

Lecture 1 Introduction and Basics

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What are we trying to accomplish?

The sample analysis was shown only in class and is not viewable in this version of the notes.

Agenda

- ▶ Course overview
- ▶ Introduction to R, RStudio and R Markdown
- ▶ Programming basics

How this class will work

- ▶ No programming knowledge presumed
- ▶ Some stats knowledge presumed. E.g.:
 - ▶ Hypothesis testing (t-tests, confidence intervals)
 - ▶ Linear regression
- ▶ Synchronous attendance is encouraged, but not required
- ▶ Class will be very cumulative

Mechanics

- ▶ Two 80 minute lectures a week:
 - ▶ First 60-70 minutes: concepts, methods, examples
 - ▶ Last 10-20 minutes: short labs
- ▶ Class participation (10%)
- ▶ Quizzes (10%)
- ▶ Weekly homework (40%)
- ▶ Final project (2.5 weeks) (40%)
 - ▶ **Disclaimer:** To pass the class, you must achieve a passing score on the final project (at least 21 / 40)

Mechanics

- ▶ **Class participation (10%)**
 - ▶ **Labs:** Each lecture has an accompanying lab assignment.
 - ▶ Course website shows how participation grade will be calculated
- ▶ **Quizzes (10%)**
 - ▶ 4 quizzes in the second half of term. Dates TBA.
- ▶ **Homework assignments (40%)**
 - ▶ There will be 5 weekly HW assignments
 - ▶ Single *lowest* HW score will be dropped
 - ▶ HW assigned on Wednesdays, **due Wednesdays at 1:30PM ET**
 - ▶ Late homework **will not be accepted for credit**
- ▶ **Final project (40%)**
 - ▶ You will write a report analysing a policy question using a publicly available data set

Course resources

- ▶ Assignments, office hours, class notes, grading policies, useful references on R:
<http://www.andrew.cmu.edu/~achoulde/94842/>
- ▶ Canvas for **gradebook** and for **turning in homework**
- ▶ Piazza for **discussion forum** (embedded in Canvas)
 - ▶ Please **post class/homework related question on Piazza** instead of emailing the teaching staff
- ▶ Check the class website for everything else
- ▶ No required textbook, but I highly recommend:
 - ▶ Garrett Grolemond and Hadley Wickham, R for Data Science

Goal of this class

This class will teach you to use R to:

- ▶ Generate graphical and tabular data summaries
- ▶ Efficiently manipulate data using **tidyverse** libraries
- ▶ Perform statistical analyses (e.g., hypothesis testing, regression modeling)
- ▶ Produce *reproducible* statistical reports using R Markdown
- ▶ Near the end of class we'll also preview how to integrate R with other tools (e.g., databases, web, etc.)

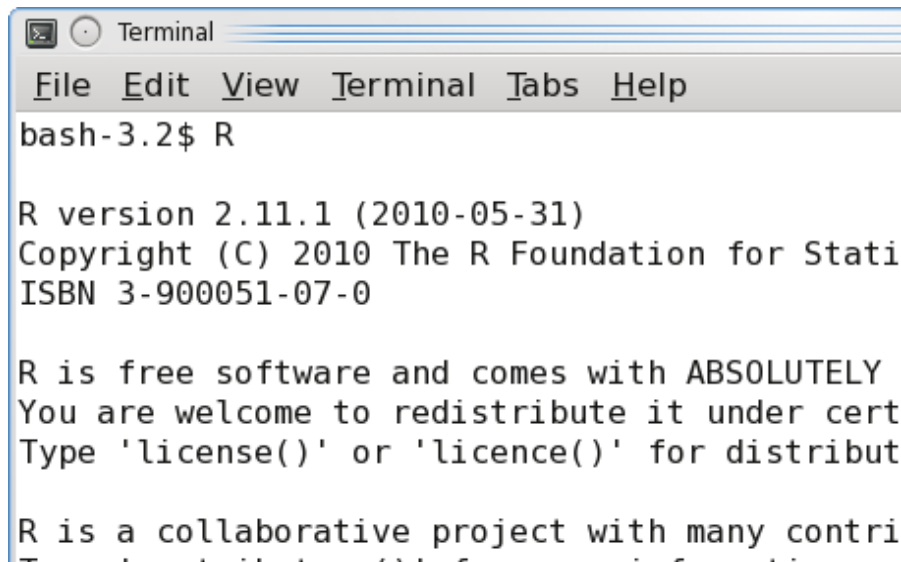
Why R?

