

MFE R Programming Workshop

Week 1

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Overview

Goals

- ▶ Learn to program in R.
- ▶ What does programming mean?
 - ▶ Language syntax.
 - ▶ Debugging.
 - ▶ Finding solutions.
 - ▶ Translating math to code.
- ▶ This is just the beginning, you'll develop these skills throughout the program.

R as a language

- ▶ R is object oriented.
 - ▶ Everything is an object and functions operate differently when passed different types of objects.
- ▶ R is functional.
 - ▶ You write fewer loops.
 - ▶ You write cleaner code.

R vs C++

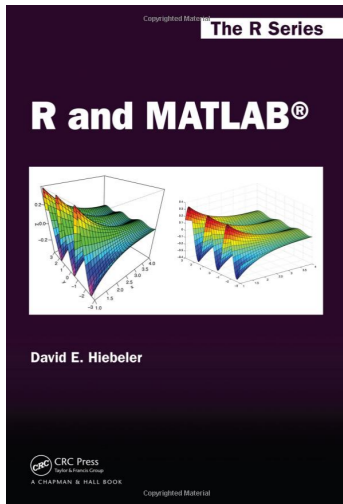
- ▶ Both are useful, and you will use both in the MFE program.
- ▶ R is an interpreted language.
 - ▶ Low programmer time.
 - ▶ A great tool for data munging, statistics, regressions, etc.
 - ▶ However, certain tasks in R can be slow (e.g. loops).
- ▶ C++ is very fast, but it takes longer to write programs.
- ▶ We can use both together!
- ▶ A good workflow:
 1. Write your program in R.
 2. If the program is too slow, benchmark your code.
 3. Try to speedup any bottlenecks in R.
 4. Convert any remaining bottlenecks to C++.

Jack of All Trades, Master of None

- ▶ You are better served by learning R and C++ very well, rather than trying to learn R, C++, MATLAB, Python, Julia, SAS, etc.
- ▶ The MFE program is just too short.
 - ▶ You also need to learn finance!
- ▶ Once you are proficient with R and C++, learning other languages is easy.
- ▶ Don't become a master of none!

MATLAB

- If you want to learn MATLAB after learning R, take a look at **R and MATLAB** by David Hiebeler.



Structure

- ▶ I will talk at the beginning of each class.
- ▶ For the remainder of the time you will break into your study groups and work on programming tasks.
- ▶ Tasks are designed to introduce you to the building blocks that will be used for course assignments throughout the MFE program.
- ▶ This course is a programming course with emphasis on methods for finance:
 - ▶ You will see finance terms and math.
 - ▶ You *may* not understand all of the finance, but you will learn it throughout the program.
- ▶ The key skills will be translating mathematical algorithms into code and developing the ability to find helpful resources.

Questions

Any questions before we start?

R Resources: Books

- ▶ Introductory:
 - ▶ R for Everyone by Jared P. Lander
 - ▶ R Cookbook by Paul Teetor (free at [UCLA LearnIT](#))
 - ▶ R for Data Science by Hadley Wickham (free as well)
- ▶ Intermediate:
 - ▶ The Art of R Programming by Norman Matloff
- ▶ Advanced:
 - ▶ Software for Data Analysis by John Chambers
 - ▶ Extending R by John Chambers
 - ▶ Advanced R by Hadley Wickham

