Introduction to Computing for Economics and Management

Lecture 2: Introduction to R, variables, vectors

Previous Lecture: Assistants

Teaching Assistants

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Previous Lecture: Assistants

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Previous Lecture: What are the Course Objectives ?

- Learn basic concepts of programming

- Course topics include
  - Introduction into basic data structures (vector, matrix, lists, etc.)
  - Program control statements (conditional execution, loops, etc.)
  - Data visualization (scatter plots, histograms, etc.)
  - Input and Output (import internet data, export graphics, etc.)

- We use the free R programming language and environment for statistical computing and graphics which is available for Windows, MacOS and Linux

How can we achieve the course objectives ?

- No rush!

- Lecture: Stop me, ask questions, try to answer my questions.
- Problem Session: Repeat the lecture with examples.
- Lab Session: Hands-on experience!

How can we achieve the course objectives ?

Attend the lecture every Wednesday 13:00 – 15:00,

- Room NH405

- Attend the 1 hour Problem Session directly after the lecture in NH405
  - Problem session starts this week, Wednesday 28th of September

- **Use R and practice at home every week**

- Attend the Lab Session
  - CMPE140.01: Friday 13:00 - 15:00, CMPE Building, Room B4
  - CMPE140.02: Friday 15:00 - 17:00, CMPE Building, Room B4

Attendance check

- We provide for each student a one-time code
  - at each lecture
  - at each lab session
  - at each problem session

- Each student has to submit the Student ID together with the one-time code

- Only submissions on the day of lecture/lab are valid

Submission page: http://goo.gl/kGFkPj

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Submission pag .gl/kGFkF

Grading

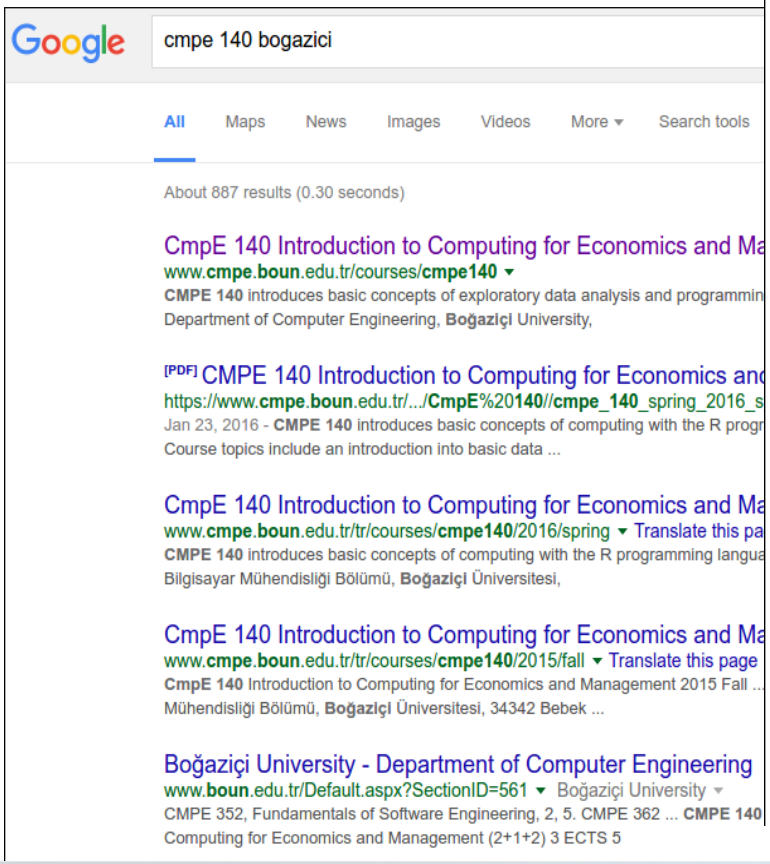
Scores	
Lecture and problem session attendance	10 %
Lab session (quiz)	30 %
Midterm	25 %
Final	45 %

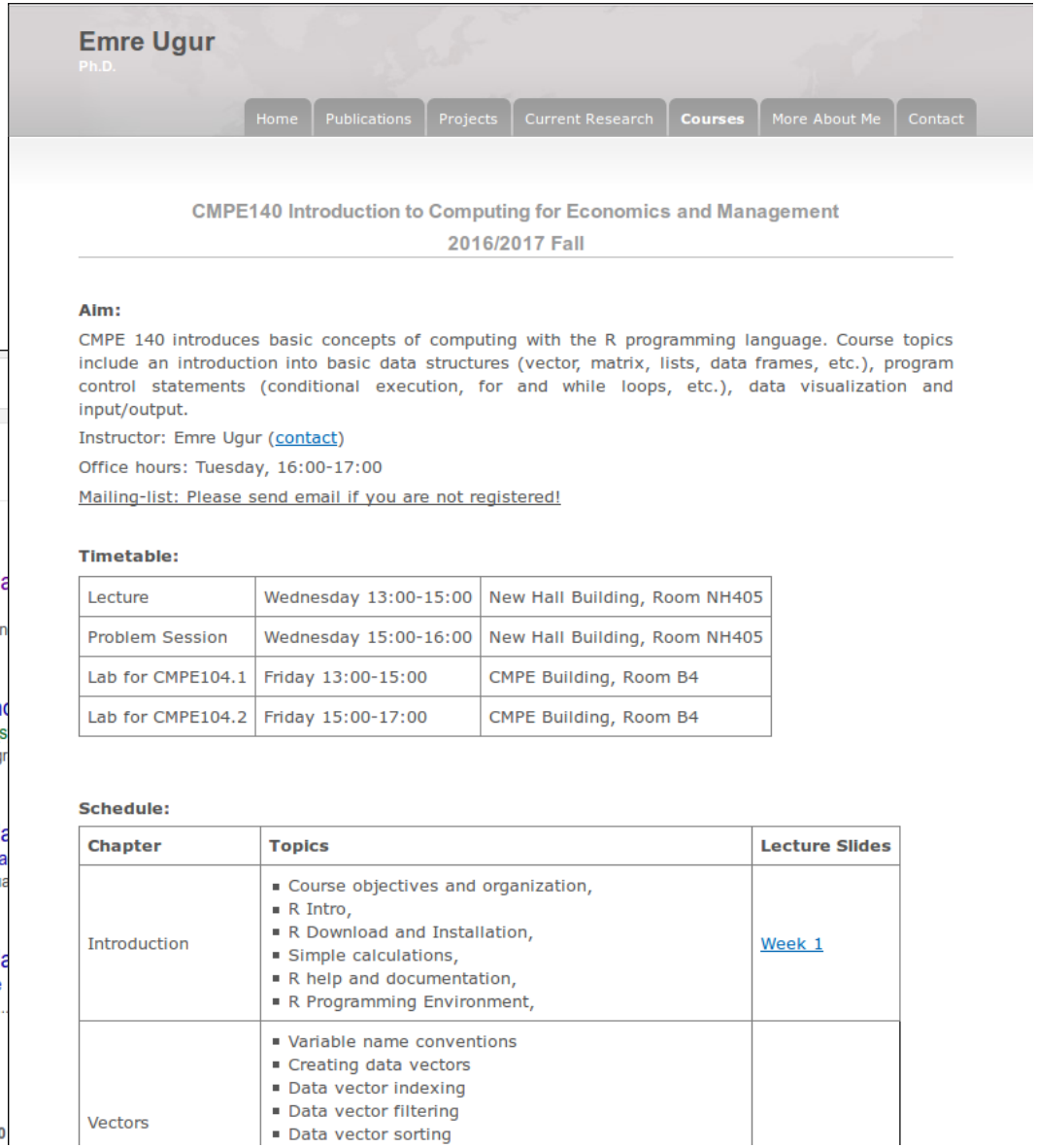
- Attend to your own section in Lab sessions!
  - Automatic grading