- ▶ Free (open-source)
- ▶ Programming language (not point-and-click)
- ▶ Excellent graphics
- ▶ Offers broadest range of statistical tools
- ▶ Easy to generate reproducible reports
- ▶ Easy to integrate with other tools

The R Console

Basic interaction with R is through typing in the **console**

This is the **terminal** or **command-line** interface



```
bash-3.2$ R

R version 2.11.1 (2010-05-31)
Copyright (C) 2010 The R Foundation for Statistical Computing
ISBN 3-900051-07-0

R is free software and comes with ABSOLUTELY NO WARRANTY.
You are welcome to redistribute it under certain conditions.
Type 'license()' or 'licence()' for distribution details.

R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' for how to cite R in publications.
Type 'demo()' for some demos in a terminal window.
Type 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.
```

The R Console

- ▶ You type in commands, R gives back answers (or errors)
 - ▶ Menus and other graphical interfaces are extras built on top of the console
 - ▶ We will use **RStudio** in this class
1. Download R: <http://lib.stat.cmu.edu/R/CRAN>
 2. Then download RStudio: <http://www.rstudio.com/>

RStudio is an IDE for R

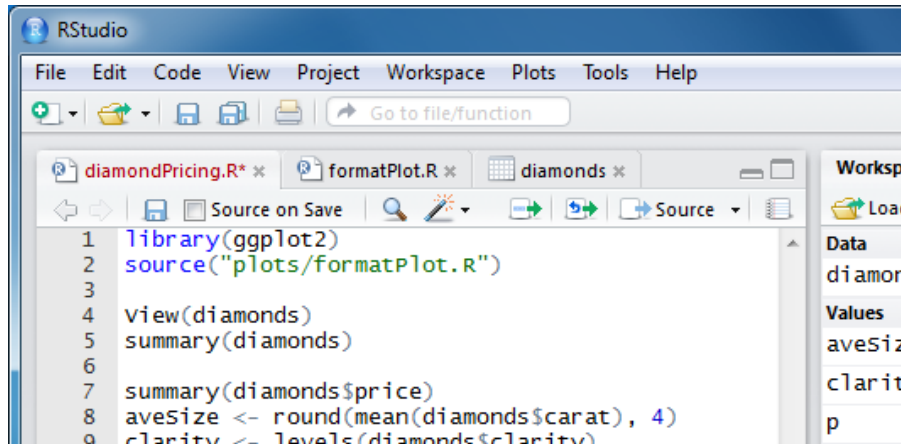
RStudio has 4 main windows ('panes'):

- ▶ Source
- ▶ Console
- ▶ Workspace/History
- ▶ Files/Plots/Packages/Help

RStudio is an IDE for R

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RStudio: Panes overview

1. **Source** pane: create a file that you can save and run later
2. **Console** pane: type or paste in commands to get output from R
3. **Workspace/History** pane: see a list of variables or previous commands
4. **Files/Plots/Packages/Help** pane: see plots, help pages, and other items in this window.

