2018-09-05-dundee Software Carpentry: R lesson speaker notes

These notes are for the tutor(s) on the first morning session of the Software Carpentry course held on 5-7th September 2018 at the University of Dundee, teaching the refresher in R.

Learning objectives

- Introduction/refresher for `RStudio`
  - understand what `RStudio` is
  - know the main windows of `RStudio` and what functions they provide
- Introduction/refresher for `RStudio` and `git`/`GitHub` project setup
  - create a project in `RStudio`
  - use good practice for project layout in `RStudio`
  - place a project under `git` version control with `RStudio`
- Refresher for flow control in `R`
  - understand and use `if()`...`else()` statements
  - understand and use `for()` loops
  - understand and use `while()` loops
- Refresher for functions in `R`
  - understand the composition of an `R` function
  - how to call functions
  - how to write functions
  - understand when to write functions for good code structure
- Introduction to `RMarkdown` and `knitr`
  - understand the purpose of literate programming
  - understand what a Markdown document is
  - understand and be able to use `RMarkdown` syntax
- Good programming practice
  - good choices for variable names
  - understand the importance of good documentation
  - when and how to write comments in code

Prerequisites

We assume that the learners have prior exposure to many concepts:

- `R`
- variables and variable assignment
- `R` data types and data structures, especially `data.frame`s
- using `R` packages
- `R` base graphics and `ggplot2`

Things to remember

Clearing the console in `R`

- remove all variables

```
rm(list=ls())
```

Get a 'clean' console

```
CTRL + L
```

SLIDES

TITLE: Programming in R

ETHERPAD

- **DEMONSTRATE LINK AND PAGE**
- Please use the course etherpad to
  - make notes
  - ask questions (someone will be looking at the page)
  - share your knowledge with the rest of the class
  - relive the class afterwards

LEARNING OBJECTIVES

- We're being **QUITE AMBITIOUS**, but we've a lot of time this morning, so should be OK
- We're covering some **FUNDAMENTALS OF `RSTUDIO`**
  - **CREATING** projects and **PUTTING UNDER VERSION CONTROL**
- We're covering some **FUNDAMENTALS OF PROGRAMMING** in R, but principles that are **APPLICABLE TO ANY LANGUAGE**
- We're learning some **BEST PRACTICES FOR WRITING AND ORGANISING CODE**
- Much of the morning session is **INTENDED AS A REFRESHER**
- We'll be **ASSUMING YOU ALREADY USE R** so are familiar with some aspects:
  - R syntax
  - data types and data structures (e.g. `data.frame`s)
  - variables, and variable assignment
  - R packages
  - R base graphics and `ggplot2`

- **IF ANYTHING IS NEW OR UNCLEAR, PLEASE ASK STRAIGHT AWAY**

SECTION 01: `RSTUDIO`

LEARNING OBJECTIVES

- We're going to cover the **BASIC ELEMENTS OF AN `RSTUDIO` SESSION**
- How `RStudio` **HELPS WITH LIVE ANALYSES**
- How `RStudio` **HELPS WITH WRITING CODE FOR REPRODUCIBLE ANALYSIS**

WHAT IS `RSTUDIO`?

- `RStudio` is an **INTEGRATED DEVELOPMENT ENVIRONMENT** (IDE)
    - available on **ALL MAJOR OPERATING SYSTEMS**
    - available **AS A WEBSERVER**
- On the left is a Mac screenshot, Windows on the right
- `RStudio` provides **PANES** so you can:
    - write **LIVE CODE** (console pane)
    - **VISUALISE AND QUERY DATA LIVE** (graphics and environment pane)
    - write **SCRIPTS AND DOCUMENTS FOR REUSE** (editor pane)
    - **MANAGE PROJECTS AND FILES** (file/`git` panes)

`RSTUDIO` OVERVIEW - **INTERACTIVE DEMO**

- **REMIND PEOPLE THEY CAN USE RED/GREEN STICKIES AT ANY TIME**

    - **(INTRODUCE RED/GREEN STICKIES IF NECESSARY)**

- **ASK PEOPLE TO START `RSTUDIO`**

    - There will be problems. Deal with them, now. It's OK if a couple of people are getting help when you start.

- **DESCRIBE THE STARTING VIEW OF `RSTUDIO`**

- You should see **THREE PANELS**

    - Interactive `R` **CONSOLE**: **type here and get instant feedback**
    - **ENVIRONMENT/HISTORY** window
    - Files/Plots/Packages/Help/Viewer: **interacting with files on the computer, and viewing help and some output**

- **REMEMBER THE WINDOWS ARE MOBILE AND PEOPLE COULD HAVE THEM IN ANY CONFIGURATION - THE EXACT ARRANGEMENT IS UNIMPORTANT**
- We're going to use `R` in the interactive console to get used to some of the features of the language, and `RStudio`.
  - **THE RIGHT ANGLED BRACKET IS A PROMPT**: `R` expects input
  - Type calculations, then press `return`
- **DEMO CODE: ASK PEOPLE TO TYPE ALONG**

```
> 1 + 100
[1] 101
> 30 / 3
[1] 10
```

- **RESULT IS INDICATED WITH A NUMBER** `[1]` this indicates the line with output in it
- If you type an **INCOMPLETE COMMAND**, `R` will wait for you to complete it with the prompt `+`
- **DEMO CODE**

```
> 1 +
+
```

- The **PROMPT CHANGES TO** `+` **WHEN** `R` **EXPECTS MORE INPUT**
- You can either complete the line, or use `Esc` (`Ctrl-C`) to exit

```
> 1 +
+ 6
[1] 7
> 1 +
+

>
```