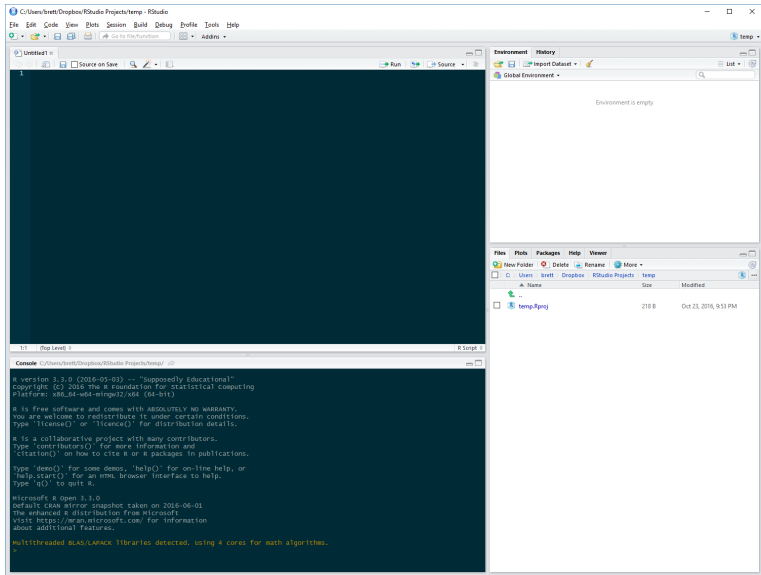
Other Resources

- ▶ Book series:
 - ▶ [Use R!](#) Springer series
 - ▶ FYI: Many Springer textbooks are just \$25 through <http://link.springer.com/>. You need to be on campus or signed into the UCLA VPN. You can download the pdfs for free.
 - ▶ O'Reilly R Books (free at [UCLA LearnIT](#))
- ▶ Built in documentation!
 - ▶ `?funcname`
- ▶ [Journal of Statistical Software](#)
- ▶ Data science courses on [Coursera](#)
- ▶ [Data Camp](#)
- ▶ <https://www.r-bloggers.com/>
- ▶ <https://twitter.com/rstudiotips>
- ▶ Google, Stack Overflow, etc.

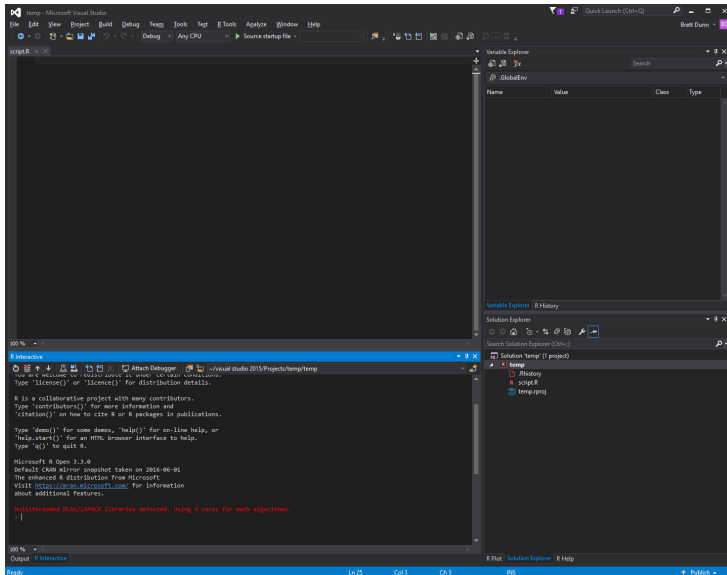
R Environment

- ▶ First, you need an R distribution.
 - ▶ I recommend Microsoft R Open.
 - ▶ <https://mran.revolutionanalytics.com/download/>
- ▶ Second, you need an integrated development environment (IDE) for R.
 - ▶ **R Studio** is a fantastic environment to interact with R.
 - ▶ Other options:
 - ▶ **R Tools for Visual Studio** if you use Visual Studio.
 - ▶ **Emacs Speaks Statistics (ESS)** if you use Emacs.
- ▶ I am going to assume that you have a working installation of R Studio and that you have a basic understanding of how it works.
- ▶ I will show you some Visual Studio.
- ▶ My focus is going to be on R programming.

RStudio

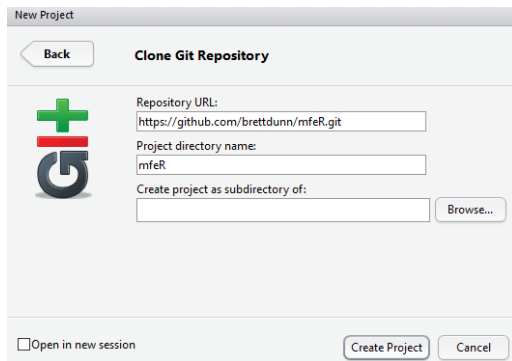


R Tools for Visual Studio



Course Materials

- ▶ <https://github.com/brettdunn/mfeR>
- ▶ The materials for this course were created in RStudio, using R Markdown.
- ▶ To create your own RStudio project:
 - ▶ File / New Project / Version Control / Git
 - ▶ Enter the URL



R Basics

Command Line Interface

- ▶ To run a command in R, type it into the console next to the > symbol and press the Enter key.

```
2 + 3
```

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

- ▶ Up Arrow + Enter repeats the line of code.
- ▶ Esc (Windows/Mac) or Ctrl-C (Linux) interrupts a command.