Console pane

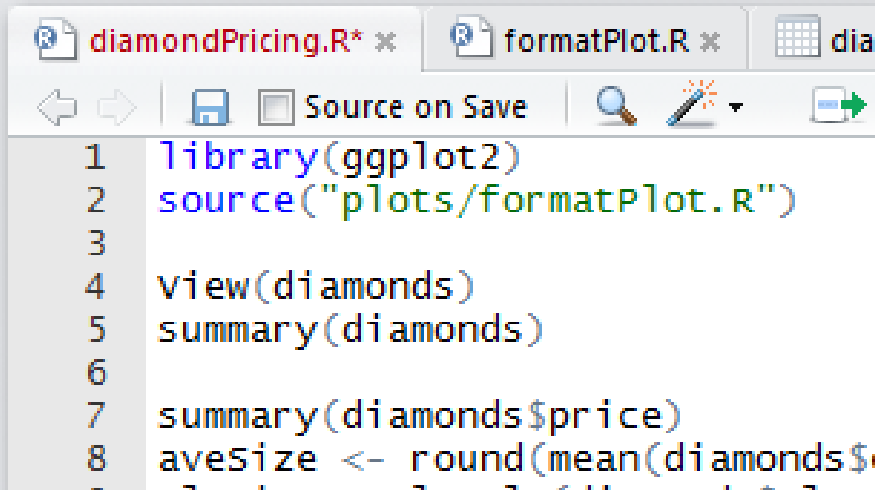
- ▶ Use the **Console** pane to type or paste commands to get output from R
- ▶ To look up the help file for a function or data set, type `?function` into the Console
 - ▶ E.g., try typing in `?mean`
- ▶ Use the tab key to auto-complete function and object names

Console ~/ 

	x		y
Min.	: 0.000	Min.	: 0.000
1st Qu.	: 4.710	1st Qu.	: 4.720
Median	: 5.700	Median	: 5.710
Mean	: 5.731	Mean	: 5.735
3rd Qu.	: 6.540	3rd Qu.	: 6.540

Source pane

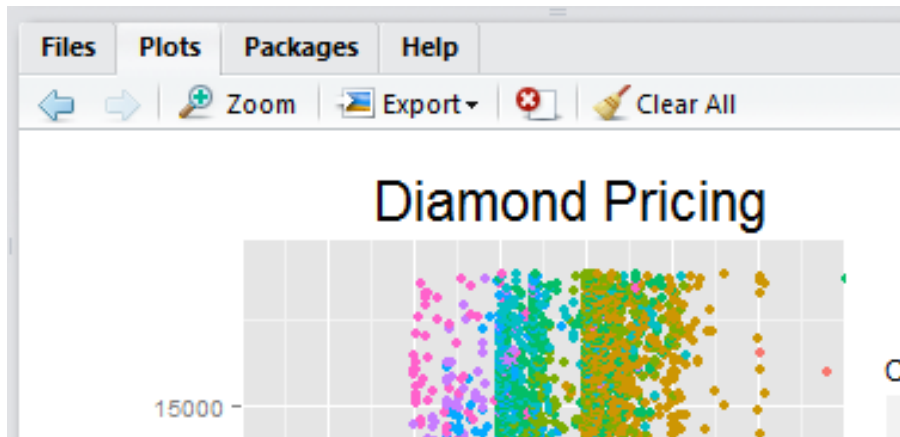
- ▶ Use the **Source** pane to create and edit R and Rmd files
- ▶ The menu bar of this pane contains handy shortcuts for sending code to the **Console** for evaluation



```
1 library(ggplot2)
2 source("plots/formatPlot.R")
3
4 view(diamonds)
5 summary(diamonds)
6
7 summary(diamonds$price)
8 aveSize <- round(mean(diamonds$price), 2)
```


Files/Plots/Packages/Help pane

- ▶ By default, any figures you produce in R will be displayed in the **Plots** tab
 - ▶ Menu bar allows you to Zoom, Export, and Navigate back to older plots
- ▶ When you request a help file (e.g., ?mean), the documentation will appear in the **Help** tab



RStudio: Source and Console panes

Source window: Create a file here, so that you can save and run it later (or turn in as homework)

Any non-command line
should start with a #



```
1 #  
2 # David Choi  
3 # HW 1  
4 #  
5  
6 # Here are the  
7 x = sqrt(5)  
8 y = sqrt(2)  
9 z = x + y  
10 z  
11
```