- `R` obeys the usual **PRECEDENCE OPERATIONS** (`(`, `**`/`^`, `/`, `*`, `+`, `-`)
- **DEMO CODE**
  - **NOTE SPACES AROUND OPERATORS**

```
> 3 + 5 * 2
[1] 13
> (3 + 5) * 2
[1] 16
> 3 + 5 * 2 ^ 2
[1] 23
```

```
> 3 + 5 * (2 ^ 2)
[1] 23
```

- **ARROW KEYS** recover old commands

- The `HISTORY` **TAB** shows all commands used
- `R` will report in **SCIENTIFIC NOTATION**
    - **CHECK THAT EVERYONE KNOWS WHAT SCIENTIFIC NOTATION IS**


```
> 2 / 1000
[1] 0.002
> 2 / 10000
[1] 2e-04
> 5e3
[1] 5000
```

BUILT-IN FUNCTIONS

- `R` has many **STANDARD MATHEMATICAL FUNCTIONS**
- **FUNCTION SYNTAX**
    - type the function name
    - open parentheses
    - type input value
    - close parentheses
    - press return
- **DEMO CODE** - ask for example functions

```
> sin(1)
[1] 0.841471
> log(1)
[1] 0
> log10(10)
[1] 1
> log(10)
[1] 2.302585
```

GETTING HELP FOR BUILT-IN FUNCTIONS

- How do we learn more about a function, or the difference between `log()` and `log10()`?

    - **USE R BUILT-IN HELP**
- **DEMO CODE**

```
> ?log
> help(sin)
```

- This brings up help in the **HELP WINDOW**
    - Scroll to the bottom of the page to find **EXAMPLE CODE**
- You can also use the **SEARCH BOX** at the top of the help window (try `reduce`)

```
> ??log
> args(log)
function (x, base = exp(1))
NULL
> args(log10)
function (x)
NULL
```

- If you're not sure about spelling, the editor has **AUTOCOMPLETION** which will suggest all possible endings for something you type (try `chartr`)
- **USE TAB TO SEE AUTOCOMPLETIONS FOR VARIABLES**

```
> myvar = 10
> myv[TAB]
```

NUMERICAL COMPARISONS

- We can do **COMPARISONS** in R
    - Comparisons return TRUE or FALSE.
- **DEMO CODE**

```
> 1 == 1
[1] TRUE
> 1 != 2
[1] TRUE
> 1 < 2
[1] TRUE
> 1 <= 1
[1] TRUE
> 1 > 0
[1] TRUE
> 1 >= -9
[1] TRUE
```

- **NOTE:** when comparing numbers, it's better to use `all.equal()` (*machine numeric tolerance*) **ASK IF THERE'S ANYONE FROM MATHS/PHYSICS/COMPUTER SCIENCE**

```
> pi - 1e-8 == pi
[1] FALSE
> all.equal(pi, pi - 1e-8)
[1] TRUE
> all.equal(1.0, 1.0)
[1] TRUE
> all.equal(1.0, 1.1)
[1] "Mean relative difference: 0.1"
> ?all.equal
> all.equal(pi, pi - 1e-8)
[1] TRUE
> all.equal(pi, pi - 1e-8, 1e-16)
[1] "Mean relative difference: 3.183099e-09"
> all.equal(pi, pi - 1e-32)
[1] TRUE
> all.equal(pi, pi - 1e-32, 1e-16)
[1] TRUE
# The precision is set as the square root calculation below - this may
differ from machine to machine
> .Machine$double.eps
[1] 2.220446e-16
> sqrt(.Machine$double.eps)
[1] 1.490116e-08
```

- **THE ORDER/CONSTRUCTION OF MATHEMATICAL OPERATIONS CAN MATTER**
  - Write somewhere if possible: $a = ¥log(0.01^{200})$, $b = 200 ¥times ¥log(0.01)$
  - These two mathematical expressions are exactly equal: $a = b$
  - But computers are not mathematicians, they're machines. Numbers are susceptible to this *rounding error*, so what happens is this:

```
> log(0.01 ^ 200)
[1] -Inf
> 200 * log(0.01)
[1] -921.034
```

- **COMPUTERS DO WHAT YOU TELL THEM, NOT NECESSARILY WHAT YOU WANT**

WORKING IN RSTUDIO

- `RStudio` offers **SEVERAL WAYS TO WRITE CODE**
  - We'll not see all of them today
  - You've seen **DIRECT INTERACTION IN THE CONSOLE** (entering variables)

  - `RStudio` also has an editor for writing scripts, notebooks, markdown documents, and Shiny applications (**EXPLAIN BRIEFLY**)
  - It can also be used to write plain text

- **INTERACTIVE DEMO OF `R` SCRIPT**

- Click on `File` -> `New File` -> `Text File`. **NOTE THAT THE EDITOR WINDOW OPENS**

- Enter the following text, and **EXPLAIN CSV**

  - plain text file
  - one row per line
  - column entries separated by commas
  - first row is header data
  - **NEEDS A BLANK LINE AT THE END**
  - **DATA DESCRIBES CATS**
  - Note that the tab is currently `Untitled1`

```
coat,weight,likes_string
calico,2.1,1
black,5.0,0
tabby,3.2,1
```

- **SAVE THE FILE AS `feline_data.csv`**

  - Click on disk icon
  - Enter filename `feline_data.csv`
  - Note that the name in the tab has changed

- **CLOSE THE EDITOR FOR THAT FILE**

- Click on `File` -> `New File` -> `R Script`.