- Midterm (21st Oct) and Final:
  - Multiple-choice
- Quizes:
  - Multiple choice (and programming)

Course Material – Web page

- The material is adapted from Bert Arnrich's slides.
- You find all course material on my lecture page:
- www.cmpe.boun.edu.tr/~emre/courses/CMPE140/





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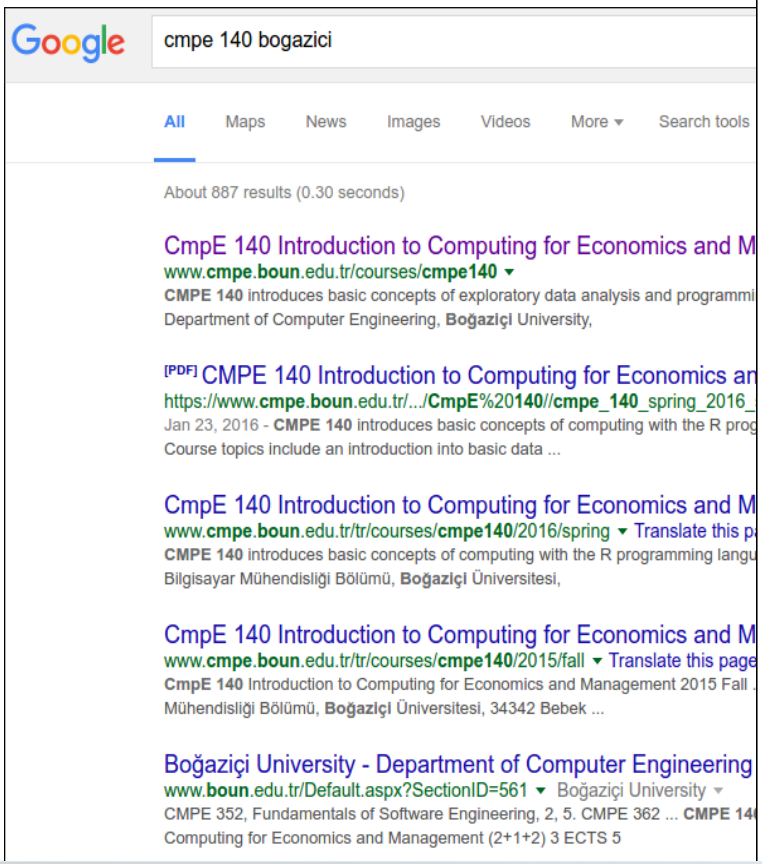
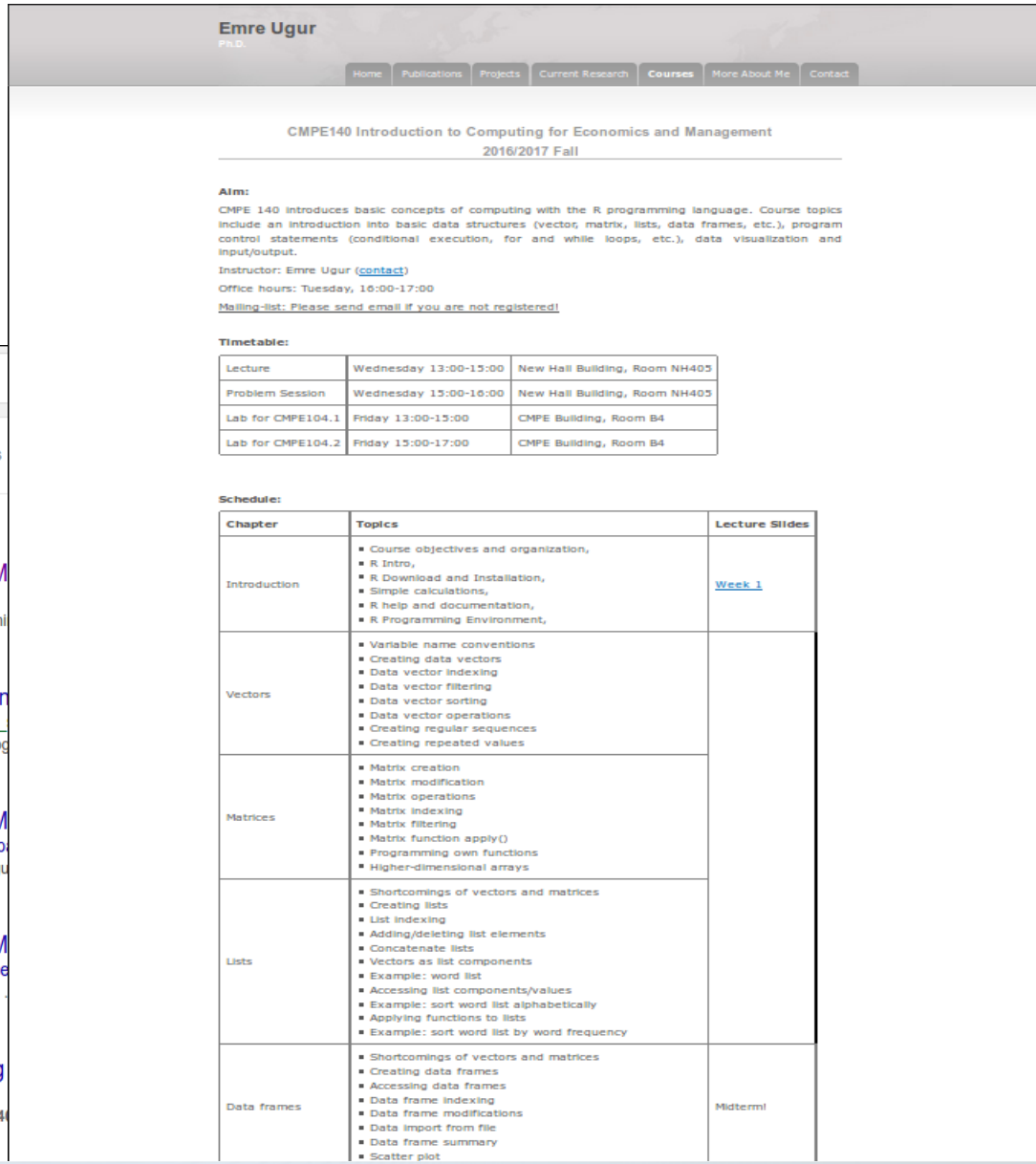