Console: Type or paste

Variables

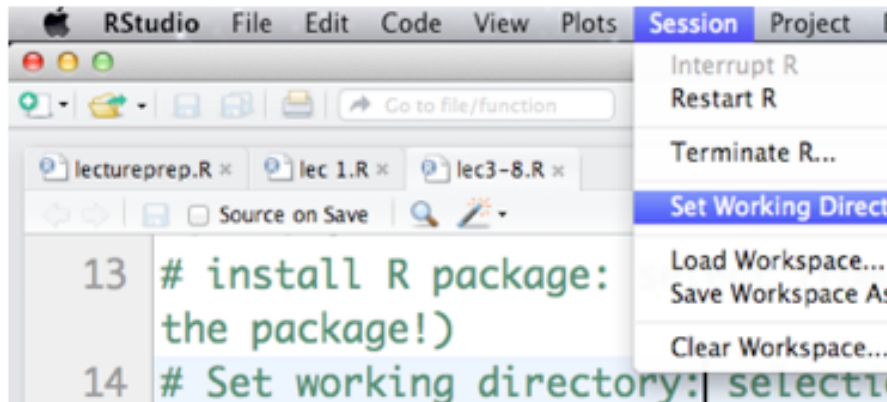
- Save the results of a command in memory by **giving it a name:**

`z` uses `x` and `y`: _____

Values are not linked;

Two helpful menu

- Set the current directory:

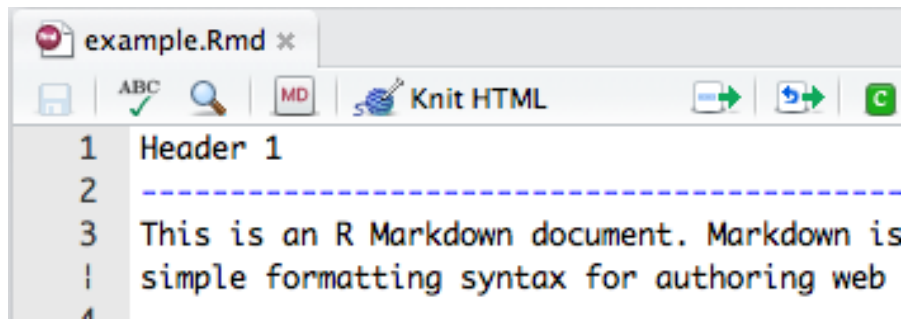


R Markdown

- ▶ R Markdown allows the user to integrate R code into a report
- ▶ When data changes or code changes, so does the report
- ▶ No more need to copy-and-paste graphics, tables, or numbers
- ▶ Creates **reproducible** reports
 - ▶ Anyone who has your R Markdown (.Rmd) file and input data can re-run your analysis and get the exact same results (tables, figures, summaries)
- ▶ Can output report in HTML (default), Microsoft Word, or PDF

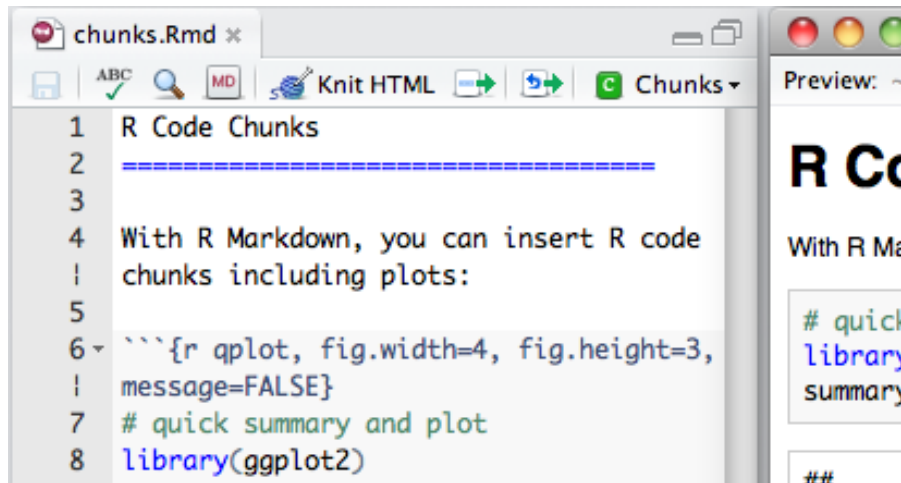
R Markdown

- ▶ This example shows an **R Markdown** (.Rmd) file opened in the Source pane of RStudio.
- ▶ To turn an Rmd file into a report, click the **Knit HTML** button in the Source pane menu bar
- ▶ The results will appear in a **Preview window**, as shown on the right
- ▶ You can knit into html (default), MS Word, and pdf format
- ▶ These lecture slides are also created in RStudio (using ioslides as the output format)