- **EXPLAIN COMMENTS** while entering the code below

  - **COMMENTS ANNOTATE YOUR CODE**: reminders for you, and information for others
  - Comments should **EXPLAIN THE WHY, NOT THE HOW** - the code should be clear enough to explain *how* at task is performed

```
# Script for exploring RStudio

# Load cat data
cats <- read.csv(file = "feline_data.csv")
```

- **EXPLAIN `read.csv()`**

  - `read.csv()` is a **FUNCTION** that reads data from a **CSV-FORMAT FILE** into a variable in `R`

- **SAVE THE SCRIPT**
    - Click on `File` -> `Save`
    - Enter filename `cats` (**EXTENSION IS AUTOMATICALLY APPLIED**)
    - Note the tab name has changed to `cats.R`
- **SHOW THE ENVIRONMENT TAB**
    - This describes all variables in the current `R` environment.
- **ASK: DO YOU SEE THE VARIABLE IN THE ENVIRONMENT?**
    - **NO** - because the code hasn't been executed, only written.
- **RUN THE SCRIPT**
    - Click on `Source`
    - **NOTE THIS RUNS THE WHOLE SCRIPT**
    - **NOTE THE CONSOLE ENTRY**
- Go to the `Environment` tab
    - **NOTE THE DATA WAS LOADED IN THE VARIABLE `cats`**
    - Note that there is a description of the data (3 obs. [rows] of 3 variables [columns])
    - **CLICK ON THE VARIABLE AND NOTE THAT THE TABLE IS NOW VISIBLE** - this is helpful
    - **YOU CANNOT EDIT THE DATA IN THIS TABLE** - you can sort and filter, but not modify the data.
        - This **ENFORCES GOOD PRACTICE: DATA SEPARATION** (compare to Excel).

SECTION 02: MY FIRST `RSTUDIO` PROJECT

LEARNING OBJECTIVES

- Good practice for `RStudio` project structure
- Load data into an `RStudio` project
- Produce summary statistics of data
- Extract subsets of data
- Plotting data in `R`

PROJECT MANAGEMENT IN RSTUDIO

- `RStudio` **TRIES TO BE HELPFUL** and provides the 'Project' concept

- Keeps **ALL PROJECT FILES IN A SINGLE DIRECTORY**
- **INTEGRATES WITH `GIT`**
- Enables switching between projects within `RStudio`
- Keeps project histories

* **INTERACTIVE DEMO**
* **CREATE PROJECT**
* Click `File` -> `New Project`
    - Options for how we want to create a project: -brand new in a new working directory
        - turn an existing directory into a project (project gets directory name)
        - or checkout a project from `GitHub` or some other repository
* Click `New Directory`
    - Options for various things we can do in `RStudio`. Here we want `New Project`
* Click `New Project`
    - We are asked for a directory name. **ENTER `swc-r-lesson`**
    - We are asked for a parent directory. **PUT YOURS ON THE DESKTOP; STUDENTS CAN CHOOSE ANYWHERE SENSIBLE**
    - **CHOOSE TO CREATE A GIT REPOSITORY**
        - This might not be available to everyone, depending on setup, so **PAUSE HERE**

* Click `Create Project`
* **YOU SHOULD SEE AN EMPTY-ISH `RSTUDIO` WINDOW**
* **INSPECT PROJECT ENVIRONMENT**
* First, **NOTE THE WINDOWS**: console; environment; files
* **CONSOLE** is empty
* **ENVIRONMENT** is empty
* **FILES** shows
    - **CURRENT WORKING DIRECTORY** (see breadcrumb trail) **IS ROOT FOR PROJECT**
    - **THREE FILES**:
        - `*.Rproj` - information about your project
        - `.Rhistory` - records actions taken on the project
        - `.gitignore` - if you created a git repository, this contains paths/names of files to be ignored

- **CREATE DIRECTORIES IN PROJECT**
- **Create directoris called `scripts` and `data`**
    - Click on `New Folder`
    - Enter directory name (`scripts`)
    - Note that the directory now exists in the `Files` tab
    - Do the same for `data/`
- **NOTE THAT WE WILL POPULATE THE DIRECTORIES AS WE GO**
- **LOOK AT THE GIT INTEGRATION**
- There is a `.gitignore` file indicating that the project is under `git` version control
- There is a **NEW TAB** called `Git` in the Environment pane
    - **CLICK ON GIT TAB**
    - There are two files, **NOTHING IS STAGED YET**
    - **STAGE THE FILES** by clicking on the checkboxes
        - It is **GOOD PRACTICE** to place the project `.Rproj` file under version control
        - **NOTE STATUS CHANGES FROM `?` TO `A`** (added)
    - **COMMIT THE FILES** by clicking `Commit`
        - **NOTE THE NEW WINDOW**
        - Show the `diff` for both files: green means added/new line
        - **ADD A COMMIT MESSAGE** - remind learners of good practice
            - good `Git` commit messages are imperative and short
        - **CLICK COMMIT**
        - Close the message box down
- **NOTE THAT THIS IS JUST LIKE WORKING WITH GIT AT THE COMMAND LINE**
- **OPEN THE `TERMINAL` TAB**
    - **NOTE WE ARE IN THE WORKING DIRECTORY**
    - **RUN COMMANDS**

```
$ git status
On branch master
nothing to commit, working tree clean
$ git ls-files
.gitignore
swc-r-lesson.Rproj
$ ls
data/                   scripts/            swc-r-lesson.Rproj
```

OBTAINING DATA

- We've already created some cat data manually

    - **THIS IS UNUSUAL** - most data comes in the form of plain text files

- **START DEMO**

- **GO TO ETHERPAD**

    - **DOWNLOAD DATA** - right-click on link and save to project's `data/` subdirectory
    - **PUT DATA UNDER VERSION CONTROL** - this is **GOOD PRACTICE**
        - For reproducibility, keep raw data with the analysis as much as is reasonable
        - Discuss when it might not be reasonable
        - **NOTE CHANGES IN `DATA/` SUBDIRECTORY**
            - the directory shows up in the `Git` tab
        - **STAGE `DATA/`**
            - note that the filename is now shown
        - **COMMIT THE DATAFILE**

INVESTIGATING `GAPMINDER`

- **INSPECT DATA IN FILES WINDOW**

    - Click on filename, and select `View File`
    - Note: **THERE ARE NO ROW NAMES**
    - Ask: **IS THIS WELL-FORMATTED DATA?** (can you tell what the data represents?)