RStudio

- ▶ To start, create a new R Script file.
 - ▶ File/New File/R Script
- ▶ You can type your commands in the R Script file and run them on the Console.
 - ▶ Easy way to save your work.
 - ▶ `Ctrl+Enter` sends the line at the cursor to the console.
 - ▶ `Ctrl+Shift+S` runs the entire file.
 - ▶ Help/Keyboard Shortcuts lists all the available shortcuts.
 - ▶ Check out the multiple cursors.
- ▶ For larger tasks with many files, create an R project.
- ▶ Visual Studio is similar.

General Comments

- ▶ Make your code easy to read.
- ▶ Check out [Google's R Style Guide](#)
- ▶ Comment your code!

Google's R Style Guide

R is a high-level programming language used primarily for statistical computing and graphics. The goal of the R Programming Style Guide is to make our R code easier to read, share, and verify. The rules below were designed in collaboration with the entire R user community at Google.

Summary: R Style Rules

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

R Packages

- ▶ A package is essentially a library of prewritten code designed to accomplish some task or a collection of tasks.
- ▶ R has a huge collection of user-contributed packages.
 - ▶ Warning: Not all packages are of the same quality.



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CRAN Task Views

Bayesian Inference
Chemometrics and Computational Physics
Clinical Trial Design, Monitoring, and Analysis
Cluster Analysis & Finite Mixture Models
Differential Equations
Probability Distributions
Econometrics
Analysis of Ecological and Environmental Data
Design of Experiments (DoE) & Analysis of Experimental Data
Extreme Value Theory
Empirical Finance
Statistical Genetics
Graphic Displays & Dynamic Graphics & Graphic Devices & Visualization
High-Performance and Parallel Computing with R
Machine Learning & Statistical Learning
Medical Image Analysis
Meta-Analysis
Multivariate Statistics
Natural Language Processing
Numerical Mathematics
Official Statistics & Survey Methodology

R Packages

- ▶ Installing a packages:
 - ▶ Ctrl+7 in RStudio accesses the packages pane
 - ▶ You can also type `install.packages("packageName")`
- ▶ Uninstalling a package:
 - ▶ `remove.packages("packageName")`
- ▶ Loading packages:
 - ▶ `require(packageName)` or `library(packageName)` loads a package into R
 - ▶ The difference is that `require` returns `TRUE` if the package loads or `FALSE` if it doesn't.
- ▶ Unloading packages
 - ▶ `detach(package:packageName)`
- ▶ If two packages have the same function name use two colons:
`-package1::func` or `package2::func`

Getting Help in R

- ▶ To get help on a function, use `?`.
- ▶ The `example` function runs the examples contained in the help file.
- ▶ To run a search through R's documentation, use `??`.
- ▶ To get help on a package, type
`help(package="packageName")`

```
?seq  # pulls up the help page
example(seq)  # runs the examples in R
??"normal distribution"  # runs a search
help(package = "xts")  # gets help on the xts package
?'+'  # gets help on the + function
```

Variables

- ▶ Unlike C++, R does not require variable types to be declared.
- ▶ A variable can take on any data type.
- ▶ A variable can also hold any R object such as a function, the result of an analysis, a plot, etc.
- ▶ Variable assignment is done with `<-`.
 - ▶ `=` works, but there are reasons to prefer `<-`.
- ▶ We can remove variables (e.g. to free up memory) with the `rm` function. `gc()` runs garbage collection.

```
x <- 2  # x is a pointer  
x      # the same output as print(x)
```

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

```
rm(x)  # removes x
```

Data Types

- ▶ There are many different data types in R.
- ▶ The four main types of data most likely to be used are:
 1. numeric
 2. character (string)
 3. Date/POSIXct (time-based)
 4. logical (TRUE/FALSE)
- ▶ The data type can be checked with the `class` function

```
x <- as.Date("2010-12-21")  
class(x)
```

```
## [1] "Date"
```


Casting

```
x <- "2010-12-21"  
class(x)
```

```
## [1] "character"
```

```
x
```

```
## [1] "2010-12-21"
```

```
x <- as.Date(x)  
class(x)
```

```
## [1] "Date"
```

```
x
```

```
## [1] "2010-12-21"
```

