history(max.show=Inf) # display all previous commands
```

R Workspace

```
# save your command history
savehistory(file="myfile")  # default is ".Rhistory"
# recall your command history
loadhistory(file="myfile")  # default is ".Rhistory"
```

R Help

Once **R** is installed, there is a comprehensive built-in help system. At the program's command prompt you can use any of the following:

help.start()   # general help

help(*foo*)   # help about function *foo*

?*foo*   # same thing

apropos("*foo*") # list all function containing string foo

example(*foo*)   # show an example of function *foo*

R Help

search for foo in help manuals and archived mailing lists

RSiteSearch("*foo*")

get vignettes on using installed packages

vignette() # show available vingettes

vignette("*foo*") # show specific vignette

R Datasets

R comes with a number of sample datasets that you can experiment with. Type

> **data( )**

to see the available datasets. The results will depend on which packages you have loaded. Type

help(*datasetname***)**

for details on a sample dataset.

R Packages

- One of the strengths of R is that the system can easily be extended. The system allows you to write new functions and package those functions in a so called `R package' (or `R library'). The R package may also contain other R objects, for example data sets or documentation. There is a lively R user community and many R packages have been written and made available on CRAN for other users. Just a few examples, there are packages for portfolio optimization, drawing maps, exporting objects to html, time series analysis, spatial statistics and the list goes on and on.

R Packages

- When you download R, already a number (around 30) of packages are downloaded as well. To use a function in an R package, that package has to be attached to the system. When you start R not all of the downloaded packages are attached, only seven packages are attached to the system by default. You can use the function search to see a list of packages that are currently attached to the system, this list is also called the search path.

```
> search()
[1] ".GlobalEnv" "package:stats" "package:graphics"
[4] "package:grDevices" "package:datasets" "package:utils"
[7] "package:methods" "Autoloads" "package:base"
```

R Packages

To attach another package to the system you can use the menu or the library function. Via the menu:

Select the `Packages' menu and select `Load package...', a list of available packages on your system will be displayed. Select one and click `OK', the package is now attached to your current R session. Via the library function:

```
> library(MASS)
> shoes
$A
[1] 13.2 8.2 10.9 14.3 10.7 6.6 9.5 10.8 8.8 13.3
$B
[1] 14.0 8.8 11.2 14.2 11.8 6.4 9.8 11.3 9.3 13.6
```

R Packages

- The function library can also be used to list all the available libraries on your system with a short description. Run the function without any arguments

```
> library()
Packages in library 'C:/PROGRA~1/R/R-25~1.0/library':
base            The R Base Package
Boot            Bootstrap R (S-Plus) Functions (Canty)
class           Functions for Classification
cluster         Cluster Analysis Extended Rousseeuw et al.
codetools       Code Analysis Tools for R
datasets        The R Datasets Package
DBI             R Database Interface
foreign         Read Data Stored by Minitab, S, SAS,
                SPSS, Stata, Systat, dBase, ...
graphics        The R Graphics Package
```

R Packages

```
install = function() {
install.packages(c("moments","graphics","Rcmdr","hexbin"),
repos="http://lib.stat.cmu.edu/R/CRAN")
}
install()
```

R Conflicting objects

- It is not recommended to do, but R allows the user to give an object a name that already exists. If you are not sure if a name already exists, just enter the name in the R console and see if R can find it. R will look for the object in all the libraries (packages) that are currently attached to the R system. R will not warn you when you use an existing name.

```
> mean = 10
> mean
[1] 10
```

- The object mean already exists in the base package, but is now masked by your object mean. To get a list of all masked objects use the function conflicts.

```
>
[1] "body<-" "mean"
```

R Conflicting objects

The object mean already exists in the base package, but is now masked by your object mean. To get a list of all masked objects use the function conflicts.

```
> conflicts()
[1] "body<-" "mean"
```

You can safely remove the object mean with the function rm() without risking deletion of the mean function.

Calling rm() removes only objects in your working environment by default.

Source Codes

you can have input come from a script file (a file containing **R** commands) and direct output to a variety of destinations.

Input

The **source( )** function runs a script in the current session. If the filename does not include a path, the file is taken from the current working directory.

```
# input a script
source("myfile")
```

Output

Output

The **sink( )** function defines the direction of the output.

```
# direct output to a file
sink("myfile", append=FALSE, split=FALSE)

# return output to the terminal
sink()
```

Output

The **append** option controls whether output overwrites or adds to a file.

The **split** option determines if output is also sent to the screen as well as the output file.

Here are some examples of the **sink()** function.

output directed to output.txt in c:\projects directory.

# output overwrites existing file. no output to terminal.
sink("myfile.txt", append=TRUE, split=TRUE)

Graphs

To redirect graphic output use one of the following functions. Use **dev.off( )** to return output to the terminal.

Function	Output to
pdf("mygraph.pdf")	pdf file
win.metafile("mygraph.wmf")	windows metafile
png("mygraph.png")	png file
jpeg("mygraph.jpg")	jpeg file
bmp("mygraph.bmp")	bmp file
postscript("mygraph.ps")	postscript file

Redirecting Graphs

```
# example - output graph to jpeg file
   jpeg("c:/mygraphs/myplot.jpg")
   plot(x)
   dev.off()
```

Reusing Results

One of the most useful design features of **R** is that the output of analyses can easily be saved and used as input to additional analyses.

```
# Example 1
lm(mpg~wt, data=mtcars)
```

This will run a simple linear regression of miles per gallon on car weight using the dataframe mtcars. Results are sent to the screen. Nothing is saved.

Reusing Results

```
# Example 2
fit <- lm(mpg~wt, data=mtcars)
```

This time, the same regression is performed but the results are saved under the name fit. No output is sent to the screen. However, you now can manipulate the results.

```
str(fit) # view the contents/structure of "fit‟
```

The assignment has actually created a list called "fit" that contains a wide range of information (including the predicted values, residuals, coefficients, and more.

Reusing Results

plot residuals by fitted values

```
plot(fit$residuals, fit$fitted.values)
```

To see what a function returns, look at the **value** section of the online help for that function. Here we would look at **help(lm)**.

The results can also be used by a wide range of other functions.

```
# produce diagnostic plots
plot(fit)
```

Lecture 2: Data Input

Outline

- Data Types
- Importing Data
- Keyboard Input
- Database Input
- Exporting Data
- Viewing Data
- Variable Labels
- Value Labels
- Missing Data
- Date Values

Data Types

R has a wide variety of data types including scalars, vectors (numerical, character, logical), matrices, dataframes, and lists.

Vectors

a <- c(1,2,5.3,6,-2,4) # numeric vector

b <- c("one","two","three") # character vector

c <- c(TRUE,TRUE,TRUE,FALSE,TRUE,FALSE)

#logical vector

Refer to elements of a vector using subscripts.

a[c(2,4)] # 2nd and 4th elements of vector

Matrices

All columns in a matrix must have the same mode(numeric, character, etc.) and the same length.

The general format is

mymatrix <- **matrix(***vector*, **nrow=***r*, **ncol=***c*, **byrow=***FALSE*,**dimnames=list(***char_vector_rownames* , *char_vector_colnames***))**

byrow=TRUE indicates that the matrix should be filled by rows. **byrow=FALSE** indicates that the matrix should be filled by columns (the default). **dimnames** provides optional labels for the columns and rows.

Matrices

generates 5 x 4 numeric matrix

```
y<-matrix(1:20, nrow=5,ncol=4)
```

another example

```
cells <- c(1,26,24,68)
rnames <- c("R1", "R2")
cnames <- c("C1", "C2")
mymatrix <- matrix(cells, nrow=2, ncol=2,
byrow=TRUE, dimnames=list(rnames, cnames))
```

#Identify rows, columns or elements using subscripts.

```
x[,4] # 4th column of matrix
x[3,] # 3rd row of matrix
x[2:4,1:3] # rows 2,3,4 of columns 1,2,3
```

Arrays

Arrays are similar to matrices but can have more than two dimensions. See **help(array)** for details.

Data frames

A data frame is more general than a matrix, in that different columns can have different modes (numeric, character, factor, etc.).

```
d <- c(1,2,3,4)
e <- c("red", "white", "red", NA)
f <- c(TRUE,TRUE,TRUE,FALSE)
mydata <- data.frame(d,e,f)
names(mydata) <- c("ID","Color","Passed")
  #variable names
```

Data frames

There are a variety of ways to identify the elements of a dataframe .

myframe[3:5] # columns 3,4,5 of dataframe

myframe[c("ID","Age")] # columns ID and Age from dataframe

myframe$X1 # variable x1 in the dataframe

Lists

An ordered collection of objects (components). A list allows you to gather a variety of (possibly unrelated) objects under one name.

```
# example of a list with 4 components -
# a string, a numeric vector, a matrix, and a scaler
w <- list(name="Fred", mynumbers=a,
mymatrix=y, age=5.3)

# example of a list containing two lists
v <- c(list1,list2)
```

Lists

Identify elements of a list using the [[]] convention.

mylist[[2]] # 2nd component of the list

Factors

Tell **R** that a variable is **nominal** by making it a factor. The factor stores the nominal values as a vector of integers in the range [1... k] (where k is the number of unique values in the nominal variable), and an internal vector of character strings (the original values) mapped to these integers.