- **WHAT IS THE DATA TYPE**

    - Tabular, with **EACH COLUMN SEPARATED BY A COMMA**, so **CSV**
    - **IN THE CONSOLE** use `read.table()` to read the data in

```
gapminder <- read.table("data/gapminder-FiveYearData.csv", sep=",",
header=TRUE)
```

- Note: **IF WE DON'T ASSIGN THE RESULT TO A VARIABLE WE JUST SEE THE DATA**

- Now we've loaded our data, let's take a look at it

- **DEMO IN CONSOLE**

    - 1704 rows, 6 columns
    - Investigate types of columns
    - **POINT OUT THAT THE TYPE OF A COLUMN IS INTEGER IF IT'S A FACTOR**
    - **LENGTH OF A DATAFRAME IS THE NUMBER OF COLUMNS**

```
> str(gapminder)
'data.frame':	1704 obs. of  6 variables:
 $ country  : Factor w/ 142 levels "Afghanistan",..: 1 1 1 1 1 1 1 1 1 1
...
 $ year     : int  1952 1957 1962 1967 1972 1977 1982 1987 1992 1997 ...
```

```
 $ pop      : num  8425333 9240934 10267083 11537966 13079460 ...
 $ continent: Factor w/ 5 levels "Africa","Americas",..: 3 3 3 3 3 3 3 3 3 3
3 ...
 $ lifeExp  : num  28.8 30.3 32 34 36.1 ...
 $ gdpPercap: num  779 821 853 836 740 ...
> typeof(gapminder$year)
[1] "integer"
> typeof(gapminder$country)
[1] "integer"
> str(gapminder$country)
 Factor w/ 142 levels "Afghanistan",..: 1 1 1 1 1 1 1 1 1 1 ...
> levels(gapminder$country)
  [1] "Afghanistan"              "Albania"                    "Algeria"
"Angola"
  [5] "Argentina"                "Australia"                  "Austria"
"Bahrain"
  [...]
> length(gapminder)
[1] 6
> nrow(gapminder)
[1] 1704
> ncol(gapminder)
[1] 6
> dim(gapminder)
[1] 1704    6
> colnames(gapminder)
[1] "country"   "year"      "pop"       "continent" "lifeExp"
"gdpPercap"
> head(gapminder)
      country year      pop continent lifeExp gdpPercap
1 Afghanistan 1952  8425333      Asia  28.801  779.4453
2 Afghanistan 1957  9240934      Asia  30.332  820.8530
3 Afghanistan 1962 10267083      Asia  31.997  853.1007
4 Afghanistan 1967 11537966      Asia  34.020  836.1971
5 Afghanistan 1972 13079460      Asia  36.088  739.9811
6 Afghanistan 1977 14880372      Asia  38.438  786.1134
> summary(gapminder)
        country           year           pop               continent
lifeExp
 Afghanistan:  12   Min.   :1952   Min.   :6.001e+04   Africa  :624   Min.
:23.60
 Albania    :  12   1st Qu.:1966   1st Qu.:2.794e+06   Americas:300   1st
Qu.:48.20
 Algeria    :  12   Median :1980   Median :7.024e+06   Asia    :396
Median :60.71
 Angola     :  12   Mean   :1980   Mean   :2.960e+07   Europe  :360   Mean
:59.47
 Argentina  :  12   3rd Qu.:1993   3rd Qu.:1.959e+07   Oceania : 24   3rd
Qu.:70.85
 Australia  :  12   Max.   :2007   Max.   :1.319e+09                  Max.
:82.60
 (Other)    :1632
   gdpPercap
 Min.   :   241.2
```

```
 1st Qu.:  1202.1
 Median :  3531.8
 Mean   :  7215.3
 3rd Qu.:  9325.5
 Max.   :113523.1
```

SECTION 03: PROGRAM FLOW CONTROL

LEARNING OBJECTIVES

- In this short section, you'll learn how to **perform actions depending on values of data** in `R`
- You'll also learn how to **repeat operations, using `for()` loops**
- **These are very important general concepts, that recur in many programming languages**
- Much of the time, you can avoid using them in `R` data analyses, because `dplyr` exists, and because `R` is **vectorised**

`IF()` … `ELSE`**

- We **often want to run a piece of code, or take an action, dependent on whether some data has a particular value

  - (if it is true or false, say)

- When this is the case, we can use the general `if()` … `else` structure, which is common to most programming languages

- **DEMO IN SCRIPT**

- **CREATE NEW SCRIPT** (save as `scripts/flow_control.R`)

  - Let's say that we want to print a message if some value is greater than 10
  - **NOTE AUTOCOMPLETION/BRACKETS ETC.**
  - **THE CODE TO BE RUN GOES IN CURLY BRACES**

```
# A script to investigate flow control in R

# Synthetic data
x <- 8

# Example conditional
if (x > 10) {
  print("x is greater than 10")
}
```

- **`SOURCE` THE FILE**

- **NOTHING HAPPENS** (`x > 10` is `FALSE`)
- The `if()` block executes **ONLY IF THE VALUE IN PARENTHESES EVALUATES AS `TRUE`**

- **MODIFY THE SCRIPT**
  - Add the `else` block
  - `Source` the code: **WE GET A MESSAGE**
  - **BUT IS THE MESSAGE TRUE?**

```
# Example if statement
if (x > 10) {
  print("x is greater than 10")
} else {
  print("x is less than 10")
}
```

- **SET `x <- 10` AND TRY AGAIN**
  - Is the answer correct?