R Markdown

- ▶ To integrate R output into your report, you need to use R code chunks
- ▶ All of the code that appears in between the “triple back-ticks” gets executed when you Knit



The screenshot shows a software interface for editing R Markdown documents. The main window, titled 'chunks.Rmd', contains a code editor with the following text:

```
1 R Code Chunks
2 =====
3
4 With R Markdown, you can insert R code
5 chunks including plots:
6 ```{r qplot, fig.width=4, fig.height=3,
7   message=FALSE}
8 # quick summary and plot
9 library(ggplot2)
```

The interface includes a toolbar with icons for saving, undo, redo, and knitting. A 'Knit HTML' button is visible. To the right, a 'Preview' pane shows a rendered version of the document, displaying the title 'R Code Chunks' and the introductory text, with the R code chunk content visible below.

In-class exercise: Hello world!

1. Open **RStudio** on your machine
2. File > New File > R Markdown ...
3. Change `summary(cars)` in the first code block to `print("Hello world!")`
4. Click Knit HTML to produce an HTML file.
5. Save your Rmd file as `helloworld.Rmd`
All of your Homework assignments and many of your Labs will take the form of a single Rmd file, which you will edit to include your solutions and then submit on Canvas

Basics: the class in a nutshell

- ▶ Everything we'll do comes down to applying **functions** to **data**
- ▶ **Data**: things like 7, "seven", 7.000, the matrix $\begin{bmatrix} 7 & 7 & 7 \\ 7 & 7 & 7 \end{bmatrix}$
- ▶ **Functions**: things like `log`, `+` (two arguments), `<` (two), `mod` (two), `mean` (one)
*A function is a machine which turns input objects (**arguments**) into an output object (**return value**), possibly with **side effects**, according to a definite rule*

Data building blocks

You'll encounter different kinds of data types

- ▶ **Booleans** Direct binary values: TRUE or FALSE in R
- ▶ **Integers**: whole numbers (positive, negative or zero)
- ▶ **Characters** fixed-length blocks of bits, with special coding;
strings = sequences of characters
- ▶ **Floating point numbers**: a fraction (with a finite number of bits) times an exponent, like 1.87×10^6
- ▶ **Missing or ill-defined values**: NA, NaN, etc.

Operators (functions)

You can use R as a very, very fancy calculator

Command	Description
<code>+, -, *, \</code>	add, subtract, multiply, divide
<code>^</code>	raise to the power of
<code>%%</code>	remainder after division (ex: <code>8 %% 3 = 2</code>)
<code>()</code>	change the order of operations
<code>log()</code> , <code>exp()</code>	logarithms and exponents (ex: <code>log(10) = 2.30</code>)
<code>sqrt()</code>	square root
<code>round()</code>	round to the nearest whole number (ex: <code>round(2.30)</code>)
<code>floor()</code> , <code>ceiling()</code>	round down or round up
<code>abs()</code>	absolute value

```
7 + 5 # Addition
```

```
## [1] 12
```

```
7 - 5 # Subtraction
```

```
## [1] 2
```

```
7 * 5 # Multiplication
```

```
## [1] 35
```

```
7 ^ 5 # Exponentiation
```

```
## [1] 16807
```

```
7 / 5 # Division
```

```
## [1] 1.4
```

```
7 %% 5 # Modulus
```

```
## [1] 2
```

```
7 %/% 5 # Integer division
```

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

Operators cont'd.