```
# variable gender with 20 "male" entries and
# 30 "female" entries
gender <- c(rep("male",20), rep("female", 30))
gender <- factor(gender)
# stores gender as 20 1s and 30 2s and associates
# 1=female, 2=male internally (alphabetically)
# R now treats gender as a nominal variable
summary(gender)
```

Useful Functions

length(object) # number of elements or components
str(object) # structure of an object
class(object) # class or type of an object
names(object) # names
c(object,object,...) # combine objects into a vector
cbind(object, object, ...) # combine objects as columns
rbind(object, object, ...) # combine objects as rows
ls() # list current objects
rm(object) # delete an object
newobject <- edit(object) # edit copy and save a newobject
fix(object) # edit in place

Importing Data

Importing data into **R** is fairly simple.

For Stata and Systat, use the **foreign** package.

For SPSS and SAS I would recommend the **Hmisc** package for ease and functionality.

See the **Quick-R** section on **packages**, for information on obtaining and installing the these packages.

Example of importing data are provided below.

From A Comma Delimited Text File

first row contains variable names, comma is separator

assign the variable *id* to row names

note the / instead of \ on mswindows systems

```
mydata <- read.table("c:/mydata.csv",
header=TRUE, sep=",", row.names="id")
```

From Excel

The best way to read an Excel file is to export it to a comma delimited file and import it using the method above.

On windows systems you can use the **RODBC** package to access Excel files. The first row should contain variable/column names.

first row contains variable names

#)

From SAS

- # save SAS dataset in trasport format
  libname out xport 'c:/mydata.xpt';
  data out.mydata;
  set sasuser.mydata;
  run;
- library(foreign)

#bsl=read.xport(“mydata.xpt")

Keyboard Input

Usually you will obtain a dataframe by importing it from **SAS**, **SPSS**, **Excel**, **Stata**, a database, or an ASCII file. To create it interactively, you can do something like the following.

```
# create a dataframe from scratch
age <- c(25, 30, 56)
gender <- c("male", "female", "male")
weight <- c(160, 110, 220)
mydata <- data.frame(age,gender,weight)
```

Keyboard Input

You can also use **R**'s built in spreadsheet to enter the data interactively, as in the following example.

```
# enter data using editor
mydata <- data.frame(age=numeric(0),
gender=character(0), weight=numeric(0))
mydata <- edit(mydata)
# note that without the assignment in the line
above,
# the edits are not saved!
```

Exporting Data

There are numerous methods for exporting **R** objects into other formats . For SPSS, SAS and Stata. you will need to load the **foreign** packages. For Excel, you will need the **xlsReadWrite** package.

Exporting Data

To A Tab Delimited Text File

```
write.table(mydata, "c:/mydata.txt", sep="\t")
```

To an Excel Spreadsheet

```
library(xlsReadWrite)
   write.xls(mydata, "c:/mydata.xls")
```

To SAS

```
library(foreign)
   write.foreign(mydata, "c:/mydata.txt",
   "c:/mydata.sas",   package="SAS")
```

Viewing Data

There are a number of functions for listing the contents of an object or dataset.

```
# list objects in the working environment
ls()
# list the variables in mydata
names(mydata)
# list the structure of mydata
str(mydata)
# list levels of factor v1 in mydata
levels(mydata$v1)
# dimensions of an object
dim(object)
```

Viewing Data

There are a number of functions for listing the contents of an object or dataset.

```
# class of an object (numeric, matrix, dataframe, etc)
class(object)

# print mydata
mydata

# print first 10 rows of mydata
head(mydata, n=10)

# print last 5 rows of mydata
tail(mydata, n=5)
```

Variable Labels

R's ability to handle variable labels is somewhat unsatisfying.

If you use the **Hmisc** package, you can take advantage of some labeling features.

library(Hmisc)
label(mydata$myvar) <- "Variable label for variable *myvar*"
describe(mydata)

Variable Labels

Unfortunately the label is only in effect for functions provided by the **Hmisc** package, such as **describe()**. Your other option is to use the variable label as the variable name and then refer to the variable by position index.

```
names(mydata)[3] <- "This is the label for variable 3"
   mydata[3] # list the variable
```

Value Labels

To understand value labels in **R**, you need to understand the data structure factor.

You can use the factor function to create your own value lables.

variable v1 is coded 1, 2 or 3

we want to attach value labels 1=red, 2=blue,3=green

```
mydata$v1 <- factor(mydata$v1,
levels = c(1,2,3),
labels = c("red", "blue", "green"))
```

variable y is coded 1, 3 or 5

we want to attach value labels 1=Low, 3=Medium, 5=High

Value Labels

```
mydata$v1 <- ordered(mydata$y,
    levels = c(1,3, 5),
    labels = c("Low", "Medium", "High"))
```

Use the **factor()** function for **nominal data** and the **ordered()** function for **ordinal data**. **R** statistical and graphic functions will then treat the data appropriately.

Note: factor and ordered are used the same way, with the same arguments. The former creates factors and the later creates ordered factors.

Missing Data

In **R**, missing values are represented by the symbol **NA** (not available) . Impossible values (e.g., dividing by zero) are represented by the symbol **NaN** (not a number). Unlike SAS, **R** uses the same symbol for character and numeric data.

Testing for Missing Values

is.na(x) # returns TRUE of x is missing

y <- c(1,2,3,NA)

is.na(y) # returns a vector (F F F T)

Missing Data

Recoding Values to Missing

```
# recode 99 to missing for variable v1
# select rows where v1 is 99 and recode column v1
mydata[mydata$v1==99,"v1"] <- NA
```

Excluding Missing Values from Analyses

Arithmetic functions on missing values yield missing values.

```
x <- c(1,2,NA,3)
mean(x)          # returns NA
mean(x, na.rm=TRUE) # returns 2
```

Missing Data

The function **complete.cases()** returns a logical vector indicating which cases are complete.

```
# list rows of data that have missing values
mydata[!complete.cases(mydata),]
```

The function **na.omit()** returns the object with listwise deletion of missing values.

```
# create new dataset without missing data
newdata <- na.omit(mydata)
```

Missing Data

Advanced Handling of Missing Data

Most modeling functions in **R** offer options for dealing with missing values. You can go beyond pairwise of listwise deletion of missing values through methods such as multiple imputation. Good implementations that can be accessed through **R** include **Amelia II**, **Mice**, and **mitools**.

Date Values

Dates are represented as the number of days since 1970-01-01, with negative values for earlier dates.

```
# use as.Date( ) to convert strings to dates
mydates <- as.Date(c("2007-06-22", "2004-02-13"))
# number of days between 6/22/07 and 2/13/04
days <- mydates[1] - mydates[2]
```

Sys.Date( ) returns today's date.

Date() returns the current date and time.

Date Values

The following symbols can be used with the format( ) function to print dates.

Symbol	Meaning	Example
%d	day as a number (0-31)	01-31
%a	abbreviated weekday	Mon
%A	unabbreviated weekday	Monday
%m	month (00-12)	00-12
%b	abbreviated month	Jan
%B	unabbreviated month	January
%y	2-digit year	07
%Y	4-digit year	2007

Date Values

```
# print today's date
today <- Sys.Date()
format(today, format="%B %d %Y")
    "June 20 2007"
```

Lecture 3: Data Manipulation

Outline

- Creating New Variable
- Operators
- Built-in functions
- Control Structures
- User Defined Functions
- Sorting Data
- Merging Data
- Aggregating Data
- Reshaping Data
- Sub-setting Data
- Data Type Conversions

Introduction

Once you have access to your data, you will want to massage it into useful form. This includes creating new variables (including recoding and renaming existing variables), sorting and merging datasets, aggregating data, reshaping data, and subsetting datasets (including selecting observations that meet criteria, randomly sampling observation, and dropping or keeping variables).

Introduction

Each of these activities usually involve the use of **R**'s built-in operators (arithmetic and logical) and functions (numeric, character, and statistical). Additionally, you may need to use control structures (if-then, for, while, switch) in your programs and/or create your own functions. Finally you may need to convert variables or datasets from one type to another (e.g. numeric to character or matrix to dataframe).

Creating new variables

- Use the assignment operator **<-** to create new variables. A wide array of operators and functions are available here.
- # Three examples for doing the same computations

```
mydata$sum <- mydata$x1 + mydata$x2
mydata$mean <- (mydata$x1 + mydata$x2)/2

attach(mydata)
mydata$sum <- x1 + x2
mydata$mean <- (x1 + x2)/2
detach(mydata)
```

- mydata <- transform(mydata,

```
sum = x1 + x2,
mean = (x1 + x2)/2
)
```

Creating new variables

Recoding variables

- In order to recode data, you will probably use one or more of R's control structures.
- ```
  # create 2 age categories
  mydata$agecat <- ifelse(mydata$age > 70,
  c("older"), c("younger"))
  # another example: create 3 age categories
  attach(mydata)
  mydata$agecat[age > 75] <- "Elder"
  mydata$agecat[age > 45 & age <= 75] <-
  "Middle Aged"
  mydata$agecat[age <= 45] <- "Young"
  detach(mydata)
  ```
  ```

Creating new variables

Recoding variables

- In order to recode data, you will probably use one or more of R's control structures.
- # create 2 age categories
  mydata$agecat <- ifelse(mydata$age > 70,
  c("older"), c("younger"))

  # another example: create 3 age categories
  attach(mydata)
  mydata$agecat[age > 75] <- "Elder"
  mydata$agecat[age > 45 & age <= 75] <- "Middle Aged"
  mydata$agecat[age <= 45] <- "Young"
  detach(mydata)

Creating new variables

Renaming variables

- You can rename variables programmatically or interactively.
- # rename interactively
  fix(mydata) # results are saved on close

  # rename programmatically
  library(reshape)
  mydata <- rename(mydata, c(oldname="newname"))

  # you can re-enter all the variable names in order
  # changing the ones you need to change. The limitation
  # is that you need to enter all of them!
  names(mydata) <- c("x1","age","y", "ses")

Arithmetic Operators

Operator	Description
+	addition
-	subtraction
*****	multiplication
/	division
^ **or ****	exponentiation
x %% y	modulus (x mod y) 5%%2 is 1
x %/% y	integer division 5%/%2 is 2

Logical Operators

Operator	**Description**
<	less than
<=	less than or equal to
>	greater than
>=	greater than or equal to
==	exactly equal to
!=	not equal to
!x	Not x
x | y	x OR y
x & y	x AND y
isTRUE(x)	test if x is TRUE

Control Structures

- **R** has the standard control structures you would expect. **expr** can be multiple (compound) statements by enclosing them in braces { }. It is more efficient to use built-in functions rather than control structures whenever possible.