Red sticky for a question or issue   Green sticky if complete

- **MODIFY THE SCRIPT WITH `else if()` STATEMENT**
  - `Source` the script: **NO OUTPUT**

```
# A data point
x <- 10

# Example if statement
if (x > 10) {
  print("x is greater than 10")
} else if (x < 10) {
  print("x is less than 10")
}
```

- **MODIFY THE SCRIPT WITH A FINAL `else` STATEMENT**
  - `Source` the script: **EQUALS** output

```
# A data point
x <- 9

# Example if statement
if (x > 10) {
  print("x is greater than 10")
```

```
} else if (x < 10) {
  print("x is less than 10")
} else {
  print("x is equal to 10")
}
```

- **TRY SOME OTHER VALUES for `x`**

SLIDE: Challenge

- Build up the solution with each concept in turn

```
> gapminder$year
   [1] 1952 1957 1962 1967 1972 1977 1982 1987 1992 1997 2002 2007 1952
1957 1962 1967 1972 1977 1982 1987 1992 1997 2002 2007
  [25] 1952 1957 1962 1967 1972 1977 1982 1987 1992 1997 2002 2007 1952
1957 1962 1967 1972 1977 1982 1987 1992 1997 2002 2007
  [...]
> gapminder$year == 2002
   [1] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE
FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
  [21] FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE
  [...]
> any(gapminder$year == 2002)
[1] TRUE
> any(gapminder$year == 2001)
[1] FALSE
# Are there any records for a year
year <- 2002
if(any(gapminder$year == year)){
   print("Record(s) for this year found.")
}
```

Red sticky for a question or issue   Green sticky if complete

---

`FOR()` LOOPS

- If you want to iterate over a set of values, then `for()` loops can be used
- `for()` loops are **A VERY COMMON PROGRAMMING CONSTRUCTION**
- They express the idea: **FOR EACH ITEM IN A GROUP, DO SOMETHING (WITH THAT ITEM)**
- **DEMO IN SCRIPT** (`scripts/flow_control.R`)

- Say we have a *vector* `c(1,2,3)`, and we want to print each item
- We can **loop over all the items** and print them

- **The loop structure is**
    - `for()`, where the argument names a variable (`i`) - the *iterator*, and a set of values: **`for(i in c('a', 'b', 'c'))`**
    - A **CODE BLOCK** defined by curly braces (**note automated completion)
    - The **contents of the code block are executed for each value of the iterator**

```
# Example for loop
for (i in c('a', 'b', 'c')) {
  print(i)
}
```

- **Loops can (but shouldn't always) be nested**
- **DEMO IN SCRIPT**
    - The outer loop is executed and, **for each value in the outer loop, the inner loop is executed to completion**

```
# Example nested for loop
for (i in 1:5) {
  for (j in c('a', 'b', 'c')) {
    print(paste(i, j))
  }
}
```

- The simplest way to capture output from a loop is to add a new item to a vector each iteration of the loop
- **DEMO IN SCRIPT**
    - **REMIND:** using `c()` to append to a vector

```
# Capturing loop output in a vector
output <- c()
for (i in 1:5) {
  for (j in c('a', 'b', 'c')) {
    output <- c(output, paste(i, j))
  }
}
print(output)
```

- **GROWING OUTPUT FROM LOOPS IS COMPUTATIONALLY VERY EXPENSIVE**
    - Doing this will *really* slow down your scripts for larger datasets
    - Better to define the empty output container first (**IF YOU KNOW THE DIMENSIONS**)
- **MODIFY IN SCRIPT**

```
# Capturing loop output in a matrix
output_matrix <- matrix(nrow=5, ncol=3)
j_letters = c('a', 'b', 'c')
for (i in 1:5) {
  for (j in 1:3) {
    output_matrix[i, j] <- paste(i, j_letters[j])
  }
}
print(output_matrix)
```

`WHILE()` LOOPS

- Sometimes you need to perform some action **ONLY WHILE A CONDITION IS TRUE**
    - This isn't as common as a `for()` loop
    - It's another **GENERAL PROGRAMMING CONSTRUCTION**
- **DEMO IN SCRIPT**
    - We'll generate random numbers until one falls below a threshold
    - `runif()` generates random numbers from a uniform distribution
        - **ASK LEARNERS HOW TO GET HELP ON THIS**

```
> ?runif
```

- We print random numbers until one is less than 0.1
    - **RUN A COUPLE OF TIMES TO SHOW OUTPUT IS RANDOM**

```
# Example while loop
z <- 1
while(z > 0.1){
  z <- runif(1)
  print(z)
}
```

CHALLENGE

- Best to give example of what `letters` is, and demonstrate how the help mechanism fails for `%in%`
- Also show that `%in%` doesn't work for membership of a string - needs a vector

```
> letters
 [1] "a" "b" "c" "d" "e" "f" "g" "h" "i" "j" "k" "l" "m" "n" "o" "p" "q"
```

```
"r" "s" "t" "u" "v" "w" "x" "y" "z"
> ?%in%
Error: unexpected SPECIAL in "?%in%"
> ?in
Error: unexpected 'in' in "?in"
> ?"%in%"
> 'e' %in% letters
[1] TRUE
> 'e' %in% 'aeiou'
[1] FALSE
> 'e' %in% c('a', 'e', 'i', 'o', 'u')
[1] TRUE
```