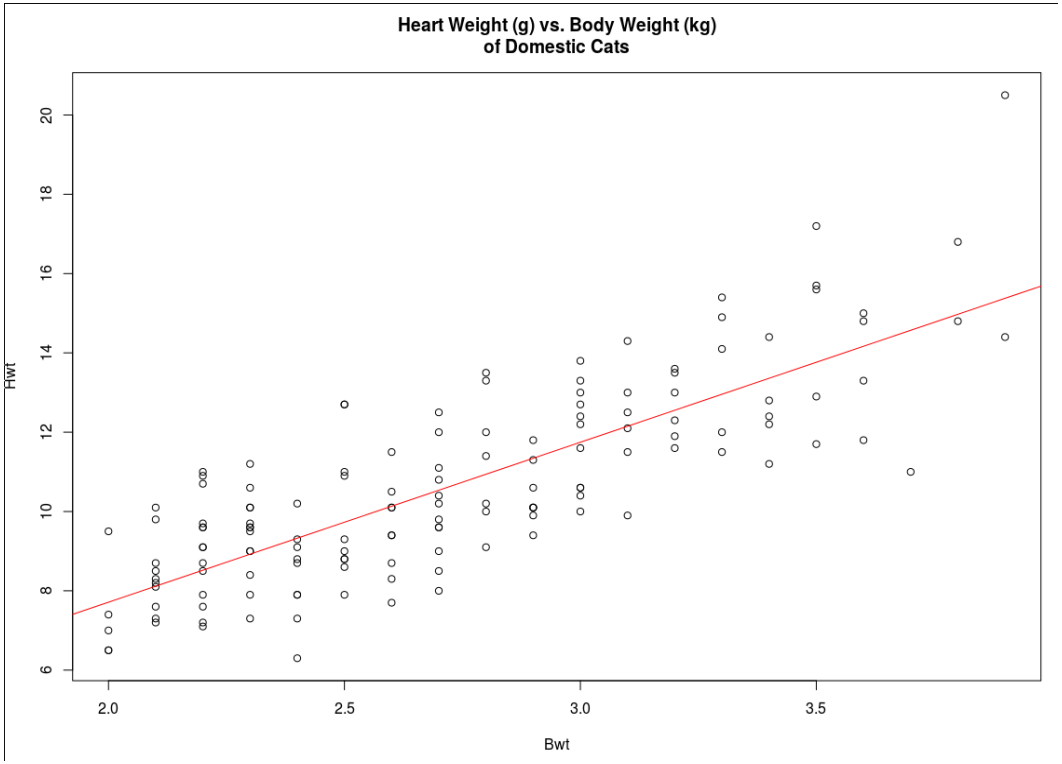


Course Material – Mailing list

- All off-line communication through mailing list
- cmpe140@listeci.cmpe.boun.edu.tr
  - All registered students are registered to the mailing-list with their emails in the boun registration system.
- If you have not received this email, let me know!

Some cool stuff for modelling and prediction

```
library("MASS")
data(cats)
with(cats, plot(Bwt, Hwt))
title(main="Heart Weight (g) vs. Body Weight (kg)\nof Domestic Cats")
lm.out = lm(Hwt ~ Bwt, data=cats)
abline(lm.out, col="red")
```

