Introduction to R

Data Analysis and Calculations

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Outline

- Introduction
- Help System
- Variables
- R environment
- Vectors
- Matrices
- Datasets (data frames)
- Lists
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Introduction

- Open source programming language for statistical computing and graphics
- Part of GNU project
- Written primarily in C and Fortran.
- Available for various operating systems: Unix/Linux, Windows, Mac
- Can be downloaded and installed from http://cran.r-project.org/

Advantages

- Easy to install. Ready to use in a few minutes.
- A few thousand supplemental packages
- Open source with a large support community: easy to find help!
- Many books, blogs, tutorials.
- Frequent updates
- More popular than major statistics packages (SAS, Stata, SPSS etc.)

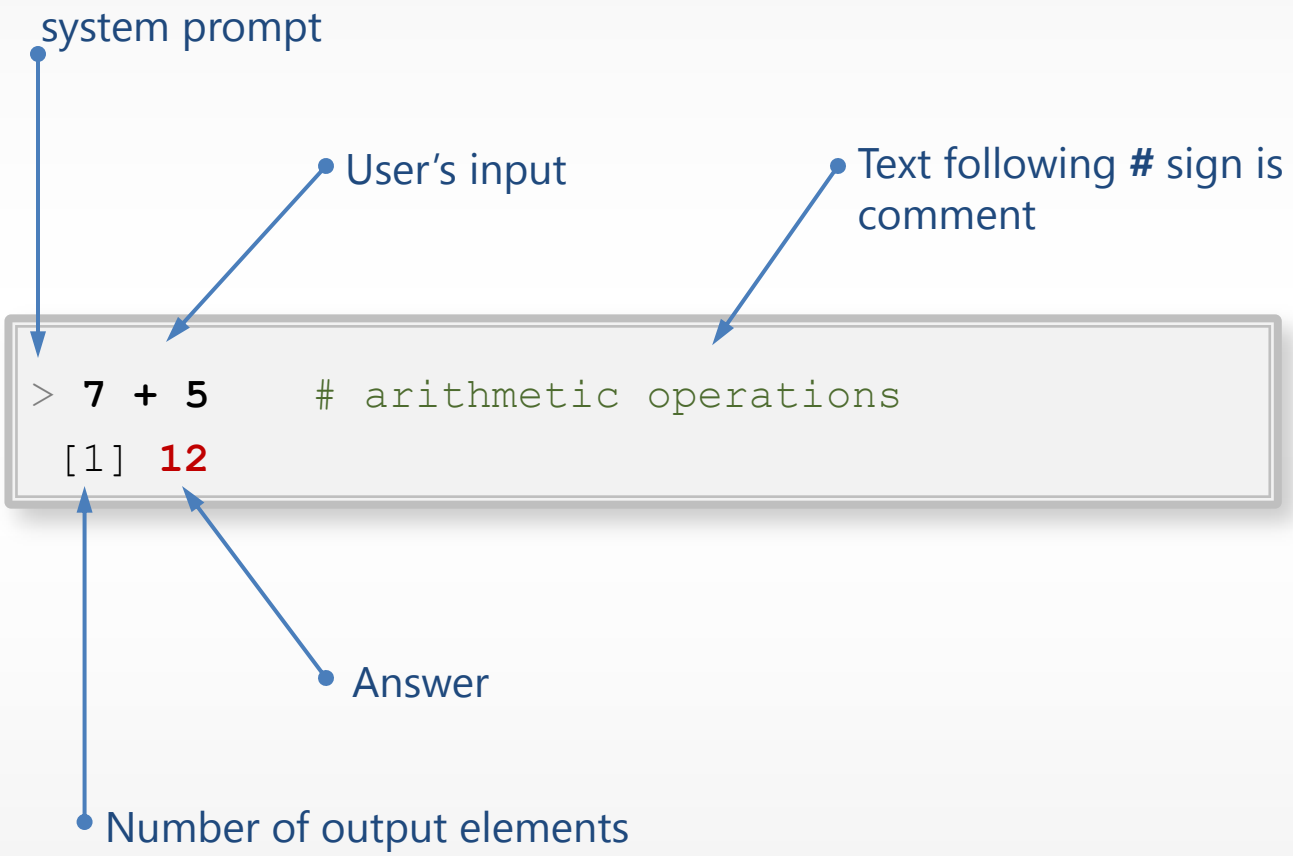
Getting Started

To start R session type R:

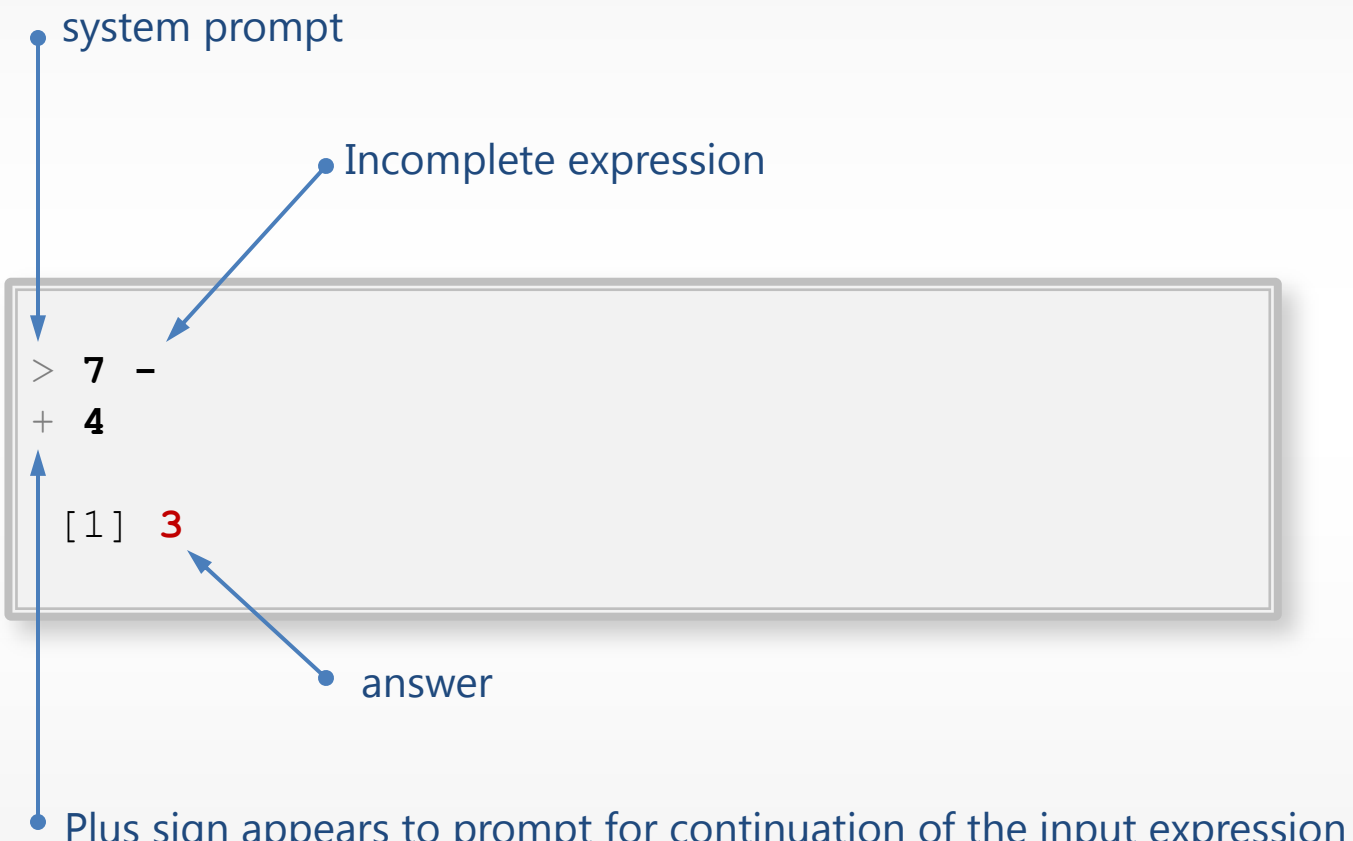
```
katana:~% R
R version 2.13.2 (2011-09-30)
Copyright (C) 2011 The R Foundation for
Statistical Computing
ISBN 3-900051-07-0
Platform: x86_64-unknown-linux-gnu (64-bit)

>
```

