Basic R tutorial

Data types and structures

Data Types

- A vector contains an indexed set of values that are all of the same type:
  - *logical*
  - *numeric*
  - *complex*
  - *character*
- The numeric type can be further broken down into *integer*, *single*, and *double* types (but this is only important when making calls to foreign functions, eg. C or Fortran.)

Data Structures

- `vector` - elements of the same type
- `factor` - categorical
- `list` - can contain objects of different types
- `matrix` - table of numbers
- `data.frame` - table of numbers and/or characters
- `environment` - hashtable
- `function`

Data Structures

- There is no need to declare the types of the variables.

```
> x <- data.frame(type=c(rep("case",2),rep("control",3)),
+                 time=rnorm(5))
> y <- 10
> z <- "a string"
> class(z)

[1] "character"

> class(x)

[1] "data.frame"
```

Creating Vectors

There are two symbols that can be used for assignment: `<-` and `=`.

```
> v <- 123

[1] 123

> s = "a string"

[1] "a string"

> t <- TRUE

[1] TRUE

> letters

 [1] "a" "b" "c" "d" "e" "f" "g" "h" "i" "j" "k" "l" "m" "n" "o" "p"
[17] "q" "r" "s" "t" "u" "v" "w" "x" "y" "z"

> length(letters)

[1] 26
```

Functions for Creating Vectors

- `c` - concatenate
- `:` - integer sequence, `seq` - general sequence
- `rep` - repetitive patterns
- `vector` - vector of given length with default value

```
> seq(1, 3)
[1] 1 2 3
> 1:3
[1] 1 2 3
> rep(1:2, 3)
[1] 1 2 1 2 1 2
> vector(mode="character", length=5)
[1] "" "" "" "" ""
```

Vectorized Arithmetic

- Most arithmetic operations in the R language are *vectorized.* That means that the operation is applied element-wise.

  ```
  > 1:3 + 10:12
  [1] 11 13 15
  ```

- In cases where one operand is shorter than the other the short operand is recycled, until it is the same length as the longer operand.

  ```
  >  1 + 1:5
  [1] 2 3 4 5 6
  >  paste(1:5, "A", sep="")
  [1] "1A" "2A" "3A" "4A" "5A"
  ```

- Many operations which need to have explicit loops in other languages do not need them with R. Try to vectorize any code you write.

Matrices and n-Dimensional Arrays

- Can be created using `matrix` and `array`.
- Are represented as a vector with a dimension attribute.

```
> x <- matrix(1:10, nrow=2)
> dim(x)

[1] 2 5

> x

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

> as.vector(x)

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

Lists

- A list is an ordered set of elements that can be arbitrary R objects (vectors, other lists, functions, ...). In contrast to atomic vectors, which are homogeneous, lists and environments can be heterogeneous.

```
> lst = list(a=1:3, b = "ciao", c = sqrt)
> lst

$a
[1] 1 2 3


$b
[1] "ciao"


$c
function (x)  .Primitive("sqrt")
> lst$c(81)

[1] 9
```

Environments

- One difference between lists and environments is that there is no concept of ordering in an environment. All objects are stored and retrieved by **name**.

```
> e1 = new.env()
> e1[["a"]] <- 1:3
> assign("b", "ciao", e1)
> ls(e1)

[1] "a" "b"
```

- Access to large environment can be sped up by using hashing (see the manual page of `new.env`).
- Names must match exactly.

Data Frames

- Data frames are a special R structure used to hold a set of spreadsheet like table. In a `data.frame`, the observations are the rows and the covariates are the columns.
- Data frames can be treated like matrices and be indexed with two subscripts. The first subscript refers to the observation, the second to the variable.
- Columns of a data frames are vectors (i.e. elements have same data type), but different columns can be vectors of different types.
- Data frames are really lists, and list subsetting can also be used on them.

Data Frames (continued)

```
> df <- data.frame(type=rep(c("case", "control"), c(2, 3)),
+                  time=rexp(5))
> df
     type      time
1    case 0.1766375
2    case 0.7737111
3 control 0.2121239
4 control 2.7640733
5 control 0.9474739
> df$time
[1] 0.1766375 0.7737111 0.2121239 2.7640733 0.9474739
```

Naming

The elements of a vector can (and often should) be given names. Names can be specified

- at creation time
- later by using `names`, `dimnames`, `rownames`, `colnames`

