A Beginner's Guide to Programming in R

Drew Schmidt
Remote Data Analysis and Visualization Center
University of Tennessee, Knoxville

June 14, 2013

Affiliations and Support

The pbdR Core Team
http://r-pbd.org

Drew Schmidt was supported in part by the project "NICS Remote Data Analysis and Visualization Center" funded by the Office of Cyberinfrastructure of the U.S. National Science Foundation under Award No. ARRA-NSF-OCI-0906324 for NICS-RDAV center.

About This Tutorial

Slides and Exercises

The slides for this tutorial are available at:

http://wrathematics.github.io/handouts/slides.pdf

The exercises for this tutorial are available at:

http://wrathematics.github.io/handouts/exercises.pdf

Contents

Contents

What is R?

- *lingua franca* for data analytics and statistical computing.
- Part programming language, part data analysis package.
- Dialect of S (Bell Labs).
- Syntax designed for data.

Who uses R?

Google, Pfizer, Merck, Bank of America, Shell[a], Oracle[b], Facebook, bing, Mozilla, okcupid[c], ebay[d], kickstarter[e], the New York Times[f]

---

[a] https://www.nytimes.com/2009/01/07/technology/business-computing/07program.html?_r=0

[b] http://www.oracle.com/us/corporate/features/features-oracle-r-enterprise-498732.html

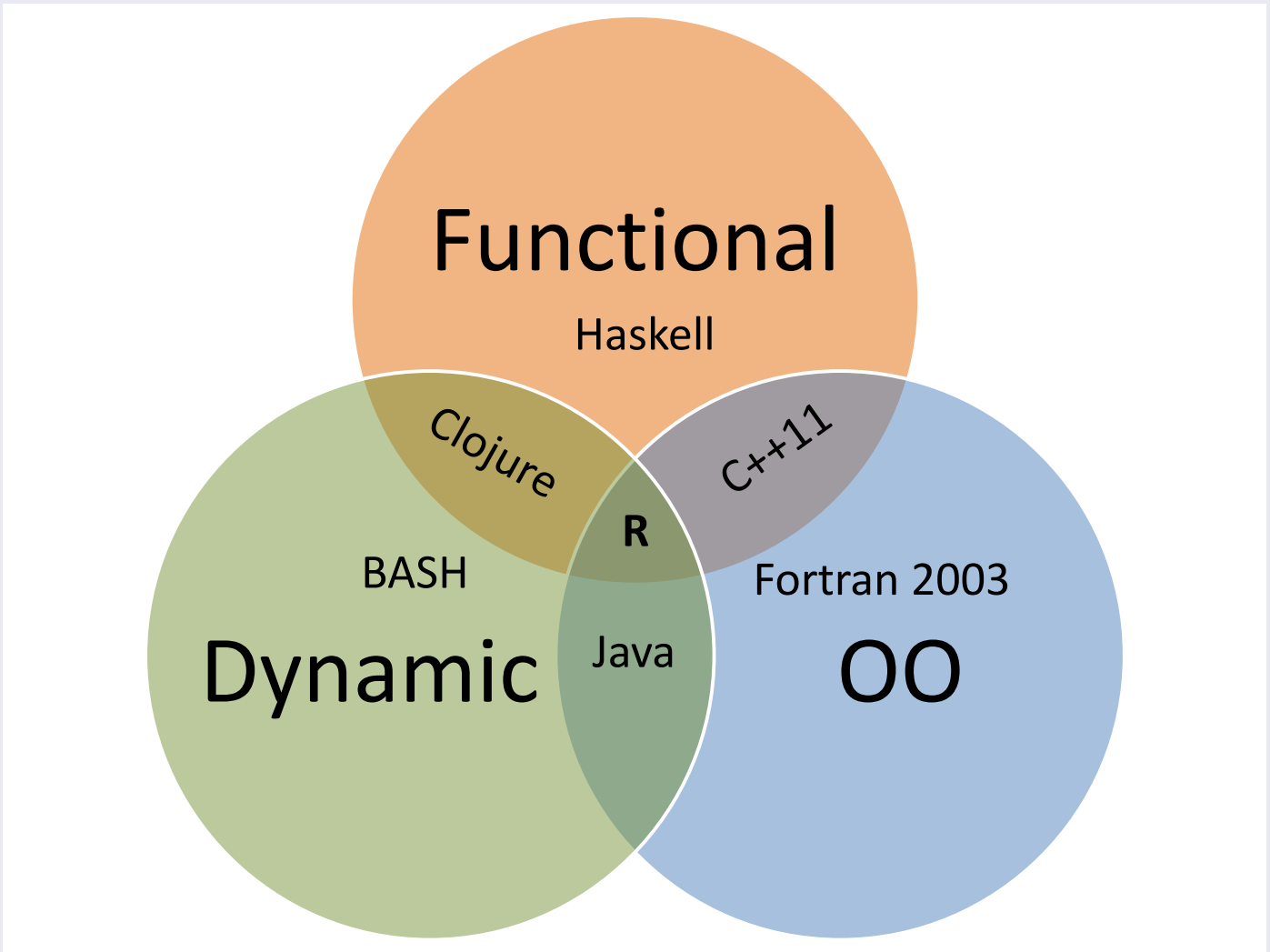
[c] http://www.revolutionanalytics.com/what-is-open-source-r/companies-using-r.php