Control Structures

- **if-else**
- if (*cond*) *expr*
  if (*cond*) *expr1* else *expr2*
- **for**
- for (*var* in *seq*) *expr*
- **while**
- while (*cond*) *expr*
- **switch**
- switch(*expr*, ...)
- **ifelse**
- ifelse(*test*,*yes*,*no*)

Control Structures

- # transpose of a matrix
  # a poor alternative to built-in t() function

```
mytrans <- function(x) {
  if (!is.matrix(x)) {
    warning("argument is not a matrix: returning NA")
    return(NA_real_)
  }
  y <- matrix(1, nrow=ncol(x), ncol=nrow(x))
  for (i in 1:nrow(x)) {
    for (j in 1:ncol(x)) {
      y[j,i] <- x[i,j]
    }
  }
return(y)
}
```

Control Structures

- ```
  # try it
  z <- matrix(1:10, nrow=5, ncol=2)
  tz <- mytrans(z)
  ```
  ```

R built-in functions

Almost everything in **R** is done through functions. Here I'm only referring to numeric and character functions that are commonly used in creating or recoding variables.

Note that while the examples on this page apply functions to individual variables, many can be applied to vectors and matrices as well.

Numeric Functions

Function	Description
abs(*x*)	absolute value
sqrt(*x*)	square root
ceiling(*x*)	ceiling(3.475) is 4
floor(*x*)	floor(3.475) is 3
trunc(*x*)	trunc(5.99) is 5
round(*x*, digits=*n*)	round(3.475, digits=2) is 3.48
signif(*x*, digits=*n*)	signif(3.475, digits=2) is 3.5
cos(*x*), sin(*x*), tan(*x*)	also acos(*x*), cosh(*x*), acosh(*x*), etc.
log(*x*)	natural logarithm
log10(*x*)	common logarithm
exp(*x*)	e^*x*

Character Functions

Function	Description
substr(*x***, start=***n1***, stop=***n2***)**	Extract or replace substrings in a character vector. x <- "abcdef" substr(x, 2, 4) is "bcd" substr(x, 2, 4) <- "22222" is "a222ef"
grep(*pattern***,** *x* **, ignore.case=**FALSE**, fixed=**FALSE**)**	Search for *pattern* in *x*. If fixed =FALSE then *pattern* is a regular expression. If fixed=TRUE then *pattern* is a text string. Returns matching indices. grep("A", c("b","A","c"), fixed=TRUE) returns 2
sub(*pattern***,** *replacement***,** *x***, ignore.case** =FALSE**, fixed=**FALSE**)**	Find *pattern* in *x* and replace with *replacement* text. If fixed=FALSE then *pattern* is a regular expression. If fixed = T then *pattern* is a text string. sub("\\s",".","Hello There") returns "Hello.There"
strsplit(*x***,** *split***)**	Split the elements of character vector *x* at *split*. strsplit("abc", "") returns 3 element vector "a","b","c"
paste(..., sep="")	Concatenate strings after using *sep* string to seperate them. paste("x",1:3,sep="") returns c("x1","x2" "x3") paste("x",1:3,sep="M") returns c("xM1","xM2" "xM3") paste("Today is", date())
toupper(*x***)**	Uppercase
tolower(*x***)**	Lowercase

Stat/Prob Functions

- The following table describes functions related to probaility distributions. For random number generators below, you can use set.seed(1234) or some other integer to create reproducible pseudo-random numbers.

Function	Description

dnorm(*x***)**	normal density function (by default m=0 sd=1)
	# plot standard normal curve
	x <- pretty(c(-3,3), 30)
	y <- dnorm(x)
	plot(x, y, type='l', xlab="Normal Deviate", ylab="Density", yaxs="i")

pnorm(*q***)**	cumulative normal probability for q (area under the normal curve to the right of q) pnorm(1.96) is 0.975
qnorm(*p***)**	normal quantile. value at the p percentile of normal distribution qnorm(.9) is 1.28 # 90th percentile
rnorm(*n***, m=**0**,sd=**1**)**	n random normal deviates with mean m and standard deviation sd. #50 random normal variates with mean=50, sd=10 x <- rnorm(50, m=50, sd=10)

dbinom(*x***,** *size***,** *prob***)**
pbinom(*q***,** *size***,** *prob***)**
qbinom(*p***,** *size***,** *prob***)**
rbinom(*n***,** *size***,** *prob***)**
	binomial distribution where size is the sample size
	and prob is the probability of a heads (pi)
	# prob of 0 to 5 heads of fair coin out of 10 flips
	dbinom(0:5, 10, .5)
	# prob of 5 or less heads of fair coin out of 10 flips
	pbinom(5, 10, .5)

dpois(*x***,** *lamda***)**
ppois(*q***,** *lamda***)**
qpois(*p***,** *lamda***)**
rpois(*n***,** *lamda***)**
	poisson distribution with m=std=lamda
	#probability of 0,1, or 2 events with lamda=4
	dpois(0:2, 4)
	# probability of at least 3 events with lamda=4
	1- ppois(2,4)

dunif(*x***, min=**0**, max=**1**)** **punif(***q***, min=0, max=**1**)** **qunif(***p***, min=**0**, max=**1**)** **runif(***n***, min=**0**, max=**1**)**	uniform distribution, follows the same pattern as the normal distribution above. #10 uniform random variates x <- runif(10)

Function	Description
mean(*x***, trim**=0, **na.rm**=FALSE**)**	mean of object x # trimmed mean, removing any missing values and # 5 percent of highest and lowest scores mx <- mean(x,trim=.05,na.rm=TRUE)
sd(*x***)**	standard deviation of object(x). also look at var(x) for variance and mad(x) for median absolute deviation.
median(*x***)**	median
quantile(*x***,** *probs***)**	quantiles where x is the numeric vector whose quantiles are desired and probs is a numeric vector with probabilities in [0,1]. # 30th and 84th percentiles of x y <- quantile(x, c(.3,.84))
range(*x***)**	range
sum(*x***)**	sum
diff(*x***, lag=***1***)**	lagged differences, with lag indicating which lag to use
min(*x***)**	minimum
max(*x***)**	maximum
scale(*x***, center=**TRUE**, scale=**TRUE**)**	column center or standardize a matrix.

Other Useful Functions

Function	Description
seq(*from* **,** *to***,** *by***)**	generate a sequence indices <- seq(1,10,2) #indices is c(1, 3, 5, 7, 9)
rep(*x***,** *ntimes***)**	repeat *x* *n* times y <- rep(1:3, 2) # y is c(1, 2, 3, 1, 2, 3)
cut(*x***,** *n***)**	divide continuous variable in factor with *n* levels y <- cut(x, 5)

Sorting

- To sort a dataframe in R, use the **order( )** function. By default, sorting is ASCENDING. Prepend the sorting variable by a minus sign to indicate DESCENDING order. Here are some examples.
- # sorting examples using the mtcars dataset
  data(mtcars)
  # sort by mpg
  newdata = mtcars[order(mtcars$mpg),]
  # sort by mpg and cyl
  newdata <- mtcars[order(mtcars$mpg, mtcars$cyl),]
  #sort by mpg (ascending) and cyl (descending)
  newdata <- mtcars[order(mtcars$mpg, -mtcars$cyl),]

Merging

To merge two dataframes (datasets) horizontally, use the **merge** function. In most cases, you join two dataframes by one or more common key variables (i.e., an inner join).