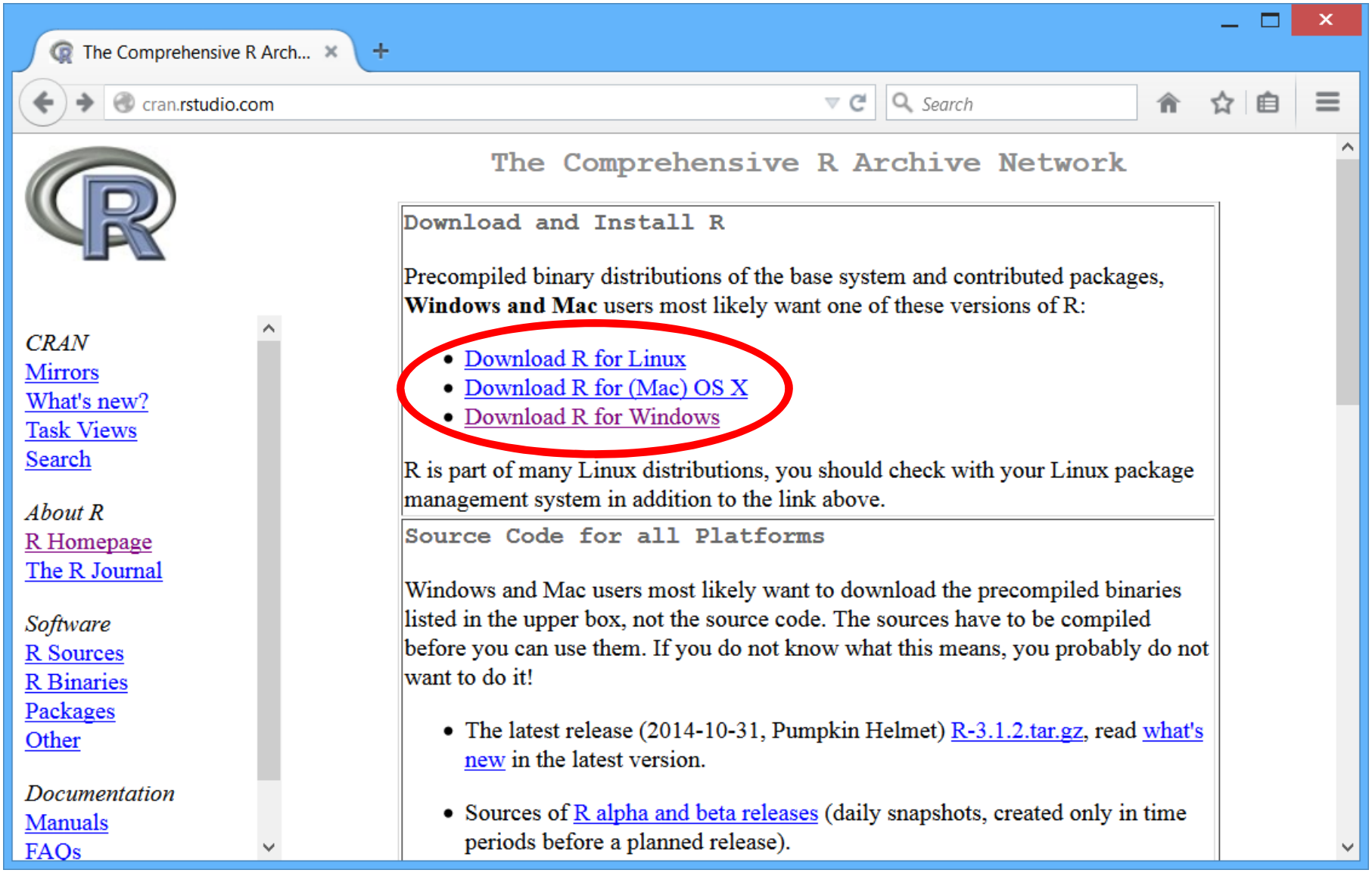


Some cool stuff for visualization

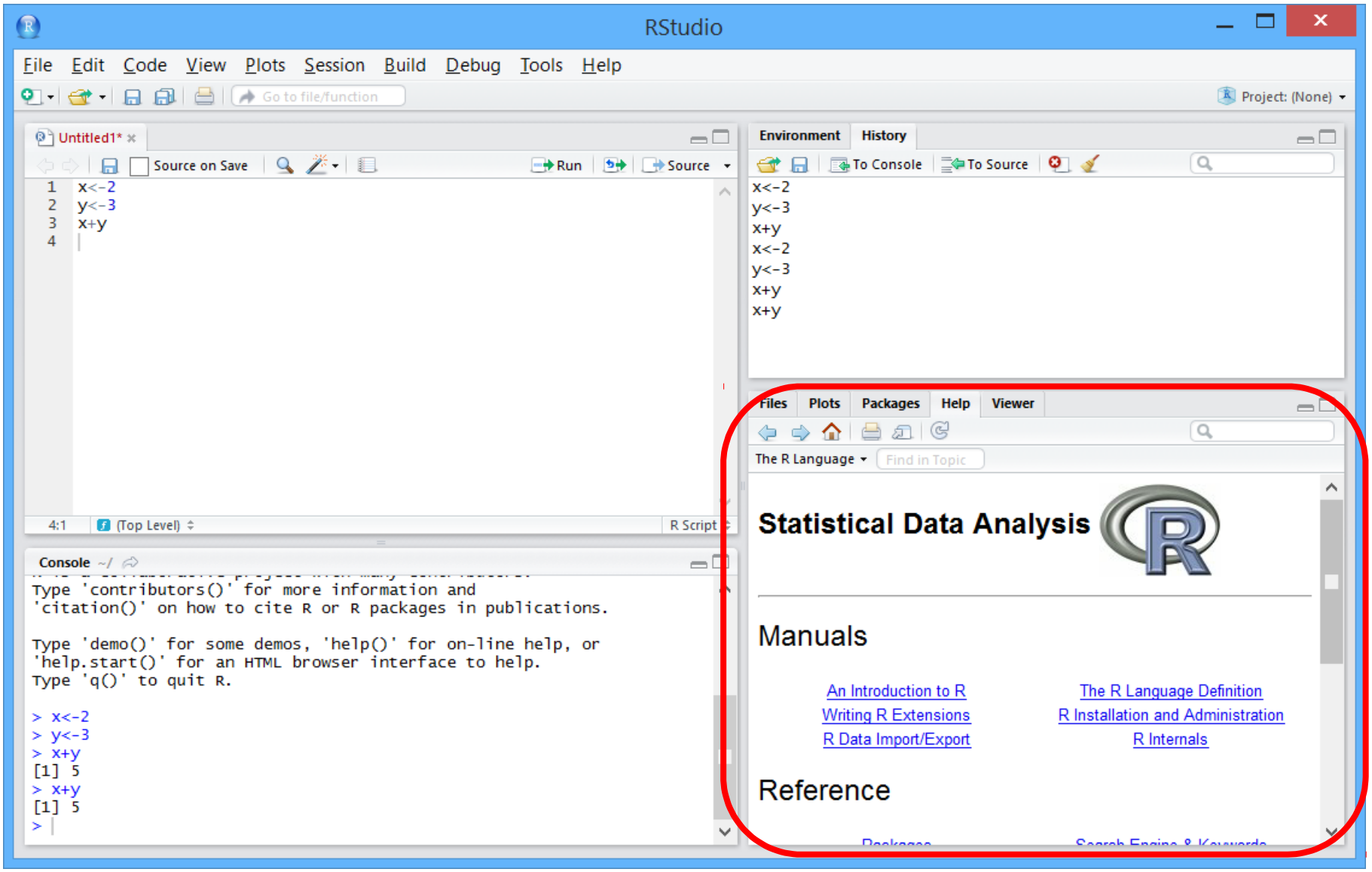
- Stock Analysis using R
- http://www.r-chart.com/2010/06/stock-analysis-using-r.html
- Want to do some quick, in depth technical analysis of Apple stock price using R? There is a package for that!

```
library('quantmod')
getSymbols("AAPL")
chartSeries(AAPL, subset='last 3
months')
addBBands()
```

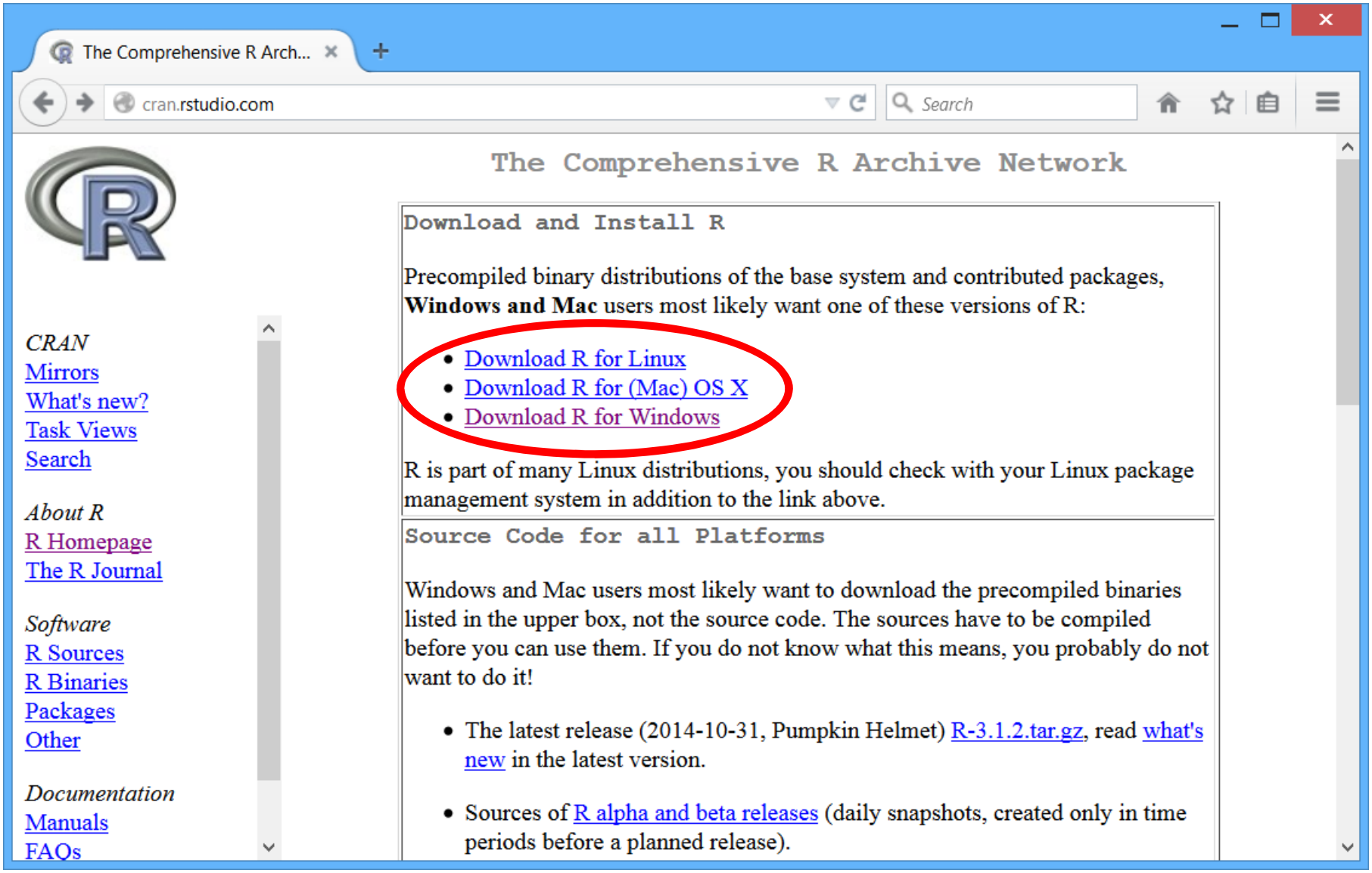
Previous lecture: R download and installation