[d] http://blog.revolutionanalytics.com/2012/09/using-r-in-production-industry-experts-share-their-experiences.html

[e] http://blog.revolutionanalytics.com/2012/09/kickstarter-facilitates-50m-in-indie-game-funding.html

[f] http://blog.revolutionanalytics.com/2012/05/nyt-charts-the-facebook-ipo-with-r.html

Language Paradigms



Data Types

- Storage: logical, int, double, double complex, character
- Structures: vector, matrix, array, list, dataframe

Starting R

1. Interactive: R
2. Batch: Rscript

Interacting with the Terminal

The default method in R is `show()`, which usually amounts to printing:

```
1
1+1
print(1+1)
sum

+ # ctrl+c to break
"+"
`+`
```

Arithmetic

```
1 7+4
2 7-4
3 7*4
4 7/4
5 7^4
6 7%%4
```

Assignment

R naming rules can be quite lax. For all practical purposes:

- Start with a letter
- Should consist of letters (any case), numbers, .'s, and _'s
- Very strange things are possible, however...

```
1 `&*()` <- 3
2 `&*()`
3 `2` <- 1
4 `2` + 1
```

Assignment

```
1  myvar <- 1
2  myvar
3
4  myvar <<- 2
5  myvar
6
7  assign(x="myvar", value=3)
8  myvar
9
10 myvar = 4
11 myvar
```

Case and Spacing

R is case sensitive, but fairly lax about spacing:

```
1 x <- 1:5
2 x
3 X
4
5 1       +   1
6 sum(x)
7 sum  (  x     )
8 s  um(x)
```

Finding Help

- R has its own manual system.
- Most of the answers to your questions lie within.
- Find help using `?` or `help()`, or search across all help with `??`.

```
1 ?sum
2 ??sum
3 help("sum")
4
5 ?+ # ctrl+c to break
6 ?"+"
```

RNG

R contains many powerful random number generators:

Beta	Binomial	Cauchy
Chi-square	Exponential	F
Gamma	Geometric	Hypergeometric
Logistic	Log Normal	Negative Binomial
Normal	Poisson	Student t
Uniform	Weibull	Wilcoxon Rank Sum

```
1 runif(5, min=0, max=10)
2 rnorm(5, mean=0, sd=1)
3 rgamma(5, shape=1)
4
5 set.seed(10)
6 runif(5)
7 set.seed(10)
8 runif(5)
```

Resources

The Art of R Programming: http://nostarch.com/artofr.htm

An Introduction to R
http://cran.r-project.org/doc/manuals/R-intro.pdf

The R Inferno
http://www.burns-stat.com/pages/Tutor/R_inferno.pdf

Mathesaurus: http://mathesaurus.sourceforge.net/

R programming for those coming from other languages: http://www.johndcook.com/R_language_for_programmers.html

Introduction to Probability and Statistics Using R http://cran.r-project.org/web/packages/IPSUR/vignettes/IPSUR.pdf

Comments and Advice

- R is part statistics package, part programming language.
- There are always 100 ways to do anything, only one of them efficient.
- R is slow; if you don't know what you're doing, it's *really* slow.
- There is an R help mailing list. Use stackoverflow instead. . . .
- Learn to love the R help system.
- If something appears broken in core R, it's probably not a bug (it's you).
- Just because something is on the CRAN does not mean it's of any value (or even functional).
- Indent your code.