More Casting

```
x <- as.numeric(x)  
class(x)
```

```
## [1] "numeric"
```

```
is.numeric(x)
```

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

```
x # number of days since Jan 1, 1970
```

```
## [1] 14964
```

Even More Casting

```
x <- as.integer(x)  # x <- 14964L assigns an integer  
class(x)
```

```
## [1] "integer"
```

```
is.integer(x)
```

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

```
is.numeric(x)  # R promotes int to numeric as needed
```

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

```
4L / 5L
```

```
## [1] 0.8
```

Logicals

```
# TRUE == 1 and FALSE == 0  
x <- TRUE  # TRUE, FALSE, T, F are logicals  
is.logical(x)
```

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

```
5 == 5  # != tests for inequality
```

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

```
"a" < "b"  # works on characters as well
```

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

Vectors

Vectors

- ▶ A vector is a collection of elements, all of the same type.
- ▶ We will learn about:
 - ▶ Recycling
 - ▶ The automatic lengthening of vectors.
 - ▶ Filtering
 - ▶ The extraction of subsets of vectors.
 - ▶ Vectorization
 - ▶ Where functions are applied element-wise to vectors.

Vectors and Assignment

- ▶ Assigning values to variables can be done with `<-`.
- ▶ Often, we create vectors using the `c()` function.
 - ▶ The “c” stands for combine because the arguments into a vector.

```
x <- c(1, 2, 3, 4)
```

```
x
```

```
## [1] 1 2 3 4
```

```
y <- c(x, 5, 6)
```

```
y
```

```
## [1] 1 2 3 4 5 6
```

Creating Vectors with seq and rep

- ▶ Both seq and rep are useful functions for generating vectors.
- ▶ See ?seq and ?rep for details
- ▶ seq is also useful in loops
- ▶ 1:10 is the same as seq(1,10,1)

```
x <- seq(from = 1, to = 10, by = 2)
x
```

```
## [1] 1 3 5 7 9
```

```
y <- rep(c(1, 2), times = 3)
y
```

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

```
rep(c(1,2), each=2)
```

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


Obtaining the Length of a Vector

- ▶ `length()` returns the vector length

```
x <- c(TRUE, FALSE, TRUE, FALSE)
length(x)
```

```
## [1] 4
```

```
x <- c()  # x is NULL
1:length(x)  # that could mess you up in a for loop
```

```
## [1] 1 0
```

```
seq(x)  # a safe way to loop through a vector
```

```
## integer(0)
```

Accessing Elements of vectors

- ▶ Elements can be accessed using `[]`
 - ▶ Help on the `[]` function can be found by typing `?'[]'`
- ▶ Unlike C/C++, R indexing starts at 1, not 0.
- ▶ The `[]` function can take a vector as an arguments.

```
x <- c("a", "b", "c", "d")  
x[1]  # access the first element
```

```
## [1] "a"
```

```
x[c(1, 3)]  # access elements 1 and 3
```

```
## [1] "a" "c"
```

```
x[c(TRUE, FALSE, TRUE, FALSE)]  # second way
```

```
## [1] "a" "c"
```

NULL and NA

- ▶ NULL is the non-existent value in R.
- ▶ NA is the missing place holder.

```
x <- 5:8  
x[2] <- NA  
x
```

```
## [1] 5 NA 7 8
```

```
y <- NULL  
length(y)
```

```
## [1] 0
```

Names of Vector Elements

- ▶ You can give names to elements of vectors, and you can access elements by their name.

```
x <- 1:3  
names(x) <- c("A", "B", "C")  
x["B"]
```

```
## B
```

```
## 2
```

Recycling

- ▶ When applying an operation to two vectors that requires them to be the same length, R automatically *recycles* the shorter one, until it is long enough to match the longer one.
- ▶ Be careful with and aware of this behavior!
- ▶ In some cases it is useful, others confusing.

```
# the shorter vector will be recycled
```

```
c(2, 4, 6) + c(1, 1, 1, 2, 2, 2)
```

```
## [1] 3 5 7 4 6 8
```

```
# this is the same as
```

```
rep(c(2, 4, 6), 2) + c(1, 1, 1, 2, 2, 2)
```

```
## [1] 3 5 7 4 6 8
```