R as a calculator



R as a calculator



R as a calculator

```
> 7 + 5                    # arithmetic operations
[1] 12

> 6 - 3 * ( 8/2 - 1 )
[1] -3

> log(10)                  # commonly used functions
[1] 2.302585

> exp(7)
[1] 1096.633

> sqrt(2)
[1] 1.414214
```

Math functions

```
sqrt(x), sum(x), sign(x), abs(x), …

# trigonometric
sin(x), cos(x), tan(x), asin(x), acos(x), …

# hyperbolic
sinh(x), cosh(x), …

# logarithmic and exponent
log(x), log10(x), log2(x) or log(x, base=10), exp(x)

# factorial and combination functions
factorial(n)      , choose(n ,m)

# built-in constants
T, F, pi, LETTERS, letters, month.abb, month.name
```

Logical operations

Symbol	Meaning
!	logical NOT
&	logical AND
|	logical OR
<	less than
<=	less than or equal to
>	greater than
>=	greater than or equal to
==	logical equals
! =	not equal

Operations in R

```
# A few operations can be listed on one line.
# Use semicolon(;) to separate them
> cos(0); sqrt(2)
[1] 1
[1] 1.414214
```

getting Help

```
> # get help on function read.table()
> ?read.table
or
> help(read.table)
> help.start()          # help in html format
```

```
> # find all functions related to the subject of interest
> help.search("data input")
```

getting Help

```
> # list all the function names that include the text matrix
> apropos("matrix")
```

```
> # see examples of function usage
> example(matrix)
```

```
> # see some demos
> demo(lm.glm)        # lm() demo
> demo(graphics)      # graphics examples
> demo(persp)         # 3D plot examples
> demo(Hershey)       # fonts, symbols, etc.
> demo(plotmath)      # plotting Math functions

> demo()              # list of demos
```

variables

Assignment operator is **<-**

Equal sign (**=**) could be used instead, but **<-** operator is preferred

```
> x <- 5          # assign value 5 to a variable
> x               # print value of x
 [1] 5
> x <- 4; y <- 3          # semicolon can be used as a separator
> z <- x*x - y*y          # assign the result to a new variable
```

variables

Caution: Be careful comparing a variable with a negative number!

```
> x <- -5        # assign value -5 to a variable

> # Wrong evaluation :
> x <-3          # Desired : Is x less than -3
> x
 [1] 3
```

variables

Caution: Be careful comparing a variable with a negative number!

```
> x <- -5        # assign value -5 to a variable

> # Correct evaluation  (use space!):
> x < -3         # Is x less than -3
 [1] TRUE

> # Even better (use parenthesis):
> x <(-7)        # Is x less than -7
 [1] FALSE
```

variables

-> can also be used as an assignment operator

```
> 5 -> a       # assign value 5 to a variable
> a
[1] 5
```

Objects can take values **Inf, -Inf, NaN** (not a number) and **NA** (not available) for missing data

```
> a -> NA      # assign "missing data" value to a variable
> a
[1] NA
```

variables

- Names of the objects may contain any combinations of letters, numbers and dots (.)

```
> sept14.2012.num <- 1000      # correct!
>
```

variables

- Names of the objects may contain any combinations of letters, numbers and dots (.)
- Names of the objects may **NOT** start with a *number*

```
> 2012.sept14.num <- 1000        # wrong!
Error: unexpected symbol in " 2012.sept14.num"
```

variables

- Names of the objects may contain any combinations of letters, numbers and dots (.)
- Names of the objects may NOT start with a number
- Case sensitive

```
> a <- 5;   A <- 7
> a
  [1] 5

> A
  [1] 7
```

variables

- Names of the objects may contain any combinations of letters, numbers and dots (.)
- Names of the objects may NOT start with a number
- Case sensitive
- Avoid renaming predefined **R** objects, constants and functions: **c, q, s, t, C, D, F, I**, and **T**

```
> # examples of correct variable assignments
> b.total <- 21;   b.average <- 3
> b.total
  [1] 21
> b.average
  [1] 3
```

string variables

Strings are delimited by " or by '.

```
> myName <- "Katia"
> myName
  [1] "Katia"

> hisName <- 'Alex'
> hisName
  [1] "Alex"
```

built-in constants

`LETTERS:`	26 upper-case letters of the Roman alphabet
`letters:`	26 lower-case letters of the Roman alphabet
`month.abb:`	3 – letter abbreviations for month names
`month.name:`	month names
`pi:`	ratio of circle circumference to diameter
`c, T, F, t`	built-in objects/functions (avoid using these as var. names)