Previous lecture: RStudio



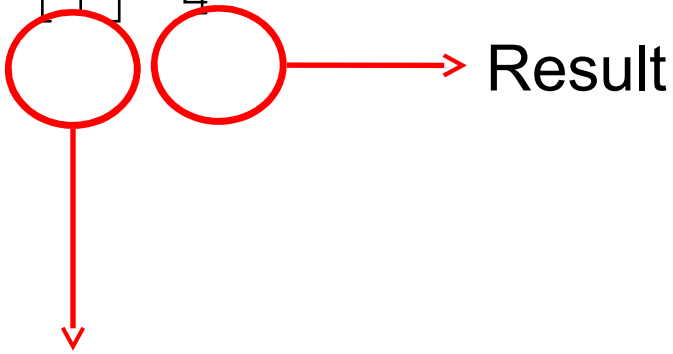
Previous lecture: R download and installation



Previous lecture: Interactive R session

Enter an arithmetic expression and receive a result

```
> 2 + 2
[1] 4

> 2 + 2
[1] 4
```



Index of the first number on a result line: we will see later that the index is helpful when we receive more than a single result

Previous lecture: Interactive R session

Do some standard calculations

```
> sqrt(4)
[1] 2

> exp(-2)
[1] 0.1353353

> cos(pi)
[1] -1

> 2 < 4
[1] TRUE
```

Data types:
- numerical
- character
- logical

Previous lecture: Interactive R session

Assign a value to the objects x and y by using the assignment operator <-

```
> x <- 2
> y <- 3
```

Not assignment if space introduced in between <-

```
> y < -3
```

Check the values of both objects

```
> x
[1] 2

> y
[1] 3
```

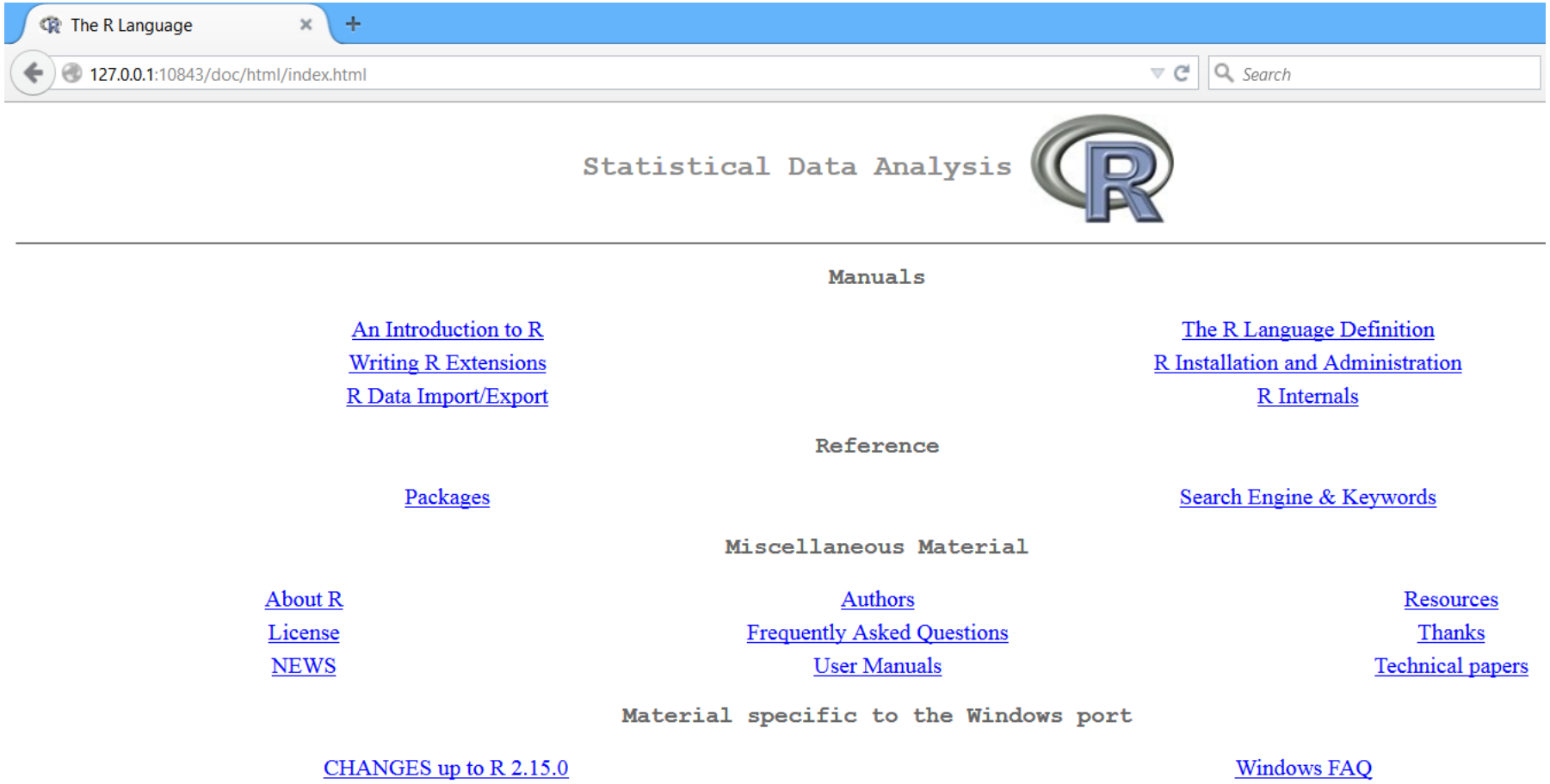
Previous lecture: Interactive R session

```
> x+y
[1] 5

> x*y
[1] 6

> x*y+3
[1] 9

> sqrt(x*y)+3
[1] 5.44949
```