```
# merge two dataframes by ID
total <- merge(dataframeA,dataframeB,by="ID")
# merge two dataframes by ID and Country
total <-
merge(dataframeA,dataframeB,by=c("ID","Country"))
```

Merging

ADDING ROWS

To join two dataframes (datasets) vertically, use the **rbind** function. The two dataframes **must** have the same variables, but they do not have to be in the same order.

total <- rbind(dataframeA, dataframeB)

If dataframeA has variables that dataframeB does not, then either:

Delete the extra variables in dataframeA or

Create the additional variables in dataframeB and set them to NA (missing)

before joining them with rbind.

Aggregating

- **It is relatively easy to collapse data in R using one or more BY variables and a defined function.**
- # aggregate dataframe mtcars by cyl and vs, returning means
  # for numeric variables
  attach(mtcars)
  aggdata <-aggregate(mtcars, by=list(cyl),
    FUN=mean, na.rm=TRUE)
  print(aggdata)
- OR use apply

Aggregating

- **When using the aggregate() function, the by variables must be in a list (even if there is only one). The function can be built-in or user provided.**
- **See also:**
- **summarize() in the Hmisc package**
- **summaryBy() in the doBy package**

Data Type Conversion

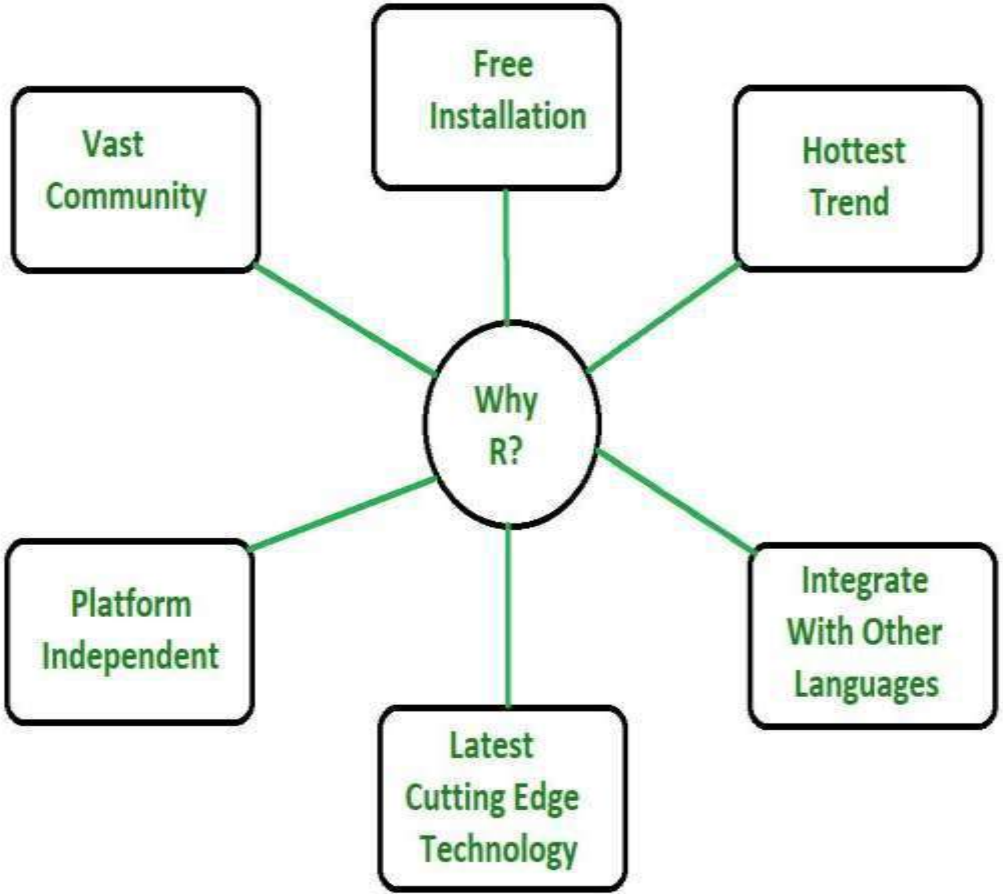
- **Type conversions in R work as you would expect. For example, adding a character string to a numeric vector converts all the elements in the vector to character.**
- **Use is.*foo* to test for data type *foo*. Returns TRUE or FALSE**
  Use as.*foo* to explicitly convert it.
- **is.numeric(), is.character(), is.vector(), is.matrix(), is.data.frame()**
  as.numeric(), as.character(), as.vector(), as.matrix(), as.data.frame)

UNIT-I

R Programming Language – Introduction

- It was designed by Ross Ihaka and Robert Gentleman at the University of Auckland, New Zealand, and is currently developed by the R Development Core Team.
- R programming language is an implementation of the S programming language

Why R Programming Language?



Features of R Programming Language

- **Basic Statistics:**
- **Static graphics**:
- **Probability distributions**:
- **Data analysis**

R DATATYPES AND OBJECTS

- Vectors
- Lists
- Matrices
- Arrays
- Factors
- Data Frames

Vectors

- # Create a vector.
- apple <- c('red','green',"yellow")