Logical Operators

- ▶ R has several logical operations that act on vectors.
- ▶ `!`, `==`, `!=`, `&`, `&&`, `|`, `||`, `xor()`, `any()`, `all()`, `>`, `>=`, `<=`, `<`

```
x <- c(TRUE,FALSE,TRUE)
y <- c(TRUE,FALSE,FALSE)
x == y
```

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

```
!x
```

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

Logical Operations (2)

- ▶ `&&`, `||`, `any()`, and `all()` return a length-one vector.

```
x <- c(TRUE,FALSE,TRUE)
y <- c(TRUE,FALSE,FALSE)
x && y
```

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

```
x & y
```

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

Filtering

- ▶ We select subsets of vectors with vectors of logicals.

```
x <- 1:5  
y <- c(TRUE,FALSE,TRUE,FALSE,TRUE)  
x[y]
```

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


Filtering (2)

- ▶ Filtering amounts to generating filtering indices (i.e. vectors of logicals).

```
x <- c(5, 2, -3, 8)
idx <- x*x > 8  # same as ">"(x*x, 8) - the 8 is recycled!
idx
```

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

Assigning to filter

- ▶ You can assign to the subsets.
 - ▶ Change elements that meet certain criteria.

```
x <- 1:6  
x[x < 2] <- NA  
x
```

```
## [1] NA 2 3 4 5 6
```

Filtering with subset()

- ▶ The subset function filters and removes any NAs.

```
x <- c(3, 1:5, NA, 79)
x
```

```
## [1] 3 1 2 3 4 5 NA 79
```

```
x[x > 4]
```

```
## [1] 5 NA 79
```

```
subset(x, x > 4)
```

```
## [1] 5 79
```

The selection function `which()`

- ▶ `which()` gives us the position in a vector where a condition occurs.

```
x <- c(3, 1:5, NA, 79)
x
```

```
## [1] 3 1 2 3 4 5 NA 79
```

```
x[x > 4]
```

```
## [1] 5 NA 79
```

```
which(x > 4)
```

```
## [1] 6 8
```

Vectorization: Functions on Vectors

- ▶ R functions typically operate on vectors.
- ▶ Often, there is an argument to ignore missing data.

```
x <- c(1:1000, NA)
mean(x)
```

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

```
mean(x, na.rm = TRUE)
```

```
## [1] 500.5
```

```
log(x)[998:1001]
```

```
## [1] 6.905753 6.906755 6.907755      NA
```

Matrices

Intro

- ▶ Matrices are vectors with a number of rows and number of columns attribute

```
myvec <- 1:10  
mymat <- matrix(myvec, nrow=2, ncol=5)  
mymat
```

```
##      [,1] [,2] [,3] [,4] [,5]  
## [1,]    1    3    5    7    9  
## [2,]    2    4    6    8   10
```

```
mymat[1,3]
```

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

Matrix operations

- Many matrix operations are surrounded by % signs

```
mymat1 <- matrix(1:4, nrow=2)
mymat2 <- matrix(5:8, nrow=2)
mymat1 %*% mymat2
```

```
##      [,1] [,2]
## [1,]   23  31
## [2,]   34  46
```

```
mymat1 + mymat2
```

```
##      [,1] [,2]
## [1,]    6  10
## [2,]    8  12
```


apply

- ▶ apply allows you to apply a function across a dimension of a matrix
- ▶ The third argument is a function!

```
mymat1 <- matrix(1:10, nrow=2)  
# mean across rows  
apply(mymat,1,mean)
```

```
## [1] 5 6
```

cbind and rbind

- Column bind and Row bind

```
mymat1 <- matrix(1:4,nrow=2)
mymat2 <- matrix(6:9,nrow=2)
mymat3 <- matrix(10:11,ncol=2)
cbind(mymat1,mymat2)
```

```
##      [,1] [,2] [,3] [,4]
## [1,]    1    3    6    8
## [2,]    2    4    7    9
```

```
rbind(mymat1,mymat3)
```

```
##      [,1] [,2]
## [1,]    1    3
## [2,]    2    4
## [3,]   10   11
```

Lists

Intro

- Lists are where you really start to see the advantages of R as a statistics and data manipulation language

```
element1 <- 1:5  
element2 <- matrix(1:6,nrow=3)  
mylist <- list(e11=element1,e12=element2)  
mylist[["e11"]]
```

```
## [1] 1 2 3 4 5
```

```
mylist[["e12"]]
```

```
##      [,1] [,2]  
## [1,]    1    4  
## [2,]    2    5  
## [3,]    3    6
```