Comments and Advice

- Be consistent.
- Generally try to use instructive names for things.
- Make your code concise, but not obtuse (don't play golf).
- Try to avoid "super functions". Breaking up complicated ideas into modular pieces can help with readability, debugging, reusability, etc.
- Google has an R style guide: https://google-styleguide.googlecode.com/svn/trunk/google-r-style.html
- The R community has few computer scientists.

Contents

Data Types

- logical
- int
- double
- double complex
- character

Data Types

R is *dynamically typed*. You do not have to declare what kind of data a variable is before you start using it:

```
1 x <- 1
2 is.numeric(x)
3 is.integer(x)
4 is.double(x)
5 x <- 1:2
6 is.numeric(x)
7 is.integer(x)
8 is.double(x)
```

Other

There are 4 "other" data "types":

- `Inf`
- `NaN`
- `NULL`
- `NA`

Inf

Numerical infinity

```
1 Inf
2 is.finite(Inf)
3 is.infinite(Inf)
4 Inf+Inf
5 1/0
```

NaN

Not a Number; numerical undefinedness.

```
1 NaN
2 is.nan(NaN)
3 Inf-Inf
4 sin(Inf)
```

NULL

The null object; a sort of placeholder for something undefined. Like a non-numeric `NaN`.

```
1 NULL
2 is.null(NULL)
3 NULL+NULL
```

NA

Missingness; not merely undefined, but *unknown*.

- Each type (logical, int, double, ...) has its own `NA`
- R is thus not boolean: `TRUE`, `FALSE`, `NA`
- Most R methods have ways of removing `NA`'s

Data Structures

- vector
- matrix
- array
- factor
- list
- dataframe

Vectors

```
1:10
10:1

c(1, 3, 5, 7, 9)
seq(from=1, to=10, by=2)

x <- 1:5
length(x)
is.vector(x)
```

Matrices

```
1  matrix(1:10)
2  matrix(1:10, nrow=5)
3  matrix(1:10, ncol=5)
4
5  x <- 1:10
6  y <- as.matrix(x)
7  dim(x)
8  dim(y)
9  dim(x) <- c(1, 10)
10 x
```

Extraction

```
1  x <- matrix(1:30, 10)
2  x
3
4  x[-1, ]
5  x[, -1]
6  x[1:5, -1]
7  x[c(2,5,7), c(1,3)]
8
9  y <- x[, -2]
10 dim(y) <- NULL
11 y
```

Replacement

```
1 x <- matrix(1:30, 10)
2 x
3
4 x[1:5, ] <- 0
5 x[7, 3] <- NA
6 x
```

Factors

```
1 factor(1:5)
2 factor(c("a", "b", "b", "a", "c"))
3
4 x <- factor(-1:1)
5 x
6 as.numeric(x)
7 as.numeric(as.character(factor(-1:1)))
```

Dataframes

```
1  c(1, "a")
2  matrix(c(1, "a"))
3
4  x <- data.frame(1, "a")
5  x
6  x[1, 1]
7  is.numeric(x[1,1])
8  x[1, 2]
9  is.numeric(x[1,2])
10
11 data.frame(a=1:5,b=5:1)
```

Lists

- Super structures
- Items can be any structure (even other lists)
- Dataframe is really just a special list

Lists

```
1 list(1)
2 x <- list(list(1), "a")
3 x
4 x[[1]]
5
6 x <- list(a=list("b", 1), z=1:5)
7 x$z
```

Contents

Logic

- Possible values are `TRUE`, `FALSE`, and `NA`
- Relational operations: ==, !=, <, <=, >, and >=

Logic

```
1  1==1
2  1!=1
3  1<1
4  1<=1
5
6  TRUE==FALSE
7
8  TRUE==1
9  FALSE==0
10
11 TRUE==T
12 FALSE==F
```

Logic

```
1  NA==NA
2  is.na(NA)
3
4  NULL==NULL
5  is.null(NULL)
6
7  NaN==NaN
8  is.nan(NaN)
9
10 Inf==Inf
11 is.infinite(Inf)
```