- print(apple)
- # Get the class of the vector.
- print(class(apple))

OUTPUT

- [1] "red"   "green" "yellow"
- [1] "character"

Lists

- A list is an R-object which can contain many different types of elements inside it like vectors
- # Create a list.
- list1 <- list(c(2,5,3),21.3,sin)
- # Print the list.
- print(list1)

result

- [[1]]
- [1] 2 5 3
- [[2]]
- [1] 21.3
- [[3]]
- function (x) .Primitive("sin")

Matrices

- # Create a matrix.
- M =matrix(c('a','a','b','c','b','a'),nrow=2,ncol=3,byrow= TRUE)
- print(M)

<u>result</u>

- [,1] [,2] [,3]
- [1,] "a" "a" "b"
- [2,] "c" "b" "a"

Arrays

- While matrices are confined to two dimensions, arrays can be of any number of dimensions.
- # Create an array.
- a <- array(c('green','yellow'),dim= c(3,3,2))
- print(a)

result

- [,1] [,2] [,3]
- [1,] "green" "yellow" "green"
- [2,] "yellow" "green" "yellow"
- [3,] "green" "yellow" "green"
-

Factors

- Factors are the r-objects which are created using a vector. It stores the vector along with the distinct values of the elements in the vector as labels.
- # Create a vector.
- apple_colors<- c('green','green','yellow','red','red','red','green')
-
- # Create a factor object.
- factor_apple<- factor(apple_colors)
-
- # Print the factor.
- print(factor_apple)
- print(nlevels(factor_apple))
- When we execute the above code, it produces the following result −
- [1] green green yellow red redred green
- Levels: green red yellow
- [1] 3

Data Frames

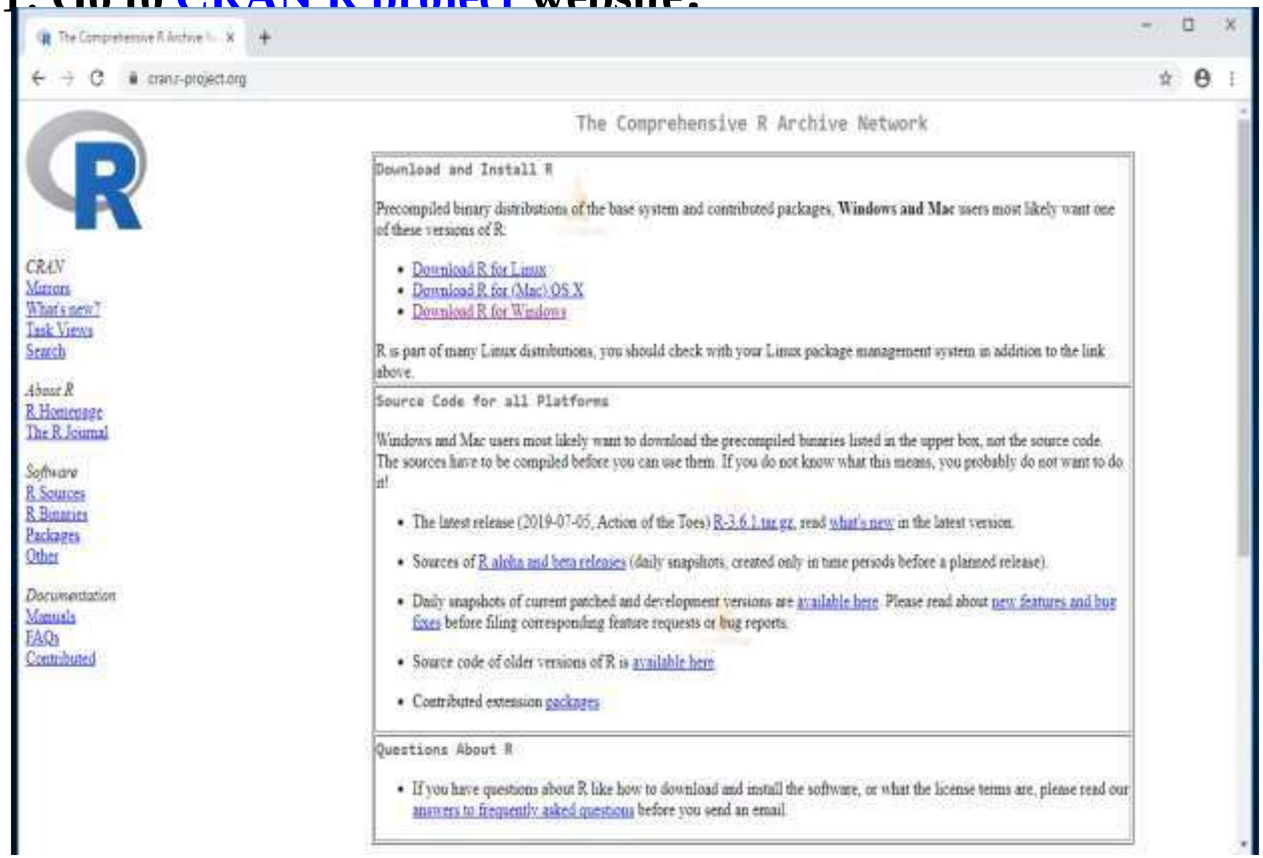
- Data frames are tabular data objects. Unlike a matrix in data frame each column can contain different modes of data.
- # Create the data frame.
- BMI <-data.frame(
-    gender =c("Male","Male","Female"),
-    height =c(152,171.5,165),
-    weight =c(81,93,78),
- Age=c(42,38,26))
- print(BMI)
- When we execute the above code, it produces the following result −
-   gender height weight Age
- 1   Male 152.0   81 42
- 2   Male 171.5   93 38
- 3 Female 165.0   78 26

READING AND WRITING DATA IN R

- **read.table(),** and read.csv(), for reading tabular data
- **readLines()** for reading lines of a text file
- **source()** for reading in R code files (inverse of dump)
- **dget()** for reading in R code files (inverse of dput)
- **load()** for reading in saved workspaces.
- Writing Data to files