Subsetting lists

- ▶ Subsets of lists are with single []

```
mylist <- list(A=1,B=2,C=3,D=4)  
# this returns a list because of the single []  
mylist[c(1,3)]
```

```
## $A  
## [1] 1  
##  
## $C  
## [1] 3
```

lapply

- ▶ lapply implicitly loops over each list element and applies a function

```
mylist <- list(A=1:10,B=2:17,C=745:791)
lapply(mylist,mean)
```

```
## $A
## [1] 5.5
##
## $B
## [1] 9.5
##
## $C
## [1] 768
```

lapply example

```
g <- c("M", "F", "F", "I", "M", "M", "F")  
lapply(c("M", "F", "I"), function(gender) which(g==gender))
```

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

```
## [1] 1 5 6
```

```
##
```

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

```
## [1] 2 3 7
```

```
##
```

```
## [[3]]
```

```
## [1] 4
```

Data Frames

Intro

- ▶ In my mind, `data.frame` is the core data type in R
- ▶ The nicest part is that they can hold different types
- ▶ Each column must be the same length

```
dat1 <- 1:4
dat2 <- rep(c("A","B"),each=2)
myframe <- data.frame(col1=dat1,col2=dat2)
myframe
```

```
##   col1 col2
## 1    1    A
## 2    2    A
## 3    3    B
## 4    4    B
```

Subsets

- ▶ Subsetting is just like a matrix

```
myframe[1,2]
```

```
## [1] A  
## Levels: A B
```

```
myframe[1,]
```

```
##   col1 col2  
## 1    1    A
```

```
myframe[,2]
```

```
## [1] A A B B  
## Levels: A B
```

Reading in data

- ▶ Reading in data typically gives you a `data.frame`
- ▶ `read.table` is the basic function to read in tabular data
- ▶ `read.csv` is a special case of `read.table`
- ▶ As usual see `?read.table`
- ▶ Often you want to set `stringsAsFactors = FALSE`

Adding columns

```
dat1 <- 1:4
dat2 <- rep(c("A","B"),each=2)
myframe <- data.frame(col1=dat1,col2=dat2)
myframe$col3 <- 5:8
myframe
```

```
##   col1 col2 col3
## 1     1    A     5
## 2     2    A     6
## 3     3    B     7
## 4     4    B     8
```

names

- ▶ column names in data.frames are specified by `names()`
- ▶ this is because data.frames are actually lists with special attributes
- ▶ that means that the usual list functions work on data.frames
- ▶ `lapply`, etc

Long example

```
all2006 <- read.csv("2006.csv",header=TRUE,as.is=TRUE)

# exclude hourly-wagers
all2006 <- all2006[all2006$Wage_Per=="Year", ]

# exclude weird cases
all2006 <- all2006[all2006$Wage_Offered_From > 20000,]

all2006$rat <- all2006$Wage_Offered_From
               / all2006$Prevailing_Wage_Amount

se2006 <- all2006[grep("Software Engineer", all2006),]
```

Control Statements

For loops (1)

```
x <- c(1:5)
y <- NULL
for(i in 1:length(x)) {
  y[i] <- x[i] + 2
}
y
```

```
## [1] 3 4 5 6 7
```


For loops (2)

- ▶ or another nice way to make a for loop

```
x <- c(1:3)
for(element in x) {
  print(element + 2)
}
```

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

```
## [1] 4
```

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

While loops

```
x <- c(1:5)
y <- NULL
i <- 1
while(i<=length(x)) {
  y[i] <- x[i] + 2
  i <- i+1
}
y
```

```
## [1] 3 4 5 6 7
```

Conditional Statements

```
x <- -10  
myabs <- x  
if(x<0) {  
  myabs <- -x  
}  
myabs
```

```
## [1] 10
```

Functions

Function definitions

- Note that the last value evaluated is what is returned by the function

```
myfunc <- function(x) x^2  
myfunc(10)
```

```
## [1] 100
```

Scope rules

- ▶ Variables defined inside a function are local to that function

```
myfunc <- function(x) {  
  N <- 10  
  N*x^2  
}  
myfunc(10)
```

```
## [1] 1000
```

```
# You can't access N out here
```

Lab 1

Let's work on Lab 1.