- Then, in the script

```
# Challenge solution
gapminder <- read.table("data/gapminder-FiveYearData.csv", sep=",",
header=TRUE)
for (c in levels(gapminder$country)) {
  if (startsWith(c, 'M')) {
    value <- TRUE
  } else {
    value <- FALSE
  }
  print(paste(c, value))
}
```

- **COMMIT THE SCRIPT TO THE REPO WHEN DONE**

Red sticky for a question or issue   Green sticky if complete

---

VECTORISATION

- `for()` and `while()` loops are useful, but they are **NOT THE MOST EFFICIENT WAY TO WORK WITH DATA IN `R`**
- **MOST FUNCTIONS IN `R` ARE VECTORISED**
  - When applied to a vector, they work on all elements in the vector
  - **NO NEED TO USE A LOOP**
- **DEMO IN CONSOLE**
  - **OPERATORS** are vectorised

```
> x <- 1:4
> x
[1] 1 2 3 4
> x * 2
[1] 2 4 6 8
```

- **YOU CAN OPERATE ON VECTORS TOGETHER**

```
> y <- 6:9
> y
[1] 6 7 8 9
> x + y
[1]  7  9 11 13
> x * y
[1]  6 14 24 36
```

- **COMPARISON OPERATORS ARE VECTORISED**

```
> x > 2
[1] FALSE FALSE  TRUE  TRUE
> y < 7
[1]  TRUE FALSE FALSE FALSE
> any(y < 7)
[1] TRUE
> all(y < 7)
[1] FALSE
```

- **MANY FUNCTIONS WORK ON VECTORS**

```
> log(x)
[1] 0.0000000 0.6931472 1.0986123 1.3862944
> x^2
[1]  1  4  9 16
> sin(x)
[1]  0.8414710  0.9092974  0.1411200 -0.7568025
```

CHALLENGE

```
# Challenge solution
countries <- levels(gapminder$country)
mstart <- startsWith(countries, 'M')
print(countries[mstart])
```

- **COMMIT MODIFIED SCRIPT**

Red sticky for a question or issue   Green sticky if complete

---

SECTION 04: FUNCTIONS

LEARNING OBJECTIVES

- **YOU'VE ALREADY BEEN USING BUILT-IN FUNCTIONS (e.g. `log()`)** and, I hope, have found them useful
- Functions let us run a complex series of commands in one go
  - **YOU WOULDN'T HAVE TO WANT TO WRITE/REPEAT BASIC CALCULATIONS FOR `log()` EACH TIME YOU USE IT**
  - They keep the operation under a **MEMORABLE OR DESCRIPTIVE NAME**, which makes the code **READABLE AND UNDERSTANDABLE**, and they are invoked with that name
  - There are a **DEFINED SET OF INPUTS AND OUTPUTS** for a function, so **WE KNOW WHAT BEHAVIOUR TO EXPECT**

WHY FIUNCTIONS?

- Functions let us **RUN A COMPLEX SERIES OF RELATED COMMANDS IN ONE GO**
  - Can be **LOGICALLY** or **FUNCTIONALLY** related
- It helps when functions have **DESCRIPTIVE AND MEMORABLE NAMES**, as this makes code **READABLE AND UNDERSTANDABLE**
- We invoke functions with their name
- We **A DEFINED SET OF INPUTS AND OUTPUTS** - aids clarity and understanding
- **FUNCTIONS ARE THE BUILDING BLOCKS OF PROGRAMMING**
- As a **RULE OF THUMB** it is good to write small functions with one obvious, clearly-defined task.
  - As you will see we can **CHAIN SMALL FUNCTIONS TOGETHER TO MANAGE COMPLEXITY**

DEFINING A FUNCTION

- Functions have a **STANDARD FORM** in R
  - We **DECLARE A `<function_name>`**

    - We use the `function` *function*/keyword to assign the function to `<function_name>`
    - Inputs (*arguments*) to a function are defined in parentheses: These are defined as variables for use within the function **AND DO NOT EXIST OUTSIDE THE FUNCTION**
    - The code block (**cCURLY BRACES**) encloses the function code, the *function body*.
    - **NOTE THE INDENTATION** - *Easier to read, but does not affect execution*
    - The code `<does_something>`
    - The `return()` function returns the value, when the function is called

- **DEMO IN SCRIPT**

    - **CREATE NEW SCRIPT `functions.R`**
    - Write and `Source`

```
# Example function
# Returns the sum of two input values
my_sum <- function(a, b) {
  the_sum <- a + b
  return(the_sum)
}
```

- **ADD SCRIPT TO VERSION CONTROL**

- **DEMO IN CONSOLE**

    - **SOURCE** the script

```
> my_sum(3, 7)
[1] 10
> a
Error: object 'a' not found
> b
Error: object 'b' not found
```

- **GOOD VARIABLE NAMING IS IMPORTANT**

    - For a function this size, and so simple, it's clear what `a` and `b` are - but that is not always the case
    - We can make the function clearer by changing these names

- **CHANGE VARIABLE NAMES IN-PLACE**

- **TEST THE SCRIPT**

```
# Example function
# Returns the sum of two input values
my_sum <- function(val1, val2) {
  the_sum <- val1 + val2
```

```
  return(the_sum)
}
```

```
> source('~/Desktop/swc-r-lesson/scripts/functions.R')
> my_sum(3, 7)
[1] 10
> a
Error: object 'a' not found
> val1
Error: object 'val1' not found
> val2
Error: object 'val2' not found
```