- Following are few functions for writing (exporting) data to files.
- **write.table(),** and write.csv() exports data to wider range of file format including csv and tab-delimited.
- **writeLinest()** write text lines to a text-mode connection.
- **dump()** takes a vector of names of R objects and produces text representations of the objects on a file (or connection). A dump file can usually be sourced into another R session.
- **dput()** writes an ASCII text representation of an R object to a file (or connection) or uses one to recreate the object.
- **save()** writes an external representation of R objects to the specified file.

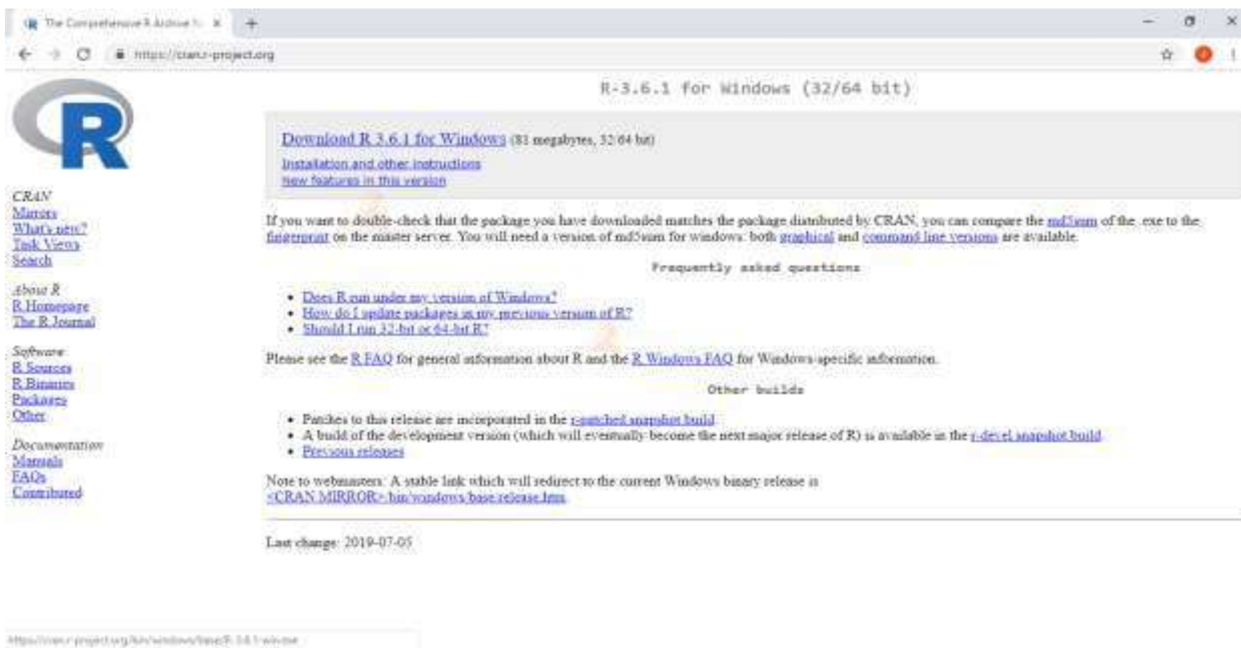
Install R on windows

- **Step – 1: Go to CRAN R project website.**



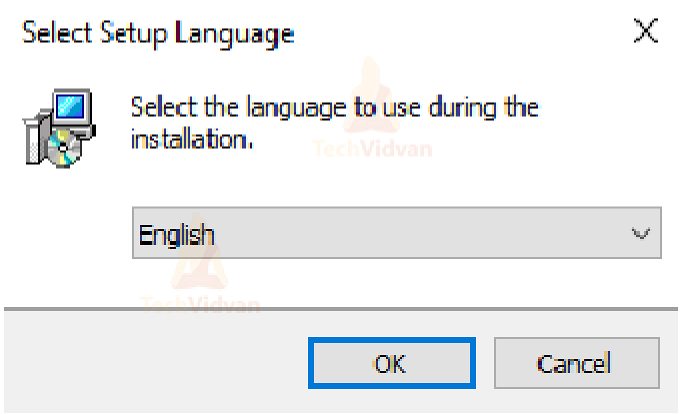
Step – 2: Click on the Download R for Windows link.

- **Step – 3:** Click on the base subdirectory link or install R for the first time link.
- **Step – 4**: Click Download R X.X.X for Windows (X.X.X stand for the latest version of R. eg: 3.6.1) and save the executable .exe file.

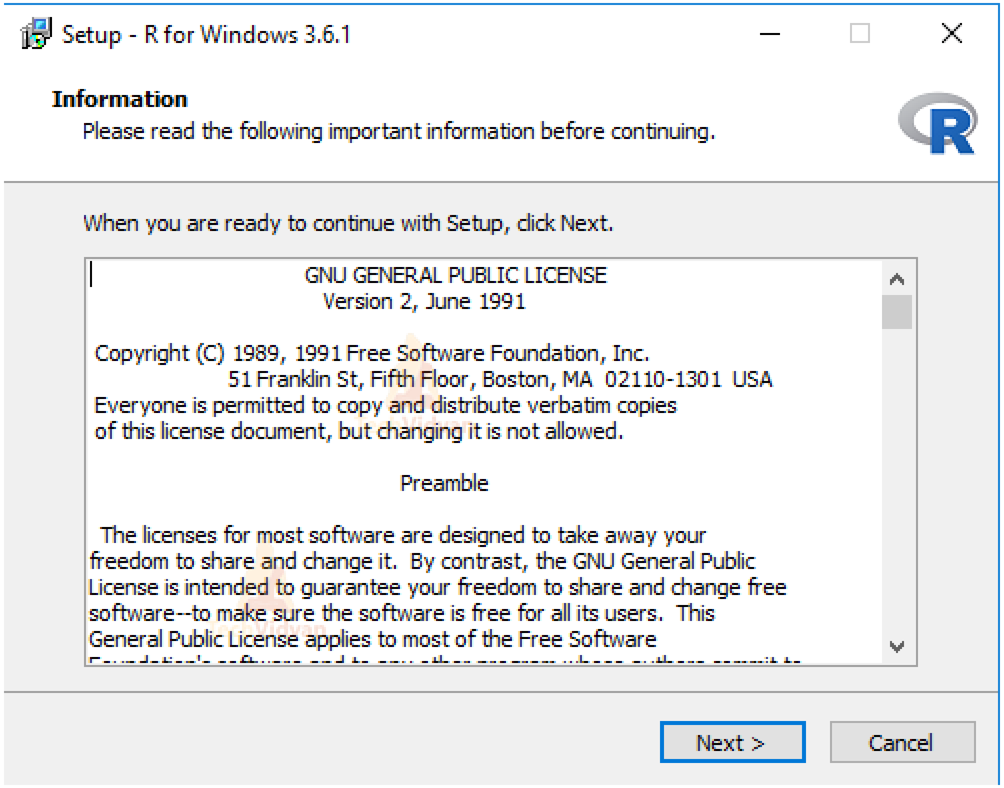


Step – 5: Run the .exe file and follow the installation instructions.

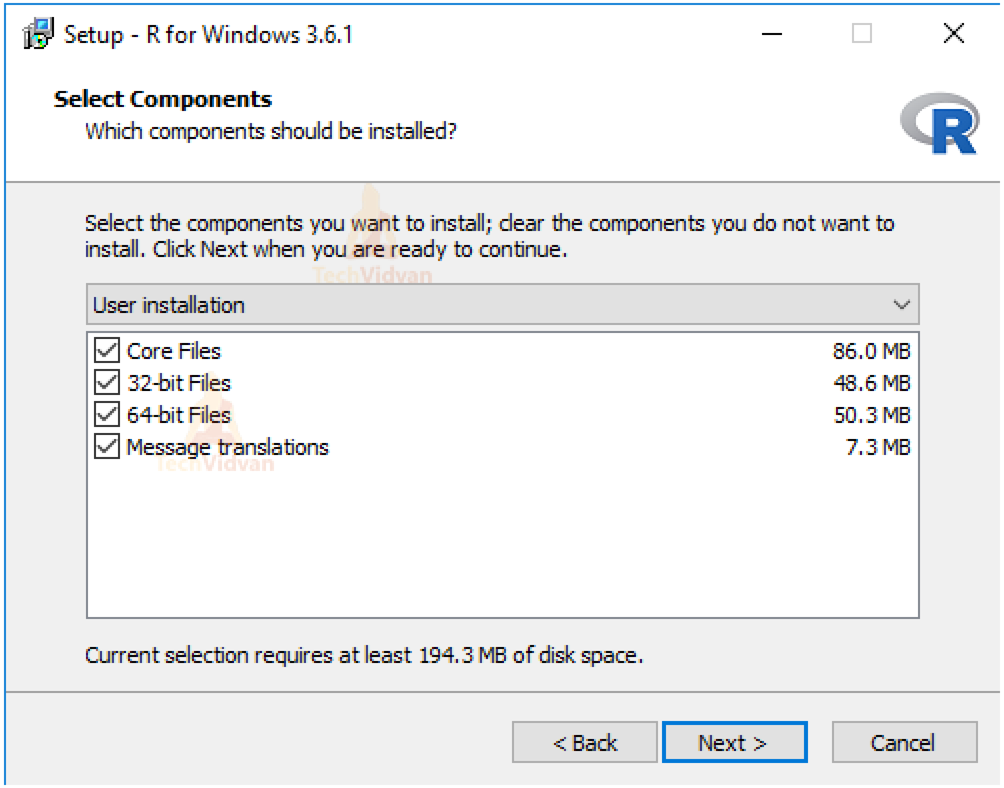
- 5.a. Select the desired language and then click Next.



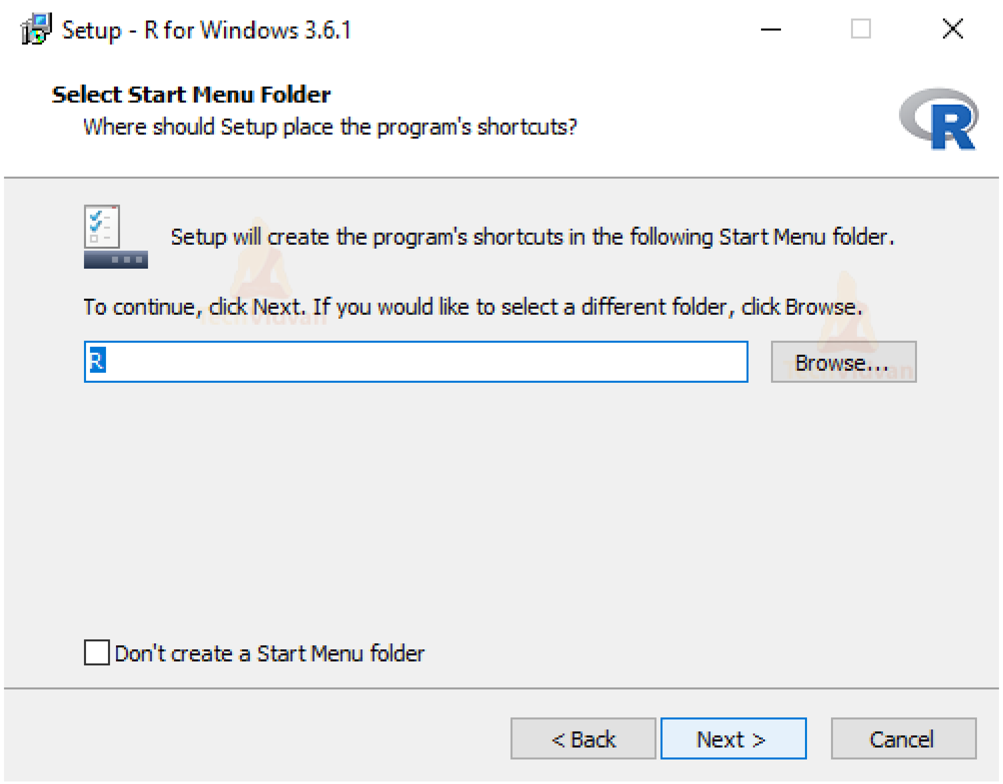
5.b. Read the license agreement and click Next.



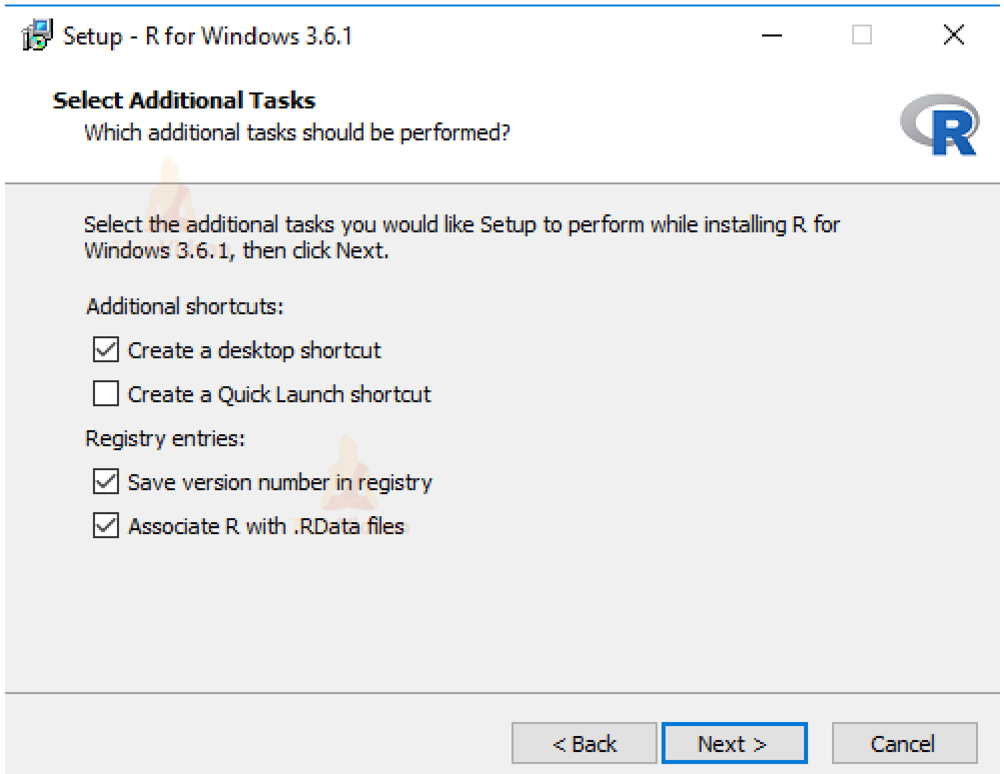
5.c. **Select the components you wish to install (it is recommended to install all the components).**



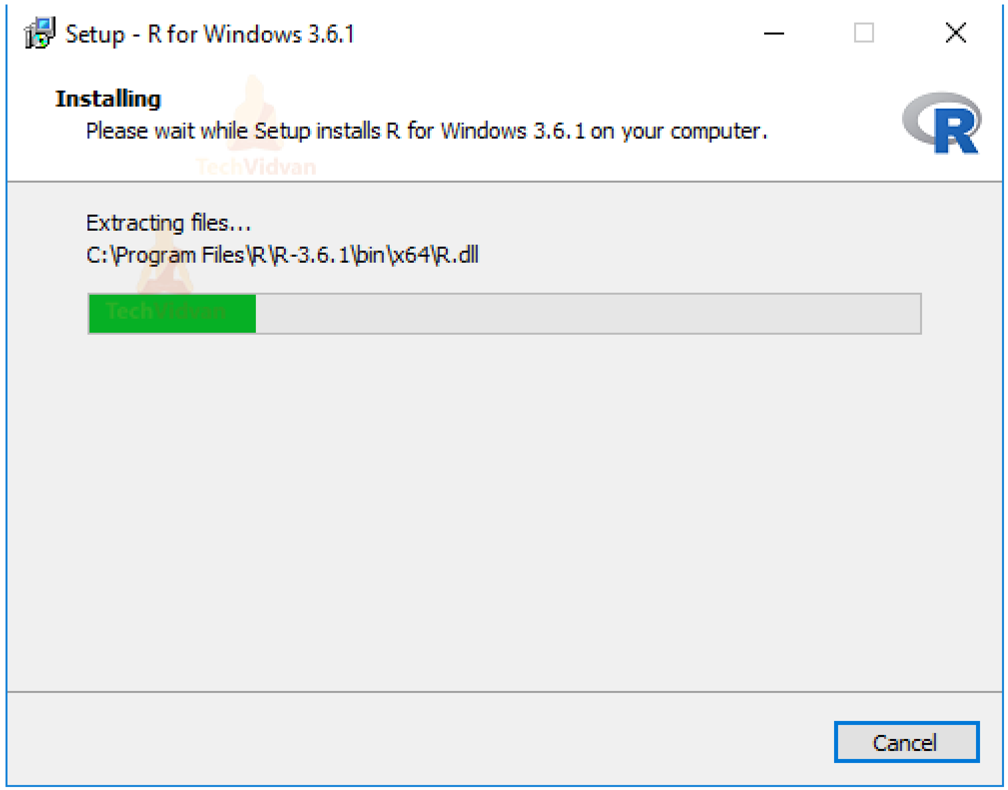
5.d. Enter/browse the folder/path you wish to install R into and then confirm by clicking Next



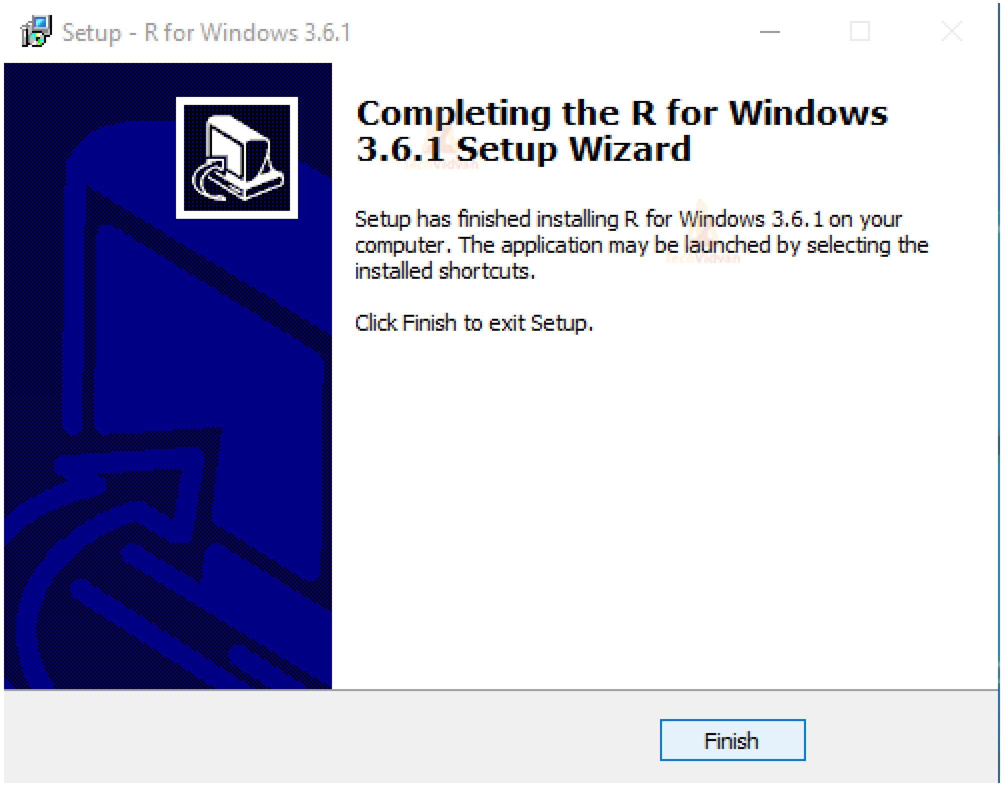
5.e. Select additional tasks like creating desktop shortcuts etc. then click Next



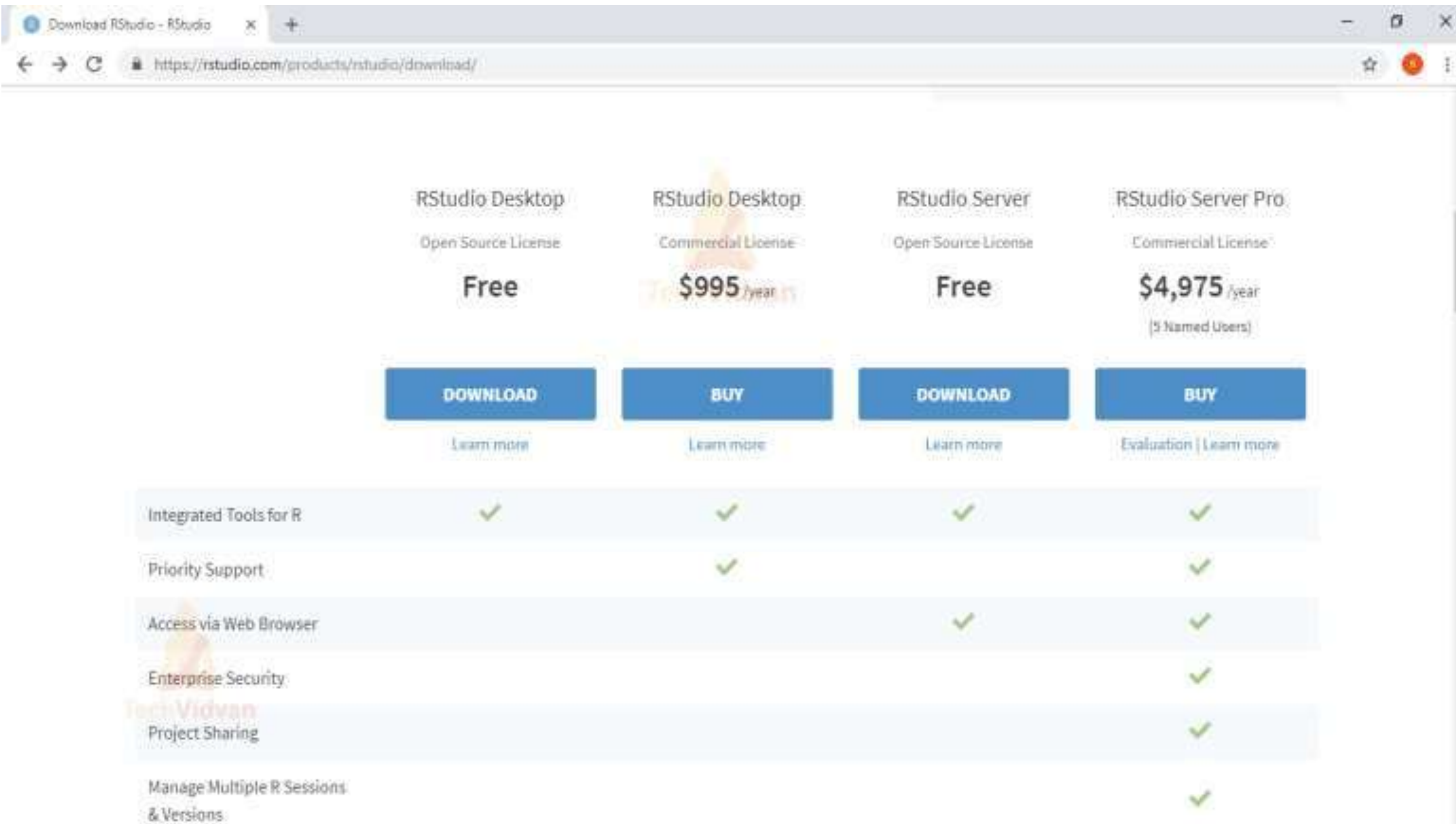
5.f. Wait for the installation process to complete.



5.g. Click on Finish to complete the installation.



Install R Studio on Windows



Arithmetic Operators

Operator	Description
+	Addition
-	Subtraction
*	Multiplication
/	Division
^ or **	Exponentiation

Logical Operators

- Operator Description
- < Less Than
- > Greater Than
- <= Less Than or Equal To
- >= Greater Than or Equal To
- == Exactly Equal To
- != Not Equal To
- !a Not a
- a&b a AND b

Types of Operators