```
> x <- c(a=0, b=2)
> x

a b
0 2

> names(x) <- c("Australia", "Brazil")
> x

Australia    Brazil
        0         2
```

Naming

```
> x <- matrix(c(4, 8, 5, 6, 4, 2, 1, 5, 7), nrow=3)
> dimnames(x) <- list(
+   year = c("2005", "2006", "2007"),
+   "mode of transport" = c("plane", "bus", "boat"))
> x
```

```
      mode of transport
year   plane bus boat
  2005     4   6    1
  2006     8   4    5
  2007     5   2    7
```

Data types for microarrays

- `ExpressionSet` - one channel data (package *Biobase*)
- `NChannelSet` - multiple channels data (package *Biobase*)
- `AffyBatch` - Affymetrix data (package *affy*)
- `beadLevelData` and `lumiBatch` - Illumina data (package *beadarray* and *lumi* respectively)

About AnnotatedDataFrame

- An `AnnotatedDataFrame` consists of a collection of samples and the values of variables measured on those samples. There is also a description of each variable measured.
- `AnnotatedDataFrame` coordinates a `data.frame` with its metadata.

ExpressionSet and Cie. structure

- `assayData` - expression values in identical sized matrices
- `phenoData` - sample annotation in `AnnotatedDataFrame`
- `featureData` - feature annotation in `AnnotatedDataFrame`
- `experimentData` - description of the experiment as a `MIAME` object
- `annotation` - type of chip as a `character`
- `protocolData` - scan dates as a `character`

ExpressionSet

```
> library("Biobase")
> data(sample.ExpressionSet)
> class(sample.ExpressionSet)

[1] "ExpressionSet"
attr(,"package")
[1] "Biobase"

> dim(sample.ExpressionSet)

Features  Samples
     500       26

> slotNames(sample.ExpressionSet)

[1] "experimentData"    "assayData"          "phenoData"
[4] "featureData"       "annotation"         "protocolData"
[7] ".__classVersion__"
```

ExpressionSet

```
> sample.ExpressionSet

ExpressionSet (storageMode: lockedEnvironment)
assayData: 500 features, 26 samples
  element names: exprs, se.exprs
protocolData: none
phenoData
  sampleNames: A B ... Z (26 total)
  varLabels: sex type score
  varMetadata: labelDescription
featureData: none
experimentData: use 'experimentData(object)'
Annotation: hgu95av2
```

Subsetting and assignments

Subsetting

- One of the most powerful features of R is its ability to manipulate subsets of vectors and arrays.
- Subsetting is indicated by `[`, `]`.
- Note that `[` is actually a function (try `get("[")`). `x[2, 3]` is equivalent to `"["(x, 2, 3)`. Its behavior can be customized for particular classes of objects.
- The number of indices supplied to `[` must be either the dimension of `x` or 1.

Subsetting with Positive Indices

- A subscript consisting of a vector of positive integer values is taken to indicate a set of indices to be extracted.

```
> x <- 1:10
> x[2]
[1] 2
> x[1:3]
[1] 1 2 3
```

- A subscript which is larger than the length of the vector being subsetted produces an NA in the returned value.

```
>  x[9:11]
[1]  9 10 NA
```

Subsetting with Positive Indices

- Subscripts which are zero are ignored and produce no corresponding values in the result.

```
> x[0:1]
[1] 1
> x[c(0, 0, 0)]
integer(0)
```

- Subscripts which are `NA` produce an `NA` in the result.

```
> x[c(10, 2, NA)]
[1] 10  2 NA
```

Assignments with Positive Indices

- Subset expressions can appear on the left side of an assignment. In this case the given subset is assigned the values on the right (recycling the values if necessary).

```
> x[2] <- 200
> x[8:10] <- 10
> x
 [1]   1 200   3   4   5   6   7  10  10  10
```

- If a zero or `NA` occurs as a subscript in this situation, it is ignored.

Subsetting with Negative Indexes

- A subscript consisting of a vector of negative integer values is taken to indicate the indices which are not to be extracted.

  ```
  > x[-(1:3)]
  ```

  ```
  [1]  4  5  6  7 10 10 10
  ```

- Subscripts which are zero are ignored and produce no corresponding values in the result.
- `NA` subscripts are not allowed.
- Positive and negative subscripts cannot be mixed.

Subsetting by Logical Predicates

- Vector subsets can also be specified by a logical vector of `TRUE`s and `FALSE`s.