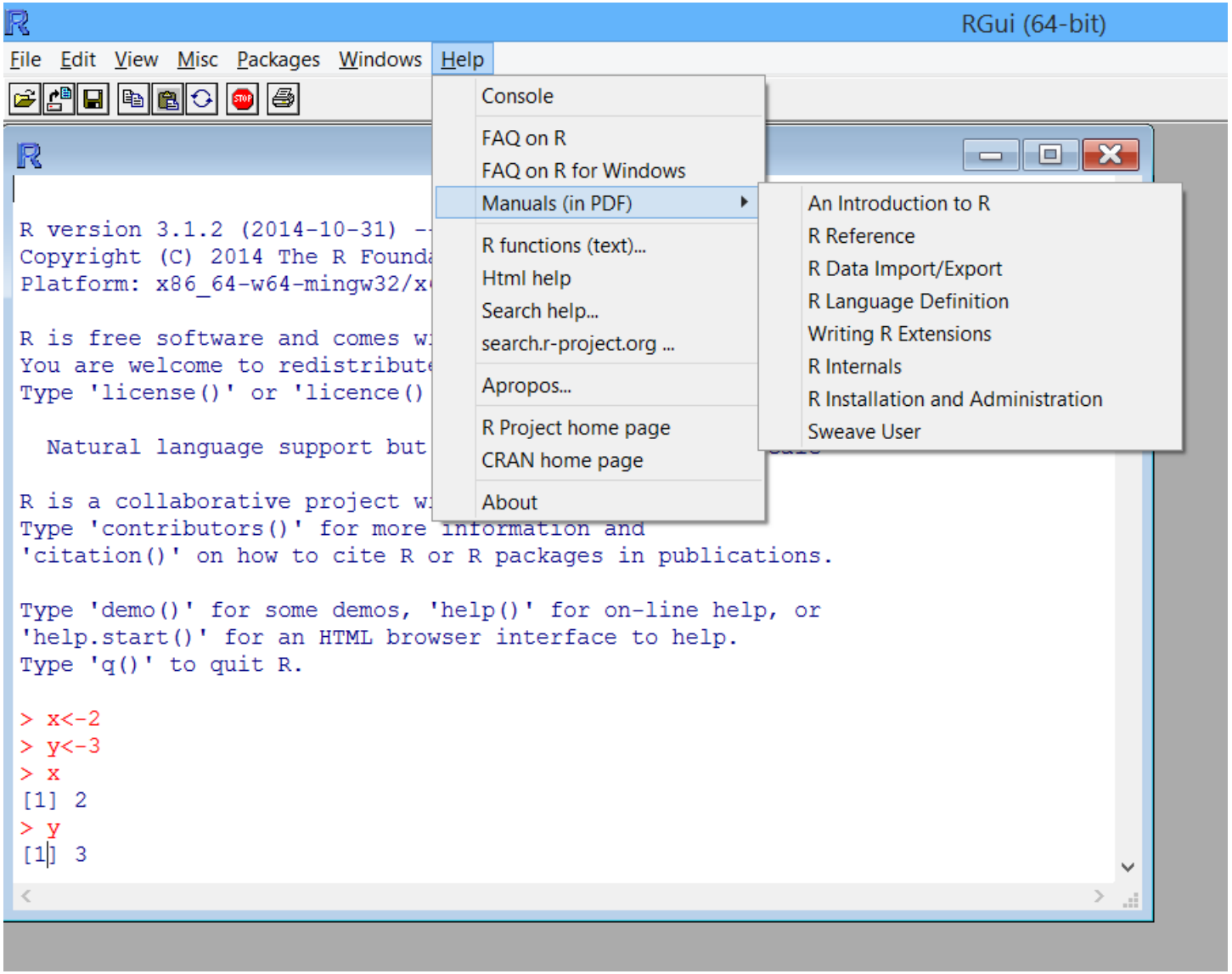
Previous lecture: getting help and documentation

Open a Web browser interface to R help

```
> help.start()
```



Previous lecture: R manuals



Program today

- Name conventions
- Creating data vectors
- Data vector indexing
- Data vector filtering
- Data vector sorting
- Data vector operations
- Creating regular sequences
- Creating repeated values

Name conventions

Object names can contain letters, digits, underscore (_), and the dot symbol (.)

```
> person1.height <- 1.70
> person1.weight <- 65
> bmi.person1 <- person1.weight /
person1.height^2
> bmi.person1
[1] 22.49135

> person2.height <- 1.75
> person2.weight <- 66
> bmi.person2 <- person2.weight /
person2.height^2
> bmi.person2
[1] 21.55102
```

Name conventions

Name must not start with a number

```
> 2a <- 3
```

- `Error: unexpected symbol in "2a"`

Name must not start with a dot followed by a digit

```
> .2x <- 2
Error: unexpected symbol in ".2x"
```

- `> .xy <- 3`

- Since names that start with a dot are special, we should not introduce them in our scripts to avoid confusion

Descriptive names

- Better use descriptive names like `person.height` instead of just `h`
- Descriptive names make scripts easier to read and understand
- With descriptive names we can usually avoid conflicts with names that are already used by the system as we will see soon

Case-sensitivity

Names are case-sensitive, e.g. `x` and `X` do not refer to the same object

```
> x <- 2
> X <- 3

> x + x


> x + X
```

Case-sensitivity

Names are case-sensitive, e.g. `x` and `X` do not refer to the same object

```
> x <- 2
> X <- 3

> x + x
[1] 4

> x + X
[1] 5
```

Names used by R

- Some names are already used by the R system, e.g. `c, q, t, C, D, F, I, T, df, pt`
- You should not use those names for your objects since it will create confusion when other people read your script
- In particular you should avoid the names `F` and `T` since they are the standard abbreviations for `FALSE` and `TRUE` and no longer work as such if you redefine them

Name check

You can check whether an object name is already used by the system when you enter the name in the console

```
> c
function (..., recursive = FALSE)
.Primitive("c")

> my.c
Error: object 'my.c' not found
```

- Whenever you get the message that object is not found, you can understand that the name is not in use

Data vectors

- The fundamental data type in R is the vector
- It is hard to imagine a R session without using vectors
- The objects `x` and `y` that we have seen so far can be considered as one-element vectors

Why we need data vectors

Operating with one-element objects is cumbersome

```
> person1.height <- 1.70
> person1.weight <- 65
> bmi.person1 <- person1.weight /
person1.height^2
> bmi.person1
[1] 22.49135

> person2.height <- 1.75
> person2.weight <- 66
> bmi.person2 <- person2.weight /
person2.height^2
> bmi.person2
[1] 21.55102
```

Data vector creation

- Instead of using a single object for a single data entry, we rather create an array of numbers which we call **data vector**

Data vectors are created with the construct `c`

```
> persons.height <- c(1.70, 1.75, 1.62)
> persons.weight <- c(65, 66, 61)

> persons.height
[1] 1.70 1.75 1.62

> persons.weight
[1] 65 66 61
```

Data vector creation

- With the construct `c` we can also concatenate vectors which is useful when we need to extend an existing vector

For example, we have data form the first two persons and we create a vector from it

```
> person.height <- c(1.70, 1.75)
```

- Now, we extend the vector with data from the third person

```
> person.height <- c(person.height, 1.62)
```

```
> person.height
[1] 1.70 1.75 1.62
```

Data vector modes

- Vector elements must all have the same mode/type

Integer mode

```
> person.weight <- c(65, 66, 61)
```

- Numeric (floating-point number)
- `> person.height <- c(1.70, 1.75, 1.62)`
- Character (string)
- `> person.name <- c("Can", "Cem", "Hande")`

Data vector modes

Logical (Boolean)

- `> person.female <- c(FALSE, FALSE, TRUE)`

Complex

- `> complex.numbers <- c(1+2i, -1+0i)`

- Other

Missing values

- In many datasets, we often have missing data, i.e. observations for which values are missing

- In R we denote a missing value with `NA`

Any vector might contain missing values

```
> person.weight <- c(65, NA, 61)
```

- `> person.name <- c("Can", "Cem", NA)`

Data vector element names

We can assign names to the elements of a data vector to make the vector more readable

```
> person.height <- c(Can=1.70, Cem=1.75,
Hande=1.62)

> person.height
  Can   Cem Hande
 1.70  1.75  1.62

> person.weight <- c(Can=65, Cem=66, Hande=61)

> person.weight
  Can   Cem Hande
   65    66    61
```

Data vector indexing

We can access a single element of a vector by providing the index of the element in square brackets [..]