- **ADD SCRIPT TO VERSION CONTROL**
- **DEMO IN SCRIPT**
    - Let's define another function: convert temperature from fahrenheit to Kelvin

```
# Convert Fahrenheit to Kelvin
fahr_to_kelvin <- function(temp) {
  kelvin <- (temp - 32) * (5 / 9) + 273.15
  return(kelvin)
}
```

- **SOURCE AND DEMO IN SCRIPT**

```
> fahr_to_kelvin(32)
[1] 273.15
> fahr_to_kelvin(-40)
[1] 233.15
> fahr_to_kelvin(212)
[1] 373.15
> temp
Error: object 'temp' not found
```

- **LET'S MAKE ANOTHER FUNCTION CONVERTING KELVIN TO CELSIUS**
- **DEMO IN SCRIPT**
    - `Source` the script

```
# Convert Kelvin to Celsius
kelvin_to_celsius <- function(temp) {
  celsius <- temp - 273.15
  return(celsius)
}
```

- **SOURCE AND DEMO IN CONSOLE**

```
> kelvin_to_celsius(273.15)
[1] 0
> kelvin_to_celsius(233.15)
[1] -40
> kelvin_to_celsius(373.15)
[1] 100
```

- **WE COULD DEFINE A NEW FUNCTION TO CONVERT FAHRENHEIT TO CELSIUS**
  - But it's **EASIER TO COMBINE EXISTING FUNCTIONS** we've already written
  - **AVOIDS INTRODUCING NEW BUGS**
  - Efficient to **REUSE CODE**
- **DEMO IN CONSOLE**

```
> fahr_to_kelvin(212)
[1] 373.15
> kelvin_to_celsius(fahr_to_kelvin(212))
[1] 100
```

- **DEMO IN SCRIPT**

```
# Fahrenheit to Celsius
fahr_to_celsius <- function(temp) {
  celsius <- kelvin_to_celsius(fahr_to_kelvin(temp))
  return(celsius)
}
```

- **DEMO IN CONSOLE**
  - **NOTE: AUTOMATICALLY TAKES ADVANTAGE OF R's VECTORISATION**

```
> fahr_to_celsius(212)
[1] 100
> fahr_to_celsius(32)
[1] 0
> fahr_to_celsius(-40)
[1] -40
> fahr_to_celsius(c(-40, 32, 212))
[1] -40   0 100
```

DOCUMENTING FUNCTIONS

- It's important to have well-named functions (and variables... **THIS IS A FORM OF DOCUMENTATION - SELF-DOCUMENTING CODE**)
- But it's not a detailed explanation
- You've found R's help useful, but it doesn't exist for your functions until you write it
- **YOUR FUTURE SELF WILL THANK YOU FOR DOING IT!**
- **SOME GOOD PRINCIPLES TO FOLLOW WHEN WRITING DOCUMENTATION ARE:**
  - Say **WHAT** the code does (and **WHY**) - *more important than how* (the code does that)
  - Define your inputs and outputs
  - Provide an example
- **DEMO IN CONSOLE**

```
> ?fahr_to_celsius
No documentation for ‘fahr_to_celsius’ in specified packages and
libraries:
you could try ‘??fahr_to_celsius’
> ??fahr_to_celsius
```

- **DEMO IN SCRIPT**
  - We add documentation as comment strings in the function

```
# Fahrenheit to Celsius
fahr_to_celsius <- function(temp) {
  # Convert input temperature from fahrenheit to celsius scale
  #
  # temp        - numeric
  #
  # Example:
  # > fahr_to_celsius(c(-40, 32, 212))
  # [1] -40   0 100
  celsius <- kelvin_to_celsius(fahr_to_kelvin(temp))
  return(celsius)
}
```

- **SOURCE** the script
- **DEMO IN CONSOLE**

```
> ?fahr_to_celsius
No documentation for ‘fahr_to_celsius’ in specified packages and
libraries:
you could try ‘??fahr_to_celsius’
```

- We read the documentation by providing the function name **ONLY**

```
> fahr_to_celsius
function(temp) {
  # Convert input temperature from fahrenheit to celsius scale
  #
  # temp        - numeric
  #
  # Example:
  # > fahr_to_celsius(c(-40, 32, 212))
  # [1] -40   0 100
  celsius <- kelvin_to_celsius(fahr_to_kelvin(temp))
  return(celsius)
}
```

- **COMMIT SCRIPT TO VERSION CONTROL**

FUNCTION ARGUMENTS

- **DEMO IN SCRIPT** (`functions.R`)
  - `Source` script

```
# Report countries in gapminder data
list_countries <- function(data) {
  # Returns countries from the gapminder dataset
  #
  # data          - gapminder data.frame
  #
  # Example:
  # countries <- list_countries(gapminder)
  countries <- levels(data$country)
  return(countries)
}
```

- **SOURCE SCRIPT**
- **DEMO IN CONSOLE**

```
> list_countries(gapminder)
  [1] "Afghanistan"            "Albania"                "Algeria"
  [4] "Angola"                 "Argentina"              "Australia"
  [7] "Austria"                "Bahrain"                "Bangladesh"
  [...]
```

- So, those are *all* the `gapminder` countries - but what if we want to **GET COUNTRIES STARTING WITH A GIVEN LETTER?**
- **DEMO IN SCRIPT** (`functions.R`)
    - `Source` script

```
> list_countries(gapminder, 'M')
Error in list_countries(gapminder, "M") : unused argument ("M")
```

- The function doesn't understand what we want
- We need to **TELL THE FUNCTION TO EXPECT A LETTER**
    - **DEMO IN SCRIPT**
    - Don't forget to update the documentation

```
# Report countries in gapminder data
list_countries <- function(data, letter) {
  # Returns countries from the gapminder dataset,
  # filtered by starting letter
  #
  # data          - gapminder data.frame
  # letter        - character
  #
  # Example:
  # countries <- list_countries(gapminder)
  countries <- levels(data$country)
  matches <- startsWith(countries, letter)
  return(countries[matches])
}
```