```
> x = 1:10
> x > 5
 [1] FALSE FALSE FALSE FALSE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE
> x[x > 5]
[1]  6  7  8  9 10
```

- `NA` values used as logical subscripts produce `NA` values in the output.
- The subscript vector can be shorter than the vector being subsetted. The subscripts are recycled in this case.
- The subscript vector can be longer than the vector being subsetted. Values selected beyond the end of the vector produce `NA`s.

Subsetting by Name

- If a vector has named elements, it is possible to extract subsets by specifying the names of the desired elements.

```
> x <- c(a=1, b=2, c=3)
> x[c("c", "a", "foo")]
   c    a <NA>
   3    1   NA
```

- If several elements have the same name, only the first of them will be returned.
- Specifying a non-existent name produces an `NA` in the result.

Subsetting matrices

- when subsetting a matrix, missing subscripts are treated as if all elements are named; so `x[1,]` corresponds to the first row and `x[,3]` to the third column.
- for arrays, the treatment is similar, for example `y[,1,]`.
- these can also be used for assignment, `x[1,]=20`

Subsetting Arrays

- Rectangular subsets of arrays obey similar rules to those which apply to vectors.
- One point to note is that arrays can also be treated as vectors. This can be quite useful.

```
>  x = matrix(1:9, ncol=3)
>  x[ x > 6 ]
[1] 7 8 9
>  x[ x > 6 ] = 0
>  x
     [,1] [,2] [,3]
[1,]    1    4    0
[2,]    2    5    0
[3,]    3    6    0
```

Subsetting and Lists

- Lists are useful as containers for grouping related thing together (many R functions return lists as their values).
- Because lists are a recursive structure it is useful to have two ways of extracting subsets.
- The `[ ]` form of subsetting produces a sub-list of the list being subsetted.
- The `[[ ]]` form of subsetting can be used to extract a single element from a list.

List Subsetting Examples

- Using the `[ ]` operator to extract a sublist.

```
> lst[1]
$a
[1] 1 2 3
```

- Using the `[[ ]]` operator to extract a list element.

```
> lst[[1]]
[1] 1 2 3
```

- As with vectors, indexing using logical expressions and names is also possible.

List Subsetting by Name

- The dollar operator provides a short-hand way of accessing list elements by name. This operator is different from all other operators in R, it does not *evaluate* its second operand (the string).

  ```
  > lst$a
  [1] 1 2 3
  > lst[["a"]]
  [1] 1 2 3
  ```

- For `$` partial matching is used, for `[[` it is not by default, but can be turned on.

Accessing Elements in an Environment

- Elements in environments can be accessed through, `get`, `assign`, `mget`.
- You can also use the dollar operator and the `[[ ]]` operator, with character arguments only. No partial matching is done.

```
>  e1$a
[1] 1 2 3
>  e1[["b"]]
[1] "ciao"
```

Assigning values in Lists and Environments

- Items in lists and environments can be (re)placed in much the same way as items in vectors are replaced.

```
> lst[[1]] = list(2,3)
> lst[[1]]
[[1]]
[1] 2


[[2]]
[1] 3
```

```
> e1$b = 1:10
> e1$b
 [1]  1  2  3  4  5  6  7  8  9 10
```

Subsetting ExpressionSet

```
> sample.ExpressionSet[1:2, 2:5]
ExpressionSet (storageMode: lockedEnvironment)
assayData: 2 features, 4 samples
  element names: exprs, se.exprs
protocolData: none
phenoData
  sampleNames: B C D E
  varLabels: sex type score
  varMetadata: labelDescription
featureData: none
experimentData: use 'experimentData(object)'
Annotation: hgu95av2
```

Packages

Packages

- In R the primary mechanism for distributing software is via *packages*
- CRAN is the major repository for packages.
- You can either download packages manually or use `install.packages` or `update.packages` to install and update packages.
- In addition, on Windows and other GUIs, there are menu items that facilitate package downloading and updating.
- It is important that you use the R package installation facilities. You cannot simply unpack the archive in some directory and expect it to work.

Packages - Bioconductor

- Bioconductor packages are hosted in CRAN-style repositories and are accessible using `install.packages`.
- The most reliable way to install Bioconductor packages (and their dependencies) is to use `biocLite`.
- Bioconductor has both a release branch and a development branch. Each Bioconductor release is compatible with its contemporary R release.
- Bioconductor packages have vignettes.

Useful Functions

Getting Help

There are a number of ways of getting help:

- `help.start` and the HTML help button in the Windows GUI
- `help` and `?`: `help("data.frame")`
- `help.search`, `apropos`
- `RSiteSearch` (requires internet connection)
- Online manuals
- Mailing lists

Get information about object

- `class`
- `length` - length of vectors or factors
- `dim` - dimensions of an object
- `head` and `tail` - first or last parts of an object

Reading/Writing files

- `read.table` - creates a `data.frame` from a table format file
- `write.table` - writes a table format file from a `data.frame`
- `save` - writes an external representation of R objects to a specified file
- `load` - reload datasets written with the function 'save'
- `read.AnnotatedDataFrame` - creates a `AnnotatedDataFrame` from a table format file

How to plot data

- Simple plot