We have the following types of operators in R programming −

- Arithmetic Operators
- Relational Operators
- Logical Operators
- Assignment Operators
- Miscellaneous Operators

- **Relational Operators**
- Following table shows the relational operators supported by R language. Each element of the first vector is compared with the corresponding element of the second vector. The result of comparison is a Boolean value(>,<,<=,>=,==,!=)
- **Logical Operators**
- Following table shows the logical operators supported by R language. It is applicable only to vectors of type logical, numeric or complex. All numbers greater than 1 are considered as logical value TRUE.
- Each element of the first vector is compared with the corresponding element of the second vector. The result of comparison is a Boolean value.(&,&&,||,|,!)

UNIT-II
CONTROL STRUCTURES AND VECTORS

- **Control Structures**
- Control structures in R allow you to control the flow of execution of a series of R expressions. Basically, control structures allow you to put some “logic” into your R code, rather than just always executing the same R code every time.
- **if and else:** testing a condition and acting on it
- **for:** execute a loop a fixed number of times
- **while:** execute a loop while a condition is true
- **repeat:** execute an infinite loop (must break out of it to stop)
- **break:** break the execution of a loop
- **next:** skip an interation of a loop
- IF AND ELSE
- if(<condition>) {
- ## do something
- } else {
- ## do something else
- }

- **For loop**
- for(i in1:10) {
- print(i)
- }
- **Nested for loop**
- x <-matrix(1:6, 2, 3)
- for(iinseq_len(nrow(x))) {
- for(j inseq_len(ncol(x))) {
- print(x[i, j])
-         }
- }
- **While loop**
- count <-0
- >while(count <10) {
- +print(count)
- +   count <- count +1
- + }

- **repeat**
- x0 <-1
- tol<-1e-8
- repeat {
- x1 <-computeEstimate()
- if(abs(x1 - x0) <tol) { ## Close enough?
- break
- } else {
-   x0 <- x1
- }
- }

- **next, break**
- next is used to skip an iteration of a loop.
- for(iin1:100) {
- if(i<=20) {
- ## Skip the first 20 iterations
- next
- }
- ## Do something here
- }

Vectors

A vector is simply a list of items that are of the same type

- **Vector operations**
- 1)create
- 2)access
- 3)modify
- 4)delete
-
```
# Vector of strings
fruits <- c("banana", "apple", "orange")