Data types

There are 5 atomic data types:

- Integer(*)

```
> int_value <- 21L
```

- Numerical

```
> num_value <- 21.69
```

- Complex

```
> cmp_value <- 7 + 3i
```

- Logical (Boolean)

```
> log_value <- ( 2 < 4 )
```

- Character string

```
> str_value <- "Hello R"
```

(*) Strictly speaking, integer is not an atomic data type

Data types

mode() or class():

```
> mode( num_value )
  [1] "numeric"
```

```
> class( str_value )
  [1] "character"
```

Note: There is some differences between these functions. See help for more information:

```
> class( int_value )
  [1] "integer"

> mode( int_value )
  [1] "numeric"
```

session commands

```
katana:~ % R      # to start an R session in the current directory

> q()     # end R session
 Save workspace image? [y/n/c]:

# y – yes
# n – no (in most cases select this option to exit the workspace without saving)
# c – cancel
katana:~ %
```

saving current session

```
> a <- 5
> b <- a + 3;
> myString <- "apple"

> # list all objects in the current session
> ls()
  [1] "a"        "b"        "myString"
```

```
> # save contents of the current workspace into .RData file
> save.image()

> # save contents to the file with a given name
> save.image(file = "myFile.Rdata")
```

```
> # save some objects to the file
> save(a,b, file = "ab.Rdata")
```

loading stored objects

```
> # load saved session
> load("myFile.Rdata")


> # list all the objects in the current workspace
> ls()
or
> objects()


> # remove objects from the current workspace
> rm(a, b)
```

other useful commands

```
> # delete the file (or directory!)
> unlink("myFile.Rdata")

> # get working directory path
> getwd()

> # set working directory path
> setwd( path )
```

other useful commands

```
> # List attached packages (on path) and R objects
> search()

> # Execute system commands
> system('ls -lt *.RData')
> system('ls -F')              # list all files in the directory


> # vector with one line per character string
> # if intern = TRUE, the output of the command – is character  strings
> system("who", intern = TRUE)
```

Tips

- Use arrow keys (“up” and “down”) to traverse through the history of commands.
- “Up arrow” – traverse backwards (older commands)
- “Down arrow” – traverse forward (newer commands)

data objects overview

Vectors, matrices, data frames & lists

- Vector – a set of elements of the same type.
- Matrix - a set of elements of the same type organized in rows and columns.
- Data Frame - a set of elements organized in rows and columns, where columns can be of different types.
- List - a collection of data objects (possibly of different types) – a generalization of a vector.

vectors

Vector : *a set of elements of the same type.*

```
2,  3,  7,  5,  1

TRUE,  FALSE,  FALSE,  TRUE,  FALSE

"Monday", "Tuesday", "Wednesday", "Thursday", "Friday"
```

vectors

To create a vector – use function "concatenate" : **c( )**

```
> myVec <- c( 1,6,9,2,5 )
> myVec
  [1]   1   6   9   2   5

> # lets find out the type of myVec object
> mode(myVec)
  [1] "numeric"

> # fill vector with consecutive numbers from 5 to 9 and print it
> print(a<- c( 5:9 ))
  [1]  5  6  7  8  9
```

vectors

We can also use function "sequence" : **seq( )**

```
> myVec <- seq( -1.1, 0.5, by=0.2 )
> myVec
 [1] -1.1 -0.9 -0.7 -0.5 -0.3 -0.1  0.1  0.3  0.5
```