```
> x <- c(1,3,6,9,12)
> y <- c(1,2,7,8,4)
> plot(x,y)
```

- Customization

```
> plot(x,y, main='Title here', col='red', pch=15)
```

- Barplots

```
> barplot(y)
```

Control-Flow

R has a standard set of control flow functions:

- Looping: `for`, `while` and `repeat`.
- Conditional evaluation: `if` and `switch`.

Two Useful String Functions

1. Concatenate strings: `paste`
2. Search strings: `grep`

Example: `paste`

```
> s <- c("apple", "banana", "lychee")
> paste(s, "X", sep="_")

[1] "apple_X"  "banana_X" "lychee_X"

> paste(s, collapse=", ")

[1] "apple, banana, lychee"
```

Example: `grep`

```
> library("ALL")
> data(ALL)
> class(ALL$mol.biol)

[1] "factor"

> negIdx <- grep("NEG", ALL$mol.biol)
> negIdx[1:10]

 [1]  2  5  6  7  8  9 12 14 16 21
```

The `apply` Family

- A natural programming construct in R is to *apply* the same function to elements of a list, of a vector, rows of a matrix, or elements of an environment.
- The members of this family of functions are different with regard to the data structures they work on and how the answers are dealt with.
- Some examples, `apply`, `sapply`, `lapply`, `mapply`, `vapply`, `eapply`.

`apply`

- `apply` applies a function over the margins of an array.
- For example,

  ```
  > apply(x, 2, mean)
  ```

  computes the column means of a matrix `x`, while

  ```
  > apply(x, 1, median)
  ```

  computes the row medians.

`apply`

`apply` is usually not faster than a `for` loop. But it is more elegant.

```
> a=matrix(runif(1e6), ncol=10)
```

```
> system.time({
+   s1 = apply(a, 1, sum)
+ })
```

```
   user  system elapsed
  0.563   0.004   0.566
```

```
> system.time({
+   s2 = numeric(nrow(a))
+   for(i in 1:nrow(a))
+     s2[i] = sum(a[i,])
+ })
```

```
   user  system elapsed
  0.287   0.000   0.287
```

See also: `rowSums` and `colSums`.

Writing Functions

Writing Functions

- Writing R functions provides a means of adding new functionality to the language.
- Functions that a user writes have the same status as those which are provided with R.
- Reading the functions provided with the R system is a good way to learn how to write functions.

A Simple Function

- Here is a function that computes the square of its argument.

```
>  square = function(x) x*x
>  square(10)

[1] 100
```

- Because the function body is vectorized, so is this new function.

```
>  square(1:4)

[1]  1  4  9 16
```

Composition of Functions

- Once a function is defined, it is possible to call it from other functions.

```
> sumsq = function(x) sum(square(x))
> sumsq(1:10)
[1] 385
```

Returning Values

- Any single R object can be returned as the value of a function; including a function.
- If you want to return more than one object, you should put them in a list (usually with names), or an S4 object, and return that.
- The value returned by a function is either the value of the last statement executed, or the value of an explicit call to `return`.
- `return` takes a single argument, and can be called from any where in a function.

Control of Evaluation

- In some cases you want to evaluate a function that may fail, but you do not want to get stuck with an error.
- In these cases the function `try` can be used.
- `try(expr)` will either return the value of the expression `expr`, or an object of class *try-error*
- `tryCatch` provides a more configurable mechanism for condition handling and error recovery.