Logic

Vectors of logicals are evaluated element-wise, not globally:

```
1 x <- c(T, F, F, T, T, F)
2 x==T
3 !x
```

Logic

Some very important functions for logical evaluations:

```
1 x <- c(T, F, F, T, T, F)
2 any(x)
3 all(x)
4 which(x)
5
6 y <- -5:5
7 which(y%%2==0)
8 y[which(y%%2==0)]
```

Loops

- Instruction set to be repeatedly executed until some condition is satisfied (possibly forever).
- R has `for()` and `while()`.
- `for()`: Iterates over a list or vector
- `while()`: Performs operations until logical condition is satisfied.

for Loop

```
1  for (i in 1:10){
2    print(i)
3  }
4
5  x <- matrix(1:30, 10)
6  colmax <- numeric(3)
7  for (i in 1:3){
8    colmax[i] <- max(x[, i])
9  }
10 colmax
```

while Loop

```
1  i <- 1
2  while (i < 11){
3    print(i)
4    i <- i+1
5  }
6
7  n <- 2
8  i <- 1
9  while (n < 1000){
10   n <- n^2
11   i <- i*2
12 }
13 n
14 i
```

The *ply Family

- `apply()`: Apply function across "margin" (dimension) of matrix.
- `lapply()`: Apply function to input data object; returns a list.
- `sapply()`: Same as `sapply()` but
- `mapply()`: Multivariate `sapply()`.
- `vapply()`: Essentially `sapply()`, sometimes faster.
- `tapply()`: Applying a function to a subset of a vector.

We will only discuss the first 3.

apply

```
1  x <- matrix(1:30, 10)
2  x
3  apply(X=x, MARGIN=1, FUN=min)
4  apply(X=x, MARGIN=2, FUN=min)
5
6  out <- numeric(3)
7  for (i in 1:3){
8    out[i] <- min(x[, i])
9  }
10 out
```

lapply and sapply

```
1 x <- 1:5
2 lapply(X=x, FUN=sqrt)
3
4 sapply(X=x, FUN=sqrt)
```

*ply Functions Internally

- `apply()`: A `for()` loop.
- `lapply()`: Internal R voodoo; faster than a loop.
- `sapply()`: Essentially the same as `lapply()`.

When does all this choice matter?

- loops are slow.
- `apply()` is the same speed as a loop, but often more readable
- `lapply()` is faster than looping.
- Vectorization is fastest of all.

We can prove it by timing the different options with the `system.time()` function.

Loop Speeds

```
# No initialization
system.time({
  x <- 5000:1
  sin <- numeric(0)
  for (i in 1:length(x)){
    sin[i] <- sin(x[i])
  }
  colmax
})

# With initialization
system.time({
  x <- 5000:1
  sin <- numeric(length(x))
  for (i in 1:length(x)){
    sin[i] <- sin(x[i])
  }
  colmax
})
```

Loop Speeds

```
1 # lapply
2 system.time(lapply(x, sin))
3 system.time(sapply(x, sin))
4
5 # vectorized
6 system.time(sin(x))
```

Contents

Functions

- Self-contained input/output machine.
- Reusable blocks of code.
- In R, functions are first class objects.
- *Evaluating the Design of the R language*, http://r.cs.purdue.edu/pub/ecoop12.pdf

Functions: Example 1

```
1  f <- function(x)
2  {
3    ret <- x+1
4    return(ret)
5  }
6
7  f(1)
8  f(2)
9  f(5)
10 f
```

Functions: Example 2

```
1  f <- function (a, b)
2  {
3    return( a - b )
4  }
5
6  f(a =1, b=2)
7  f(1, 2)
8  f(b=1, a=2)
9  f(b=1, 2)
10 f(1)
11 f(matrix(1:4, ncol=2), matrix(4:1, nrow=2))
```

Functions: Example 3

For complicated returns (especially of mixed type/class), use a list:

```
1 g <- function (a, b)
2 {
3   return(list(plus=a+b, minus=a-b, times=a*b,
        division=a/b))
4 }
5
6 g(5, 2)
7 g(1, 0)
8 g(f(2, 6), 2)
```