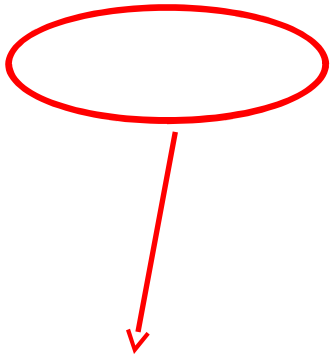
```
> person.height
  Can   Cem Hande
 1.70  1.75  1.62

> person.height[1]
Can
1.7

> person.height[2]
 Cem
 1.75
```

Data vector indexing

- Beside accessing a single element, we can select sub-vectors
- One way to select a subvector is to specify a range and use brackets

Example: select 1st and 2nd element from `person.height`

```
> person.height[1:2]
  Can Cem
 1.70  1.75
```



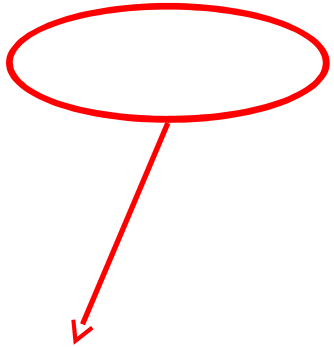
We provide a vector with range in the square brackets for selecting the subvector

Data vector indexing

- Beside accessing a single element, we can select sub-vectors
- One way to select a subvector is to specify `TRUE` for the elements we would like to select and `FALSE` for the others

Example: select 1st and 3rd element from `person.height`

```
> person.height[c(T,F,T)]
   Can  Hande
  1.70   1.62
```



We provide a Boolean index vector in the square brackets for selecting the subvector

Data vector indexing

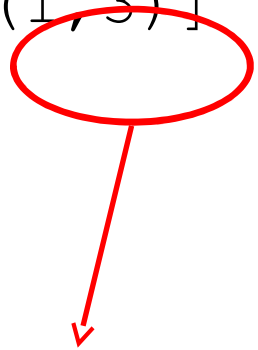
- As alternative to a Boolean index vector, we can specify the element indices directly

- Specifying element indices is more convenient in particular for large vectors

Example: select 1st and 3rd element from `person.height`

```
> person.height[c(1,3)]
  Can Hande
 1.70  1.62
```

-



We provide an index vector in the square brackets for selecting the subvector

Data vector indexing

We can select duplicates as well

```
> person.height[c(1,1,3,2,3)]
   Can    Can Hande    Cem Hande
  1.70   1.70   1.62   1.75   1.62
```

We exclude elements with neg. indices, e.g. exclude 1st entry

```
> person.height[-1]
   Cem Hande
  1.75   1.62
```

Example: exclude first and third element

```
> person.height[c(-1, -3)]
```

Data vector indexing

We can select duplicates as well

```
> person.height[c(1,1,3,2,3)]
   Can    Can Hande    Cem Hande
 1.70   1.70   1.62   1.75   1.62
```

We exclude elements with neg. indices, e.g. exclude 1st entry

```
> person.height[-1]
   Cem Hande
 1.75   1.62
```

Example: exclude first and third element

```
> person.height[c(-1, -3)]
 Cem
1.75
```

Data vector indexing

- We can change the values of the selected elements

Example: change the value of the first element

```
> person.height
   Can    Cem Hande
  1.70   1.75   1.62
```

- >

Data vector indexing

- We can change the values of the selected elements

Example: change the value of the first element

```
> person.height
  Can   Cem Hande
 1.70  1.75  1.62

> person.height[1] <- 1.72

> person.height
  Can   Cem Hande
 1.72  1.75  1.62
```

Data vector indexing

We can use the index notation to insert values in an existing vector

```
> person.height
  Can   Cem Hande
 1.70  1.75  1.62

> person.height <- c(person.height[1:2],
Lale=1.76, person.height[3])

> person.height
```

Data vector indexing

We can use the index notation to insert values in an existing vector

```
> person.height
   Can    Cem Hande
  1.70   1.75   1.62

> person.height <- c(person.height[1:2],
Lale=1.76, person.height[3])

> person.height
   Can    Cem   Lale Hande
  1.70   1.75   1.76   1.62
```

Data vector indexing

We can use the index notation to delete values from an existing vector

```
> person.height
  Can   Cem  Lale Hande
 1.70  1.75  1.76  1.62

> person.height <- person.height[-3]

> person.height
```

Data vector indexing

We can use the index notation to delete values from an existing vector

```
> person.height
  Can   Cem  Lale Hande
 1.70  1.75  1.76  1.62

> person.height <- person.height[-3]

> person.height
  Can   Cem Hande
 1.70  1.75  1.62
```

Data vector filtering

- The idea behind filtering is to first apply a Boolean evaluation function to each element of the vector

- For each single element, the Boolean evaluation function returns `TRUE` in case of a positive evaluation and `FALSE` in case of a negative evaluation

Example: persons taller than 1.65

```
> person.height > 1.65
  Can   Cem Hande
- TRUE  TRUE FALSE
```

Data vector filtering

In a second step, we use the results of the evaluation function for the filtering

```
> person.taller <- person.height > 1.65

> person.taller
  Can   Cem Hande
 TRUE  TRUE FALSE

> person.height[person.taller]
```

Data vector filtering

In a second step, we use the results of the evaluation function for the filtering

```
> person.taller <- person.height > 1.65

> person.taller
  Can   Cem Hande
 TRUE  TRUE FALSE

> person.height[person.taller]
 Can  Cem
1.72 1.75
```

Data vector filtering

We can perform evaluation and filtering in one line

```
> person.height[person.height > 1.65]
 Can  Cem
1.72 1.75
```

We provide the evaluation function directly in the square brackets for selecting the subvector which elements fulfill the evaluation function

```
> X <- person.height > 1.65

> X
  Can   Cem Hande
 TRUE  TRUE FALSE
```

Data vector filtering

- We can use filtering to selectively change those elements of a vector which fulfill the evaluation function

Example: Decrease weight by 1kg of those persons whose weight is larger than 65kg

```
> person.weight[person.weight > 65] <-
person.weight[person.weight > 65] - 1

> person.weight
  Can   Cem Hande
   65    65    61
```