Comparisons are also binary operators; they take two objects, like numbers, and give a Boolean

```
7 > 5
```

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

```
7 < 5
```

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

```
7 >= 7
```

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

```
7 <= 5
```

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

```
7 == 5
```

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

```
7 != 5
```

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

Boolean operators

Basically “and” and “or”:

```
(5 > 7) & (6*7 == 42)
```

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

```
(5 > 7) | (6*7 == 42)
```

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

(will see special doubled forms, && and ||, later)

More types

- ▶ `typeof()` function returns the type
- ▶ `is.foo()` functions return Booleans for whether the argument is of type *foo*
- ▶ `as.foo()` (tries to) “cast” its argument to type *foo* — to translate it sensibly into a *foo*-type value

Special case: `as.factor()` will be important later for telling R when numbers are actually encodings and not numeric values. (E.g., 1 = High school grad; 2 = College grad; 3 = Postgrad) `##`

```
typeof(7)
```

```
## [1] "double"
```

```
is.numeric(7)
```

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

```
is.na(7)
```

```
is.character(7)
```

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

```
is.character("7")
```

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

```
is.character("seven")
```

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

```
is.na("seven")
```

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

Variables

We can give names to data objects; these give us **variables**

A few variables are built in:

```
pi
```

```
## [1] 3.141593
```

Variables can be arguments to functions or operators, just like constants:

```
pi*10
```

```
## [1] 31.41593
```

```
cos(pi)
```

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

Assignment operator

Most variables are created with the **assignment operator**, <- or =

```
time.factor <- 12  
time.factor
```

```
## [1] 12
```

```
time.in.years = 2.5  
time.in.years * time.factor
```

```
## [1] 30
```

The assignment operator also changes values:

```
time.in.months <- time.in.years * time.factor  
time.in.months
```

```
## [1] 30
```

```
time.in.months <- 45  
time.in.months
```

```
## [1] 45
```

- ▶ Using names and variables makes code: easier to design, easier to debug, less prone to bugs, easier to improve, and easier for others to read
- ▶ Avoid “magic constants”; use named variables
- ▶ Use descriptive variable names
 - ▶ Good: `num.students <- 35`
 - ▶ Bad: `ns <- 35`

The workspace

What names have you defined values for?

```
ls()
```

```
## [1] "time.factor"      "time.in.months" "time.in.years"
```

Getting rid of variables:

```
rm("time.in.months")  
ls()
```

```
## [1] "time.factor"      "time.in.years"
```

First data structure: vectors

- ▶ Group related data values into one object, a **data structure**
- ▶ A **vector** is a sequence of values, all of the same type
- ▶ `c()` function returns a vector containing all its arguments in order

```
students <- c("Sean", "Louisa", "Frank", "Farhad", "Li")  
midterm <- c(80, 90, 93, 82, 95)
```

- ▶ Typing the variable name at the prompt causes it to display

```
students
```

```
## [1] "Sean" "Louisa" "Frank" "Farhad" "Li"
```


Indexing

- ▶ `vec[1]` is the first element, `vec[4]` is the 4th element of `vec`

```
students
```

```
## [1] "Sean" "Louisa" "Frank" "Farhad" "Li"
```

```
students[4]
```

```
## [1] "Farhad"
```

- ▶ `vec[-4]` is a vector containing all but the fourth element

```
students[-4]
```

```
## [1] "Sean" "Louisa" "Frank" "Li"
```

Vector arithmetic

Operators apply to vectors “pairwise” or “elementwise”:

```
final <- c(78, 84, 95, 82, 91) # Final exam scores  
midterm # Midterm exam scores
```

```
## [1] 80 90 93 82 95
```

```
midterm + final # Sum of midterm and final scores
```

```
## [1] 158 174 188 164 186
```

```
(midterm + final)/2 # Average exam score
```

```
## [1] 79 87 94 82 93
```

```
course.grades <- 0.4*midterm + 0.6*final # Final course grades  
course.grades
```

```
## [1] 78.8 86.4 94.2 82.0 92.6
```