Or function "repeat" : **rep( )**

```
> myVec <- rep( 7, 3)
> myVec
 [1] 7 7 7
```

vectors

What can we do with vectors?

```
> # create more vectors:
> a <- c( 1, 2, 4 )
> b <- c( 7, 3 )
> ab <- c( a, b )
> ab
  [1]  1  2  4  7  3

> # append more values
> ab[6:10] <- c( 0, 6, 4, 1, 9)
```

vectors

What can we do with vectors?

```
> # access individual elements
> ab[3]
  [1]  4        # notice:  index starts with 1 (like in FORTRAN)

> # list all but 3rd element
> ab[-3]
  [1]  1  2  7  3  0  6  4  1  9

> # list 3 elements, starting from the second
> ab[2:4]
  [1]  2  4  7

> # list a few elements
> ab[c(1, 3, 5)]    # this technique is called slicing
  [1]  1  4  3
```

vectors

Accessing vector data (partial list)

```
x[n]              nth element
x[-n]             all but nth element
x[1:n]            first n elements
x[-(1:n)]         elements starting from n+1
x[c(1,3,6)]       specific elements
x[x>3 & x<7]      all element greater than 3 and less than 7
x[x<3 | x>7]      all element less than 3 or greater than 7
length(x)         vector length
which(x == max(x))          which indices are largest
```

Math with vectors (partial list)

Any math function used for scalars:

```
sqrt, sin, cos, tan, asin, acos, atan, log, exp etc.
```

Standard vector functions:

```
max(x), min(x), range(x)
sum(x), prod(x)          # sum and product of elements
mean(x) , median(x)      # mean and median values of vector
var(x), sd (x)           # variance and standard deviation
IQR(x)                   # interquartile range
```

vectors

Additional functions of interest:

```
> # cumulative maximum and minimum
> x <- c( 12, 14, 11, 13, 15, 12, 10, 17, 13, 9, 19)

> cummax(x)          # running (cumulative) maximum
  [1] 12 14 14 14 15 15 15 17 17 17 19

> cummin(x)          # running (cumulative) minimum
  [1] 12 12 11 11 11 11 10 10 10  9  9

> # repetitions of a value
> rep("yes", 5 )
  [1] "yes" "yes" "yes" "yes" "yes"

> gender <- c( rep("male", 3 ), rep("female",2) )
```

vectors

Creating a composition of operations:

```
> # define a vector that holds scores for a group of numbered athletes
> scores <- c(80,95,70,90,95,85,95,75)
> # how many athletes do we have?
> num <- length(scores)
> # get the vector that holds the number of each athlete
> id <- 1:num
> # what is the maximum score
> best <- max(scores)
> # which athletes got the maximum score
> id[scores == best]

> # we can do all this in just ONE powerful statement !
> (1:length(scores))[scores == max(scores)]
[1]  2  5  7
```

Handling of missing data:

```
> # Sometimes data are not available
> y <- c( 3, 2, NA, 7, 1, NA, 5)

> #  in some cases we might want to replace them with some other value
> v[is.na(v)] <- 0        # replace missing data with zeros

> #  the following will not work:
> v[ v == NA ] <- 0

> v == NA                 # v is unchanged because all the elements of v==NA evaluate to NA
 [1] NA NA NA NA NA NA NA
```

vectors

Operations with 2 vectors:

```
> x <- c(2, 4, 6, 8)
> y <- c(1, 2, 3, 4)

> print(r1 <- x + y)     # print the result
  [1]  3  6  9  12

> (r2 <- x - y)          # another way to print the result
  [1]  1  2  3  4

> (r3 <- x * y)     # Note: multiplication is performed for elements
  [1]  2  8  18 32

> (r4 <- x / y)
  [1]  2  2  2  2
```

vectors

If we would like to perform a "usual" - scalar - multiplication, we should use %*% :

```
> x <- c(2, 4, 6, 8)
> y <- c(1, 2, 3, 4)

> x %*% y
      [,1]
[1,]   60
```

vectors

Operations with vectors of different length:

```
> x <- c(2, 3, 4, 8)
> y <- c(1, 2, 3)
> r1 <- x + y
 Warning message:
 In x + y : longer object length is not a multiple
of shorter    object length

> r1
 [1]  3  5  7  9
```

Example – finding a unit vector:

```
> x <- c(1, 4, 8)
> x2 <- x * x
> x2sum <- sum(x2)
> xmag <- sqrt(x2sum)
> x / xmag
  [1] 0.1111111 0.4444444 0.8888889

# This can be done with just one line:
> x / sqrt(sum(x*x))
 [1] 0.1111111 0.4444444 0.8888889
```

vectors

Useful vector operations:

`sort(x)`	returns sorted vector (in increasing order)
`rev(x)`	reverses the order of elements
`unique(x)`	returns the vector of unique elements
`duplicate(x)`	returns the logical vector indicating non-unique elements

vectors

Useful vector operations:

```
which.max(x)        returns index of the larges element

which.min(x)        returns index of the smallest element

which(x == a)       returns vector of indices i, for which x[i]==a

summary(x)          summary statistics (mean, median, min, max, quartiles)
```

Useful vector operations (handling of missing values) :

```
is.na(x)          returns the logical vector indicating missing elements

na.omit(x)                suppress observations with missing data

sum(is.na(x))             get the number of missing elements

which(is.na(x))           get indices of the missing elements in a vector

mean( x, na.rm=TRUE )     calculate mean of all non-missing elements

x[is.na(x)] <- 0          replace all missing elements with zeros
```

vectors

Named vector elements :

```
# define a vector
> v <- c("Alex", "Johnson")
> v
 [1] "Alex"   "Johnson"

# provide names of vector's elements
> names(v) <- c("first", "last")

> v
      first     last
 [1] "Alex"   "Johnson"
```

vectors

Named vector elements :

```
# an alternative way to provide names to the vecotr elements
> v <- c(first = "Alex", last = "Johnson")
> v
     first     last
 [1] "Alex"   "Johnson"

# access vector elements using names
> v["first"]
 [1] "Alex"
```

matrices

Matrix : *a set of elements of the same type organized in rows and columns.*

```
2   3   7   5   1
7   9   1   4   0
8   2   6   3   7
```

```
TRUE    FALSE   FALSE
FALSE   TRUE    FALSE
FALSE   FALSE   TRUE
```

matrices

Matrices are very similar to vectors. The data (of the same type) organized in rows and columns.

There are a few way to create a matrix

Using **matrix(data, nrow, ncol, byrow)** function:

```
> mat <- matrix(seq(1:21) ,nrow = 7)
> mat
     [,1] [,2] [,3]
[1,]    1    8   15
[2,]    2    9   16
[3,]    3   10   17
[4,]    4   11   18
[5,]    5   12   19
[6,]    6   13   20
[7,]    7   14   21
```

matrices

The byrow argument specifies how the matrix is to be filled. By default, R fills out the matrix column by column (similar to FORTRAN and Matlab, and unlike C/C++ and WinBUGS).

If we prefer to fill in the matrix row-by-row, we must activate the *byrow* setting:

```
> mat <- matrix(seq(1:21) ,nrow=7, byrow=TRUE)
> mat
     [,1] [,2] [,3]
[1,]    1    2    3
[2,]    4    5    6
[3,]    7    8    9
[4,]   10   11   12
[5,]   13   14   15
[6,]   16   17   18
[7,]   19   20   21
```

matrices

To create an identity matrix of size N x N, use **diag()** function:

```
> dmat <- diag(5)

> dmat
     [,1] [,2] [,3] [,4] [,5]
[1,]    1    0    0    0    0
[2,]    0    1    0    0    0
[3,]    0    0    1    0    0
[4,]    0    0    0    1    0
[5,]    0    0    0    0    1
```

matrices

To find dimensions of a matrix, use **dim()** function:

```
> dmat <- diag(5)
> dim( dmat)
[1]    5    5
```

To find the number of rows and columns of a matrix, use **nrow()** and **ncol()** respectfully:

```
> dmat <- matrix(seq(1:21) ,nrow = 7)
> nrow( dmat)
[1]    7
> ncol( dmat)
[1]    3
```

matrices

Operations with matrices:

```
> # transpose
> mat <- t(mat)
> mat
     [,1] [,2] [,3] [,4] [,5] [,6] [,7]
[1,]    1    4    7   10   13   16   19
[2,]    2    5    8   11   14   17   20
[3,]    3    6    9   12   15   18   21
```

matrices

Matrix multiplication:

```
> # matrix' elements  multiplication
> x <- matrix( seq(1:9), nrow=3)
> y <- matrix( seq(1:9), nrow=3, byrow=TRUE)
> (x * y)
     [,1] [,2] [,3]
[1,]    1    8   21
[2,]    8   25   48
[3,]   21   48   81

> # as with vectors, to perform usual matrix multiplication, use %*%
> (x %*% y)
     [,1] [,2] [,3]
[1,]   66   78   90
[2,]   78   93  108
[3,]   90  108  126
```

matrices

Other operations:

```
> # return diagonal elements
>  diag(x)
  [1] 1 5 9

> # row sum and means:
>  rowSums(x)
  [1] 12 15 18
>  rowMeans(x)
  [1] 4 5 6

> # column sum and means:
>  colSums(x)
  [1] 12 15 18
>  colMeans(x)
  [1] 2 5 8
```