- Now the function should accept a letter, and report only countries starting with the letter
- **SOURCE THE SCRIPT**

```
> list_countries(gapminder, 'M')
 [1] "Madagascar" "Malawi"     "Malaysia"   "Mali"       "Mauritania"
"Mauritius"  "Mexico"
 [8] "Mongolia"   "Montenegro" "Morocco"    "Mozambique" "Myanmar"
```

- So that works, but we have a problem:

```
> list_countries(gapminder)
Error in startsWith(countries, letter) :
  argument "letter" is missing, with no default
```

- **NO LETTER PROVIDED MEANS NO OUTPUT**
    - We need to handle this

    - 1 - **PROVIDE A DEFAULT VALUE** (NULL)
    - 2 - **TEST FOR VALUE AND TAKE ALTERNATIVE ACTIONS**
- **DEMO IN SCRIPT**

```
# Report countries in gapminder data
list_countries <- function(data, letter=NULL) {
  # Returns countries from the gapminder dataset, optionally
  # filtered by starting letter
  #
  # data          - gapminder data.frame
  # letter        - character
  #
  # Example:
  # countries <- list_countries(gapminder)
  countries <- levels(data$country)
  if (!is.null(letter)) {
    matches <- startsWith(countries, letter)
    countries <- countries[matches]
  }
  return(countries)
}
```

- **SOURCE SCRIPT**
- **DEMO IN CONSOLE**

```
> source('~/Desktop/swc-r-lesson/scripts/functions.R')
> list_countries(gapminder)
  [1] "Afghanistan"              "Albania"                  "Algeria"
  [4] "Angola"                   "Argentina"                "Australia"
  [7] "Austria"                  "Bahrain"                  "Bangladesh"
  [...]
> list_countries(gapminder, 'M')
 [1] "Madagascar" "Malawi"     "Malaysia"   "Mali"       "Mauritania"
"Mauritius"  "Mexico"
 [8] "Mongolia"   "Montenegro" "Morocco"    "Mozambique" "Myanmar"
> list_countries(gapminder, 'G')
[1] "Gabon"         "Gambia"        "Germany"       "Ghana"
"Greece"        "Guatemala"
[7] "Guinea"        "Guinea-Bissau"
```

- **COMMIT SCRIPT TO VERSION CONTROL**

SECTION 05: DYNAMIC REPORTS

LEARNING OBJECTIVES

- In this section, we'll be learning how to create **REPRODUCIBLE, ATTRACTIVE, DYNAMIC REPORTS** with `RMarkdown`
- To do so, we'll learn some `RMarkdown` **SYNTAX**, and how to put **WORKING `R` CODE** into a document
- We'll also look at generating the report in **A NUMBER OF FILE FORMATS**, for sharing.

LITERATE PROGRAMMING

- What we're about to do is an example of **Literate Programming**, a concept introduced by Donald Knuth

- The idea of Literate Programming is that

  - The program or analysis is explained in **NATURAL LANGUAGE****
  - The **CODE** needed to run the program/analysis is **EMBEDDED IN THE DOCUMENT**
  - The whole document is executable

- We can produce these documents in `RStudio`

CREATE AN `RMarkdown` FILE

- In `R`, literate programming is **implemented in `RMarkdown` files
- To create one: **`File` $¥rightarrow$ `New File` $¥rightarrow$ `R Markdown`**
  - There is a dialog box
    - **ENTER A TITLE** (`Literate Programming`)
    - **CLICK OK**
  - Save the file (`Ctrl-S`)
    - **CREATE NEW SUBDIRECTORY** (`markdown`)**
    - **SAVE AS** `literate_programming.Rmd`
- The file gets the **EXTENSION** `.Rmd`
  - The file is **AUTOPOPULATED** with example text

COMPONENTS OF AN `RMarkdown` FILE

- The **HEADER REGION** is fenced by `---`
  - **METADATA** (author, title, date)
  - Requested **OUTPUT FORMAT**

```
---
title: "Literate Programming"
author: "Leighton Pritchard"
date: "04/12/2017"
output: html_document
---
```

- Natural language is written as plain text, with some **EXTRA CHARACTERS FOR FORMATTING**
  - **NOTE THE HASHES `#`, ASTERISKS `*` AND ANGLED BRACKETS `<>`**
- `R` code runs in the document, and is **fenced by backticks**
- **CLICK ON `KNIT`**
  - A new (pretty) document is produced in a new window
- **CROSS REFERENCE MARKDOWN TO DOCUMENT**
  - **Title, Author, Date**
  - **Header**
  - **Link**
  - **Bold**
  - **`R` code and output**
  - **Plots**
- **SHOW THAT AN HTML FILE IS PRODUCED**
- **CLICK ON `KNIT TO PDF`**
  - A new `.pdf` document opens in a new window
- **CROSS REFERENCE MARKDOWN TO DOCUMENT**
  - **NOTE:** The formatting isn't identical
- **CLICK ON `KNIT TO WORD`**
  - A new `Word` document opens up
- **CROSS REFERENCE MARKDOWN TO DOCUMENT**
  - **NOTE:** The formatting isn't identical
- **NOTE THE LOCATION OF THE OUTPUT FILES - ALL IN THE SOURCE DIRECTORY**
  - **CLOSE THE OUTPUT**

CREATING A REPORT

- We'll **CREATE A REPORT** on the `gapminder` data
  - We'll be using **LITERATE PROGRAMMING**
  - We'll also be learning some `dplyr` and `ggplot2` as we go

SECTION 06: `dplyr`