Pairwise comparisons

Is the final score higher than the midterm score?

```
midterm
```

```
## [1] 80 90 93 82 95
```

```
final
```

```
## [1] 78 84 95 82 91
```

```
final > midterm
```

```
## [1] FALSE FALSE TRUE FALSE FALSE
```

Boolean operators can be applied elementwise:

```
(final < midterm) & (midterm > 80)
```

```
## [1] FALSE TRUE FALSE FALSE TRUE
```

Functions on vectors

Command	Description
<code>sum(vec)</code>	sums up all the elements of <code>vec</code>
<code>mean(vec)</code>	mean of <code>vec</code>
<code>median(vec)</code>	median of <code>vec</code>
<code>min(vec), max(vec)</code>	the largest or smallest element of <code>vec</code>
<code>sd(vec), var(vec)</code>	the standard deviation and variance of <code>vec</code>
<code>length(vec)</code>	the number of elements in <code>vec</code>
<code>pmax(vec1, vec2), pmin(vec1, vec2)</code>	example: <code>pmax(quiz1, quiz2)</code> returns the higher of quiz 1 and quiz 2 for each student
<code>sort(vec)</code>	returns the <code>vec</code> in sorted order
<code>order(vec)</code>	returns the index that sorts the vector <code>vec</code>
<code>unique(vec)</code>	lists the unique elements of <code>vec</code>
<code>summary(vec)</code>	gives a five-number summary
<code>any(vec), all(vec)</code>	useful on Boolean vectors

Functions on vectors

```
course.grades
```

```
## [1] 78.8 86.4 94.2 82.0 92.6
```

```
mean(course.grades) # mean grade
```

```
## [1] 86.8
```

```
median(course.grades)
```

```
## [1] 86.4
```

```
sd(course.grades) # grade standard deviation
```

```
## [1] 6.625708
```

More functions on vectors

```
sort(course.grades)
```

```
## [1] 78.8 82.0 86.4 92.6 94.2
```

```
max(course.grades) # highest course grade
```

```
## [1] 94.2
```

```
min(course.grades) # lowest course grade
```

```
## [1] 78.8
```

Referencing elements of vectors

```
students
```

```
## [1] "Sean" "Louisa" "Frank" "Farhad" "Li"
```

Vector of indices:

```
students[c(2,4)]
```

```
## [1] "Louisa" "Farhad"
```

Vector of negative indices

```
students[c(-1,-3)]
```

```
## [1] "Louisa" "Farhad" "Li"
```

More referencing

`which()` returns the TRUE indexes of a Boolean vector:

```
course.grades
```

```
## [1] 78.8 86.4 94.2 82.0 92.6
```

```
a.threshold <- 90 # A grade = 90% or higher  
course.grades >= a.threshold # vector of booleans
```

```
## [1] FALSE FALSE TRUE FALSE TRUE
```

```
a.students <- which(course.grades >= a.threshold) # Applyi  
a.students
```

```
## [1] 3 5
```

```
students[a.students] # Names of A students
```

```
## [1] "Frank" "Li"
```


Named components

You can give names to elements or components of vectors

```
students
```

```
## [1] "Sean" "Louisa" "Frank" "Farhad" "Li"
```

```
names(course.grades) <- students # Assign names to the grades  
names(course.grades)
```

```
## [1] "Sean" "Louisa" "Frank" "Farhad" "Li"
```

```
course.grades[c("Sean", "Frank", "Li")] # Get final grades
```

```
## Sean Frank Li  
## 78.8 94.2 92.6
```

Note the labels in what R prints; these are not actually part of the value

Useful RStudio tips

Keystroke	Description
<tab>	autocompletes commands and filenames, and lists arguments for functions. Highly useful!
<up>	cycle through previous commands in the console prompt
<ctrl-up>	lists history of previous commands matching an unfinished one
<ctrl-enter>	paste current line from source window to console. Good for trying things out ideas from a source file.
<ESC>	as mentioned, abort an unfinished command and get out of the + prompt

“Homework” 0: Course survey

► You'll receive an announcement providing a link to a Google