Data vector filtering

Function `which()` returns the indices of those elements that fulfill the evaluation function

```
> person.height
  Can   Cem Hande
 1.72  1.75  1.62

> which(person.height > 1.65)
Can Cem
  1   2
```

Data vector sorting

We use the function `sort` for sorting a vector

```
> sort(person.height)
Hande   Can   Cem
 1.62  1.70  1.75

> sort(person.weight)
Hande   Can   Cem
   61    65    66
```

- `help(sort)` shows us that the sort function has a second parameter `decreasing`
- Since `decreasing = FALSE` is the default value, the default sorting is in ascending order

Data vector sorting

We can obtain a sorting in descending order by specifying `decreasing = TRUE`

```
> sort(person.height, decreasing = TRUE)
  Cem   Can Hande
 1.75  1.70  1.62

> sort(person.weight, decreasing = TRUE)
  Cem   Can Hande
   66    65    61
```

Data vector sorting

- Often we need to sort a vector according to the values of some other vector

We first compute an ordering

```
> person.height
   Can    Cem Hande
  1.70   1.75   1.62
```

- `> order(person.height)`

- As a result of the ordering we achieve the index positions in the right order: person 3 is first, person 1 is second, person 2 is third

Data vector sorting

- Often we need to sort a vector according to the values of some other vector

We first compute an ordering

```
> person.height
  Can   Cem Hande
 1.70  1.75  1.62

> order(person.height)
[1] 3 1 2
```

- As a result of the ordering we achieve the index positions in the right order: person 3 is first, person 1 is second, person 2 is third

Data vector sorting

We can use the resulting sorted index for sorting some other vector

```
> person.weight[order(person.height)]
Hande   Can   Cem
   61    65    66
```

- `person.weight` was sorted according to the order of `person.height`

Vector recycling

- When applying an operation to two vectors which requires them to be the same length, the shorter one will repeated until it is long enough to match the longer one

- This automatic lengthening of vectors is called recycling

Example: vector addition

```
> c(1, 2, 3) + c(1, 2, 3, 4)
```

- `[1] 2 4 6 5`

The shorter vector was automatically “recycled” to be as

```
> c(1, 2, 3, 1) + c(1, 2, 3, 4)
```

- `[1] 2 4 6 5`

Vector recycling

We usually get a warning message in case an automatic recycling appears

```
> c(1, 2, 3) + c(1, 2, 3, 4)
[1] 2 4 6 5

Warning message:
In c(1, 2, 3) + c(1, 2, 3, 4) :
  longer object length is not a multiple of shorter object length
```

Conditional element selection with the ifelse() function

- We provide the `ifelse(test, yes, no)` function with a Boolean vector `test` and two vectors `yes` and `no`

- `ifelse` returns a vector which is created from selected elements from the vectors `yes` and `no`: `yes[i]` is selected if `test[i]` is true and `no[i]` is selected if `test[i]` is false

Example (which uses recycling):

```
> ifelse(person.height > 1.7, "tall", "small")
    Can      Cem   Hande
- "small"  "tall" "small"
```

Conditional element selection with the ifelse() function

- If we need more than the two alternatives `yes` and `no` we can replace `yes` or `no` with another `ifelse()` function

Example: create three height groups small, tall and huge

- `> ifelse(?)`

```
    Can      Cem    Hande
 "tall"   "huge" "small"
```

Conditional element selection with the ifelse() function

- If we need more than the two alternatives `yes` and `no` we can replace `yes` or `no` with another `ifelse()` function

Example: create three height groups small, tall and huge

```
> ifelse(person.height > 1.7, "huge",
ifelse(person.height > 1.65, "tall", "small"))
    Can     Cem   Hande
 "tall"  "huge" "small"
```

Data vector operations

Single element operation possible but rarely used in practice

```
> person.weight[1] / person.height[1]^2
     Can
21.97134

> person.weight[2] / person.height[2]^2
     Cem
21.55102

> person.weight[3] / person.height[3]^2
    Hande
23.24341
```

Data vector operations

- We can perform calculations with vectors just like ordinary numbers

Element wise operations

```
> person.height^2
   Can     Cem   Hande
```

- `2.9584 3.0625 2.6244`

Vector addition, e.g. persons have gained/lost weight

```
> person.weight + c(1.5, 1.75, -0.5)
  Can   Cem Hande
```

- `66.50 67.75 60.50`

Data vector operations

Operations on multiple vectors

```
> person.weight / person.height^2
     Can       Cem     Hande
21.97134 21.55102 23.24341
```

The result of a vector calculation can be assigned to a new data vector for further processing

```
> bmi <- person.weight / person.height^2

> bmi
     Can       Cem     Hande
21.97134 21.55102 23.24341
```

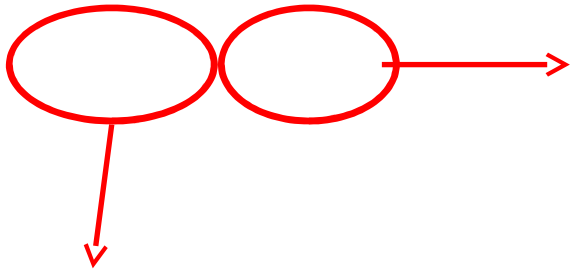
Data vector operations

- R has many built-in functions that operate on vectors

For example, we would like to `round` the resulting BMI values

```
> round(bmi)
  Can   Cem Hande
   22    22    23
```

- `> round(bmi)`



Arguments of the function are provided in parentheses

R function round

Rounding of numbers

- The help page `help(round)` shows us more options and ways how to round numeric values

`round` has an additional option `digits` to indicate the number of decimal places to be used when rounding

```
> round(bmi, digits=1)
  Can   Cem Hande
 22.0  21.6  23.2

> round(bmi, digits=2)
  Can   Cem Hande
21.97 21.55 23.24
```

Rounding of numbers

`ceiling` returns a numeric vector containing the smallest integers not less than the corresponding elements of the input vector

```
> bmi
     Can       Cem     Hande
21.97134 21.55102 23.24341

> ceiling(bmi)
  Can   Cem Hande
   22    22    24
```

Rounding of numbers

`floor` returns a numeric vector containing the largest integers not greater than the corresponding elements of the input vector

```
> bmi
     Can       Cem     Hande
21.97134 21.55102 23.24341

> floor(bmi)
  Can   Cem Hande
   21    21    23
```

Rounding of numbers

`trunc` returns a numeric vector containing the integers formed by truncating the values in the input vector toward 0

```
> bmi
     Can       Cem     Hande
21.97134 21.55102 23.24341

> trunc(bmi)
  Can   Cem Hande
   21    21    23
```

Lecture 2 finished here

Rounding of numbers

`signif` rounds the values of the input vector to the specified number of significant digits

```
> signif(bmi, digits=1)
  Can   Cem Hande
   20    20    20

> signif(bmi, digits=2)
  Can   Cem Hande
   22    22    23

> signif(bmi, digits=3)
  Can   Cem Hande
 22.0  21.6  23.2
```