# Print fruits
fruits
```
-
```
# Vector with numerical decimals in a sequence
numbers1 <- 1.5:6.5
numbers1

# Vector with numerical decimals in a sequence where the last element is not used
numbers2 <- 1.5:6.3
numbers2
```

UNIT-III

LISTS

- **LIST OPERATIONS**
- 1)CREATE
- 2)ACCESS ELEMENTS FROM GIVEN LIST
- 3)MODIFY
- 4)DELETE
- **R – Lists**
- A list in R is a generic object consisting of an ordered collection of objects. Lists are one-dimensional, heterogeneous data structures. The list can be a list of vectors, a list of matrices, a list of characters and a list of functions, and so on.

- # Creating a list by naming all its components
- empId = c(1, 2, 3, 4)
- empName = c("Debi", "Sandeep", "Subham", "Shiba")
- numberOfEmp = 4
- empList = list(
- "ID" = empId,
- "Names" = empName,
- "Total Staff" = numberOfEmp
-)
- print(empList)
-

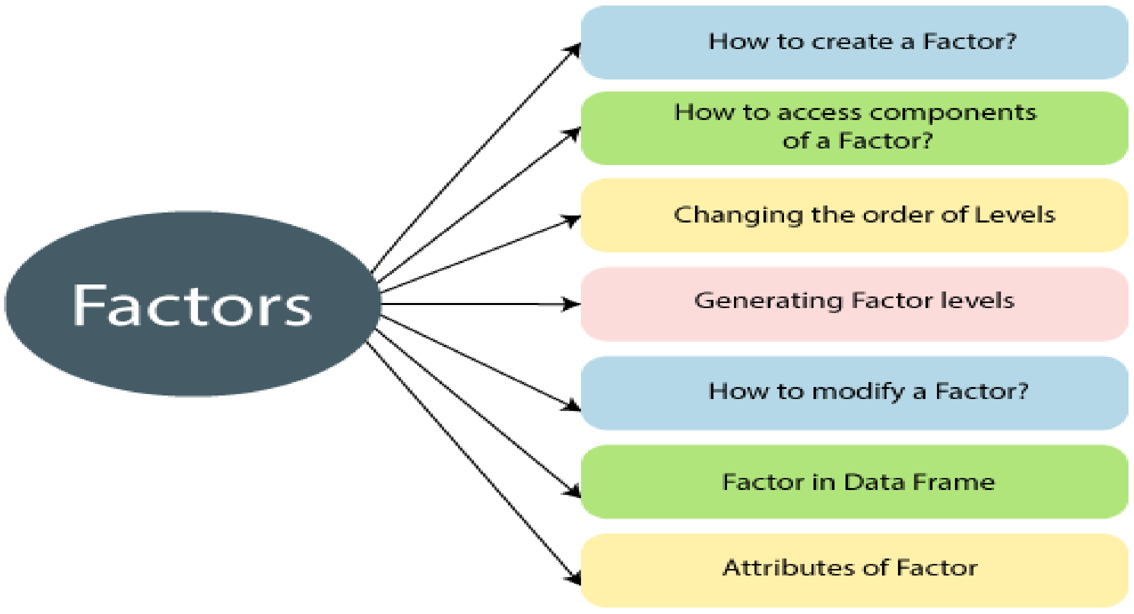
- list = c(list, list1)
  list = the original list
  list1 = the new list
- Example:
- R
- # R program to edit
- # components of a list
-
- # Creating a list by naming all its components
- empId = c(1, 2, 3, 4)
- empName = c("Debi", "Sandeep", "Subham", "Shiba")
- numberOfEmp = 4
- empList = list(
-   "ID" = empId,
-   "Names" = empName,
-   "Total Staff" = numberOfEmp
-)

- cat("Before concatenation of the new list\n")
- print(empList)
-
- # Creating another list
- empAge = c(34, 23, 18, 45)
- empAgeList = list(
-   "Age" = empAge
-)
-
- # Concatenation of list using concatenation operator
- empList = c(empList, empAgeList)
-
- cat("After concatenation of the new list\n")
- print(empList)

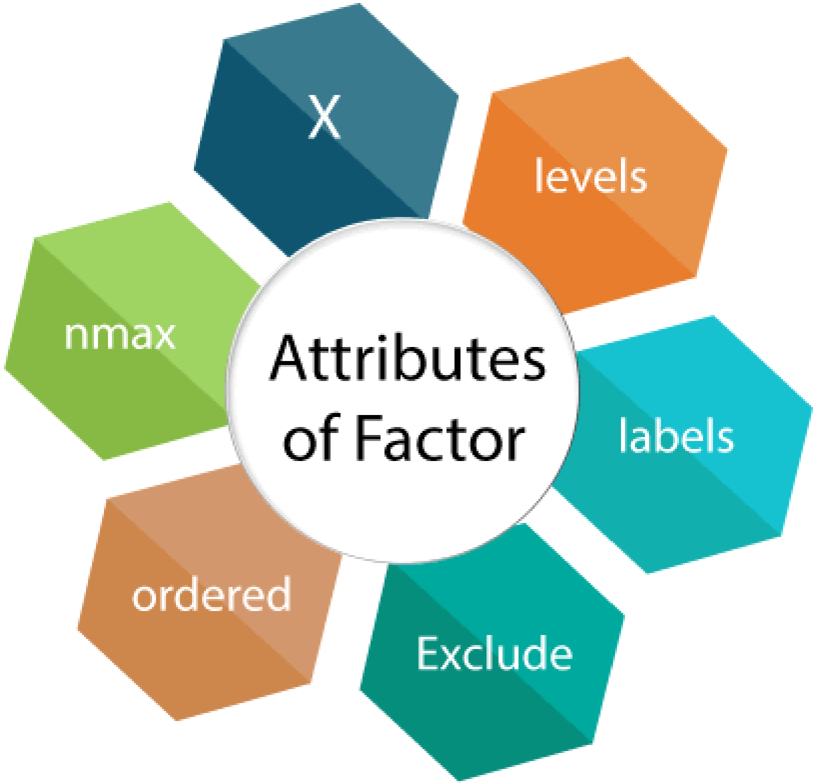
UNIT-IV

FACTORS

- **R factors**
- The factor is a data structure which is used for fields which take only predefined finite number of values. These are the variable which takes a limited number of different values.



Attributes of a factor



- **How to create a factor**?
- In R, it is quite simple to create a factor. A factor is created in two steps
- In the first step, we create a vector.
- Next step is to convert the vector Into a factor
- # Creating a vector as input.
- data <- c("Shubham","Nishka","Arpita","Nishka","Shubham","Sumit","Nishka","Shubham","Sumit","Arpita","Sumit")
-
- print(data)
- print(is.factor(data))
-
- # Applying the factor function.
- factor_data<- factor(data)
-
- print(factor_data)
- print(is.factor(factor_data))

FACTOR OPERATIONS

- 1)CREATE
- 2)ACCESS
- 3)MODIFY
- 4)DELETE

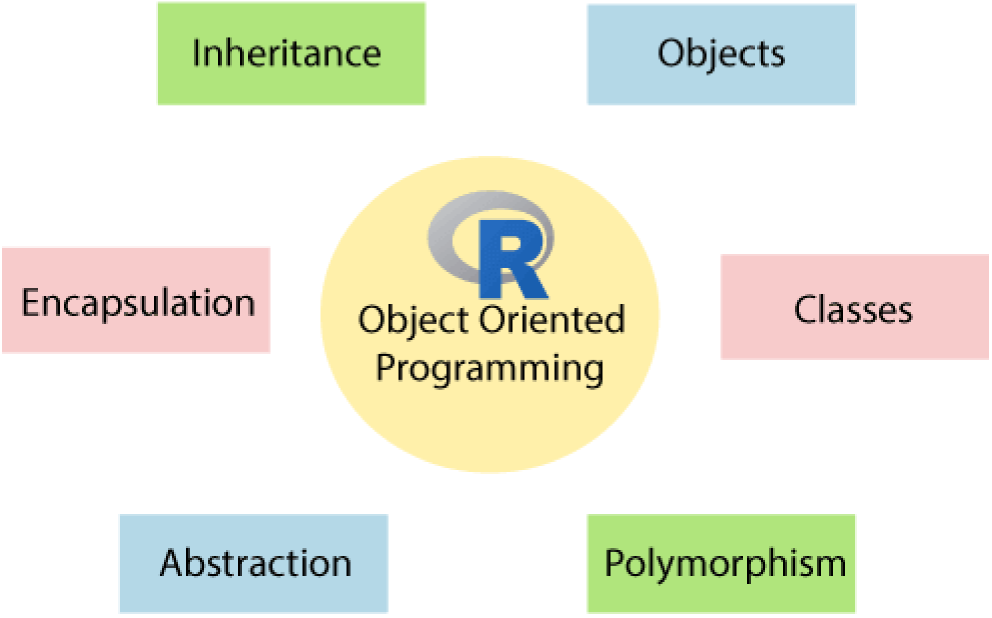
- **R Functions**
- A set of statements which are organized together to perform a specific task is known as a function. R provides a series of in-built functions.
- **steps**
- Written to carry out a specified task.
- May or may not have arguments
- Contain a body in which our code is written.
- May or may not return one or more output values
- **syntax**
- func_name <- function(arg_1, arg_2, ...) {
-   Function body
- }

UNIT-V

OOP CONCEPTS

- **What is Object-Oriented Programming in R?**
- Object-Oriented Programming (OOP) is the most popular programming language. With the help of oops concepts, we can construct the modular pieces of code which are used to build blocks for large systems. R is a functional language, and we can do programming in oops style. In R, oops is a great tool to manage the complexity of larger programs
- **S4 CLASES**
- **S3 CLASSES**

TYPES OF OOP

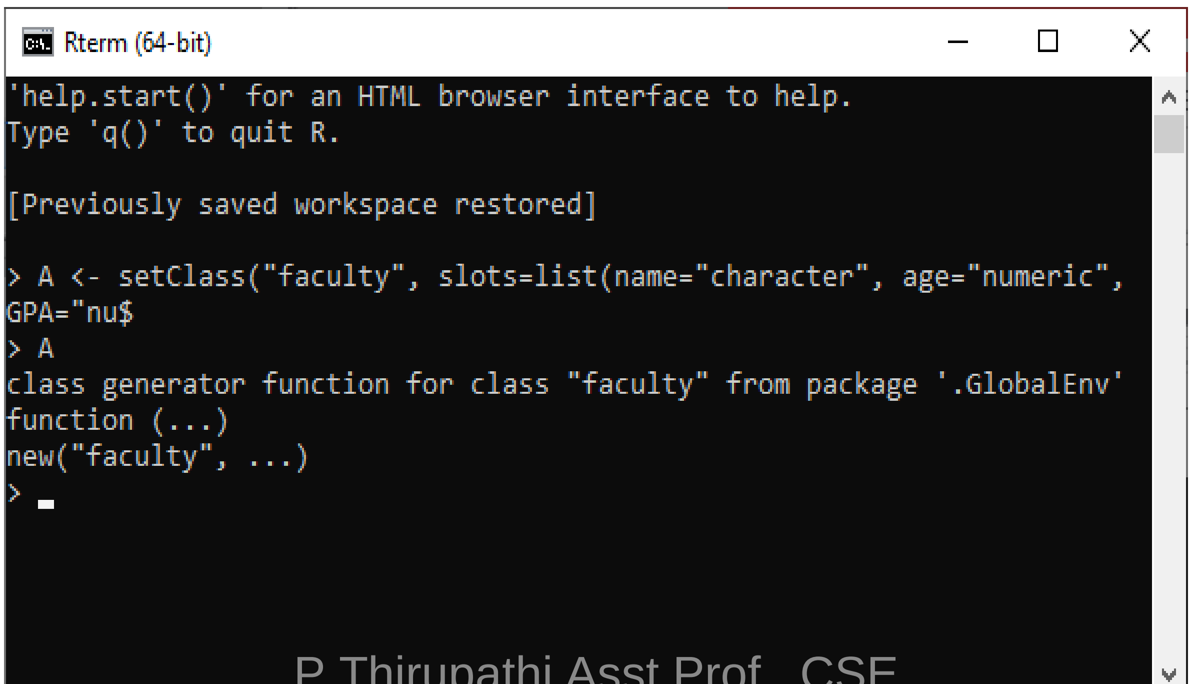

Inheritance
Objects
Encapsulation
Object Oriented
Programming
Classes
Abstraction
Polymorphism

- **S3**
- In oops, the S3 is used to overload any function. So that we can call the functions with different names and it depends on the type of input parameter or the number of parameters.
- **Play Videox**
- **S4**
- S4 is the most important characteristic of oops. However, this is a limitation, as it is quite difficult to debug. There is an optional reference class for S4.
- **Inheritance in S3**
- Inheritance means extracting the features of one class into another class. In the S3 class of R, inheritance is achieved by applying the class attribute in a vector.

- **EXAMPLE**
- class(Objet) <- c(child, parent)
- so,
-
- # create a list
- fac <-
  list(name="Shubham", age=22, GPA=3.5, country="India")
- # make it of the class InternationalFaculty which is derived from the class Faculty
- class(fac) <- c("InternationalFaculty","Faculty")
- # print it out
- fac

```
C:\Users\ajeet\R>Rscript class.R
$name
[1] "Shubham"

$age
[1] 22

$GPA
[1] 3.5

$country
[1] "India"

attr(,"class")
[1] "InternationalFaculty" "Faculty"

C:\Users\ajeet\R>
```

- **Creating S4 objects using a generator function**
- The setClass() function returns a generator function. This generator function helps in creating new objects. And it acts as a constructor.
- A <- setClass("faculty", slots=list(name="character", age="numeric", GPA="numeric"))
- A



Inheritance in S4 class

- **Step 1:**
- In the first step, we will create or define class with appropriate slots in the following way:
- setClass("faculty", slots=list(name="character", age="numeric", GPA="numeric"))
- **Step 2:**
- After defining class, our next step is to define class method for the display() generic function. This will be done in the following manner:
- **EXAMPLE:**
- setMethod("show", "faculty", function(obj) {
- cat(obj@name, "\n")
- cat(obj@age, "years old\n")
- cat("GPA:", obj@GPA, "\n")
- }