Functions: Example 4

R allows parameter defaults in functions

```
1 h <- function (a=1, b=2)
2 {
3   return(b-a)
4 }
5
6 h
7 h()
8 h(2, 1)
```

Recursive Functions

A *recursive function* is one that calls itself:

```
1  f <- function(n)
2  {
3    if (n==1)
4      return(1)
5    else {
6      if (n%%2==0)
7        return(f(n/2))
8      else
9        return(f(3*n+1))
10   }
11 }
```

Contents

Strings

- Character/word data.
- Internal storage scheme is complicated...
- *MUCH* easier to use that most other languages.
- Can have a vector, matrix, dataframe, or list of strings.

Strings: Example 1

```
1 letters
2 toupper(letters)
3 LETTERS
4 tolower(LETTERS)
```

Strings: Example 2

```
1 x <- "Star Trek is objectively better than Star Wars"
2 strsplit(x, split=" ")
3
4 y <- unlist(strsplit(x, split=""))
5 y
6 paste(rev(y), collapse="")
```

Strings: Example 3

```
1 paste(letters, letters)
2 paste(letters, letters, sep="")
3 paste(letters, letters, sep="", collapse="")
4
5 paste(paste(letters, collapse=""), paste(LETTERS,
      collapse=""), sep="")
```

Strings: Example 4

```
1 x <- rnorm(1000, mean=10)
2
3 paste("The mean of 'x' is:", mean(x))
4
5 cat(sprintf("mean:\t%.2f\nvar:\t%.2f\n", mean(x),
      var(x)))
```

Contents

I/O

- `write.csv()`, `read.csv()`,
- `write.table()`, `read.table()`
- `scan()`
- `save()` and `load()`

Reading and Writing a CSV

```
1 x <- matrix(1:30, 10)
2 write.csv(x, file="x.csv")
3 read.csv("x.csv")
4
5 write.csv(x, file="x.csv", row.names=F)
6 read.csv("x.csv", header=T)
```

Reading and Writing a CSV

```
1  x <- letters
2  y <- 1:5
3  z <- list(list("a"), b=matrix(0))
4
5  save(x, y, z, file="robjects.RData")
6  rm(x)
7  rm(y)
8  rm(z)
9  x
10 load("robjects.RData")
```

Contents

Plotting

- R is *world class* for graphics and visualization.
- Biggest package for plotting is **ggplot2** by Hadley Wickham.
- We will focus on some examples from core R...

Scatterplots

```
1 x <- 1:10
2 y <- rnorm(10)
3 plot(x, y)
4 text(x=5.5, y=0, "MY PLOT", col='red')
```

Piecharts

```
1 pie(1:5)
```

Barplots

```
1 barplot(1:5)
```

Histograms

```
1 hist(rnorm(500))
```

Saving Plots

```
1 pdf("myscatterplot.pdf")
2 plot(rnorm(4), 1:4)
3 dev.off()
4
5 png("mybarplot.png")
6 barplot(1:10)
7 dev.off()
```

Plotting

- These are all fairly "cookie-cutter".
- These can do more complicated things, but you're only making things difficult for yourself...
- Best to learn a full graphics package.
- The biggest are **ggplot2** and **lattice** (I recommend ggplot...)

Lattice:
http://www.statmethods.net/advgraphs/trellis.html
ggplot2:
http://www.statmethods.net/advgraphs/ggplot2.html

Contents

Debugging

- Sadly, debugging is how much of your programming life will be spent.
- Cleaning up messes (especially other peoples') isn't fun, but sometimes you just have no other choice.
- Your new best friends: printing and `debug()`

Debugging by Printing

- It is often enough to insert print statements in your functions, use some small test data, run function, evaluate, repeat.
- Useful for small problems you have some intuition about.

How it can fail: suppose it takes 10 minutes to evaluate the function once. . .

Using debug()

```
1 debug(myfun)
2 myfun(...)
```

Use `Q` to break debugging.

Using debug()

```
1 f <- function(x)
2 {
3   x+1
4   x+2
5   x+3
6   x+4
7
8   return(0)
9 }
```