! note: we used diag() before to create an identity matrix

matrices

Other operations:

```
> # determinant
> det(x)
  [1] 0

> # inverse matrix:
> w <- matrix(c(1,0,0,2),2)
> solve(w)
     [,1] [,2]
[1,]    1  0.0
[2,]    0  0.5

> # If the matrix is singular (not invertible), the error message is displayed:
> solve(x)
  Error in solve.default(x) :
     Lapack routine dgesv: system is exactly singular
```

matrices

Function **`solve( )`** can be used to solve a system of linear equations:

$$\begin{cases} 1 * x + 0 * y = 3 \\ 0 * x + 2 * y = 8 \end{cases}$$

```
> w <- matrix( c(1,0,0,2), 2 )
> v <- c(3, 8)
> solve(w, v)
 [1]    3   4
```

matrices

Accessing matrix data (partial list)

`x[2,3]`	element in the 2nd row, 3rd column
`x[2,]`	all elements of the 2nd row (the result is a vector)
`x[,3]`	all elements of the 3rd column (the result is a vector)
`x[c(1,3,4),]`	all elements of the 1st 3rd and 4th columns (the result is a matrix)
`x[,-3]`	all elements but 3rd column (the result is a matrix)

Logical operations similar to the vector's apply

matrices

Naming matrix rows and columns

```
rownames(x)          set or retrieve row names of matrix
colnames(x)          set or retrieve column names of matrix
dimnames(x)          set or retrieve row and column names of matrix
```

```
> # define matrix
> x <- matrix(1:6, nrow = 2)
     [,1] [,2] [,3]
[1,]    1    3    5
[2,]    2    4    6

> # specify column names:
> colnames(x) <- c("col1" , "col2", "col3")

> # specify both – row and column names:
> dimnames(x) <- list(c("col1" , "col2", "col3"),
+                     c("row1" , "row2"))
```

matrices

Combining vectors and matrices:

```
> # To stuck 2 vectors or matrices, one below the other, use rbind()
> x <- rbind( c(1,2,3) , c(4,5,6) )
> x
     [,1] [,2] [,3]
[1,]    1    2    3
[2,]    4    5    6

> # To stuck 2 vectors or matrices, next to each other, use cbind()
> x <- cbind( c(1,2,3) , c(4,5,6) )
> x
     [,1] [,2]
[1,]    1    4
[2,]    2    5
[3,]    3    6
```

data frames

- Data frames are fundamental data type in R
- A data frame is a generalization of a matrix
- Different columns may have different types of data
- All elements of any column must have the same data type

```
Age    Weight    Height    Gender
18      150        67        F
23      170        70        M
38      160        65        M
52      190        68        F
```

data frames

We can create data on the fly:

```
> age    <- c( 18, 23, 38, 52)
> weight <- c( 150, 170, 160, 190)
> height <- c( 67, 70, 65, 68)
> gender <- c("F", "M", "M", "F")

> data0 <- data.frame( Age = age, Weight = weight, Height = height,
+     Gender = gender)

> data0
  Age Weight Height Gender
1  18    150     67      F
2  23    170     70      M
3  38    160     65      M
4  52    190     68      F
```

data frames

The data usually come from an external file.

First consider a simple text file : *inData.txt*

To load such a file, use **`read.table()`** function:

```
> data1 <- read.table(file = "inData.txt", header = TRUE )
> data1

  Age Weight Height Gender
1  18    150     67      F
2  23    170     70      M
3  38    160     65      M
4  52    190     68      F
```

data frames

Often data come in a form of a spreadsheet. To read this into R, first save the data as a CSV file, for example *inData.csv*.

To load such a file, use **`read.csv()`** function:

```
> data1 <- read.csv(file="inData.csv", header=TRUE, sep=",")
> data1

  Age Weight Height Gender
1  18    150     67      F
2  23    170     70      M
3  38    160     65      M
4  52    190     68      F
```

data frames

The contents of the text file can be displayed using **file.show()** function.

```
> file.show("inData.csv")

Age,Weight,Height,Gender
18,150,67,F
23,170,70,M
38,160,65,M
52,190,68,F
```

data frames

To explore the data frame:

```
> # get column names
> names(data1)
  [1] "Age"    "Weight"   "Height"   "Gender"

> # get row names (sometimes each row is given some name)
> row.names(data1)
  [1] "1" "2" "3" "4"

> # to set the rows the names use row.names function
> row.names(data1) <- c("Mary", "Paul", "Bob", "Judy")

> data1

     Age Weight Height Gender
Mary  18    150     67      F
Paul  23    170     70      M
Bob   38    160     65      M
Judy  52    190     68      F
```

data frames

To access the data in the data frame:

```
> # access a single column
> data1$Height
 or
> data1[,3]
 or
> data1[, "Height"]
 or
> data1[[3]]        # access the object that is stored in the third list element

   [1] 67 70 65 68
```

data frames

Very convenient function to analyze the data set - **`summary()`** :

```
> summary(data1)
      Age             Weight          Height      Gender
 Min.   :18.00   Min.   :150.0   Min.   :65.0   F:2
 1st Qu.:21.75   1st Qu.:157.5   1st Qu.:66.5   M:2
 Median :30.50   Median :165.0   Median :67.5
 Mean   :32.75   Mean   :167.5   Mean   :67.5
 3rd Qu.:41.50   3rd Qu.:175.0   3rd Qu.:68.5
 Max.   :52.00   Max.   :190.0   Max.   :70.0
```

lists

List: a collection of data objects (possibly of different types) – a generalization of a vector.

```
4,    TRUE ,   "John",    7,    FALSE,    "Mary"
```

lists

A **List** is a generalized version of a vector. It is similar to ***struct*** in C.

```
> # create an empty list
> li <- list()

> li0 <- list("Alex", 120,  72, T)
> li0
[[1]]
[1] "Alex"

[[2]]
[1] 120

[[3]]
[1] 72

[[4]]
[1] TRUE
```

** Notice double brackets to access each element of the list*

lists

We can also give names to each element, i.e.:

```
> # create a list that stores data along with their names:
> li <- list(name = "Alex", weight = 120, height = 72, student = TRUE)
> li
 $name
[1] "Alex"

$weight
[1] 120

$height
[1] 72

$student
[1] TRUE
```

lists

We can access elements in the list using the indices or their names:

```
> # access using names
> li$name
[1] "Alex"

> # the name of the element can be abbreviated as long as it does not cause ambiguity:
> li$na
[1] "Alex"

> # access using the index (notice – double brackets !)
> li[[2]]
[1] 120
```

lists

We can add more elements after the list has been created

```
> li$year <- "freshman"

> # check if the element got into the list:
> li
 $name
[1] "Alex"

$weight
[1] 120

$height
[1] 72

$student
[1] TRUE

$year
[1] "freshman"
```

lists

Elements can be added using indices:

```
> li[[6]] <- 3.75

> li[7:8] <- c(TRUE, FALSE)
```

lists

Delete elements from the list, assigning NULL:

```
> li$year <- NULL

> li[[6]] <- NULL

> # check the length of the list
> length(li)
[1] 6
```

Online Resources

Online Books:

"An introduction to R. Notes on R: A Programming Environment for Data Analysis and Graphics", by W. N. Venables, etc.

"Using R for Introductory Statistics ", by John Verzani.

"R for Beginners", by Emmanuel Paradis.

"The R Guide", W. J. Owen.

"Using R for Data Analysis and Graphics. Introduction, Code and Commentary", by J. H. Maindonald.

Official CRAN R language manuals:

http://cran.r-project.org/manuals.html

Free Online Courses & Code Examples:

http://www.codeschool.com/courses/try-r by Code School

http://www.ats.ucla.edu/stat/ Institute for Digital Research and Education

Many MOOCs courses!

This tutorial has been made possible by
Scientific Computing and Visualization
group
at Boston University.

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http://www.bu.edu/tech/research/training/tutorials/list/