Introduction to R*

Part 2: Atomic Data Types - Atomic/homogeneous vectors

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Last updated: 11/26/2024 @ 20:04:58

Contents

R can be summarized in **three** principles (John M. Chambers, 2016)

- `Everything that exists in R is an` **`object`**`.`
- `Everything that happens in R is a` **`function`** `call.`
- **`Interfaces`** `to other languages are a part of R.`

1 R Objects

- R provides a number of specialized data structures: **R objects**.
- The most common types of R objects[1] are:
  - **logical**, **integer**, **double**, **character**, [**complex**, **raw**] (atomic vectors)
  - **list** (heterogeneous/recursive vectors)
  - **closure** (functions)
  - **environment**
  - **S4**
  - **symbol** (variable name)
  - **NULL**
- An R object can be referred to by symbols/variables.

- The **type** of an object in R is determined by the **typeof()** function.

1.1 The creation of R objects

- The following code creates an R object (vector of 4 integers) which bears the name **x**, e.g.:

```
x <- c(3L,17L,12L,5L)
x
```

```
[1]  3 17 12  5
```

```
cat(sprintf(" typeof(x):%s\n", typeof(x)))
```

```
 typeof(x):integer
```

Under the hood it passes through the following steps:

  - creation of an R object i.e. vector of 4 integers in memory.
  - binding/assigning the R object to the variable name x using **<-** (left arrow symbol).

- There are **less common** ways to bind variables to R objects:

  - A simple equality sign (**=**). This approach is mainly used to assign default function arguments.
  - Using the **assign()** function.

1.1.1 Examples

- **preferred** way to assign variables

```
x <- 5.0
x
```

```
[1] 5
```

```
cat(sprintf("typeof(x):%s\n", typeof(x)))
```

```
typeof(x):double
```

[1] For people interested in the details we recommend to have a look at the file *R Internals* and the R source code (especially the header file *Rinternals.h*) where all the current object types are defined.

- **less common** way to assign variables
  - Alternative 1:

    ```
    y = 5.0
    y
    ```

    ```
    [1] 5
    ```

    ```
    cat(sprintf("typeof(y):%s\n", typeof(y)))
    ```

    ```
    typeof(y):double
    ```

  - Alternative 2:

    ```
    assign("z",5.0)
    z
    ```

    ```
    [1] 5
    ```

    ```
    cat(sprintf("typeof(y):%s\n", typeof(y)))
    ```

    ```
    typeof(y):double
    ```

- functions are objects (as stated previously)

```
myvar <- function(x, av=0){

  n <- length(x)
  if(n>1){
    return(1.0/(n-1)*sum((x-av)^2))
  }else{
    stop("ERROR:: Dividing by zero (n==1) || (n==0) ")
  }
}
cat(sprintf("typeof(myvar):%s\n", typeof(myvar)))
```

```
typeof(myvar):closure
```

```
x <- rnorm(100)
myvar(x)
```

```
[1] 0.9220099
```

```
myvar(x,mean(x))
```

```
[1] 0.9200559
```

```
var(x)
```

```
[1] 0.9200559
```

1.2 The deletion of R objects

You can remove objects from (the current environment) by invoking the **rm()** function. The removal process consists of 2 steps i.e.:

- the binding between the variable name and the R object is severed.
- the R object is automatically removed from memory by R's internal garbage collector (**gc()**).

1.2.1 Examples

- Remove the variable x from the current environment

```r
ls()
```

```
[1] "myvar" "x"     "y"     "z"
```

```r
rm(x)
ls()
```

```
[1] "myvar" "y"     "z"
```

- Remove **all** variables from the current environment

```r
ls()
```

```
[1] "myvar" "y"     "z"
```

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

```
character(0)
```

"Nothing exists except atoms and empty space; everything else is opinion". (Democritos)

2 Atomic Data Types

2.1 The core/atomic data types

- R has the following 6 **atomic** data types:
  - logical (i.e. boolean)
  - integer
  - double
  - character (i.e. string)
  - complex
  - raw (i.e. byte)

The latter 2 types (i.e. complex and especially raw) are less common.

The **typeof()** function determines the **INTERNAL** storage/type of an R object.

2.1.1 Examples

- boolean/logical values: either **TRUE** or **FALSE**

```r
x1 <- TRUE
x1
```

```
[1] TRUE
```

```r
typeof(x1)
```

```
[1] "logical"
```

- integer values ($\in \mathbb{Z}$):

```r
x2 <- 3L
x2
```

```
[1] 3
```

```r
typeof(x2)
```

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

- double (precision) values:

```r
x3 <- 3.14
x3
```

```
[1] 3.14
```

```r
typeof(x3)
```

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

- character values/strings

```r
x4 <- "Hello world"
x4
```

```
[1] "Hello world"
```

```r
typeof(x4)
```

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

- complex values ($\in \mathbb{C}$):

```r
x5 <- 2.0 + 3i
x5
```

```
[1] 2+3i
```

```r
typeof(x5)
```

```
[1] "complex"
```

2.2 Operations on atomic data types

- **logical** operators: **==**, **!=**, **&&**, **||**, **!**
- **numerical** operators: **+**, **-**, *****, **/**, **^**, ****** (same as the caret), but also:
  - integer division: **%/%**
  - modulo operation: **%%**
  - Note: matrix multiplication will be performed using **%*%**
- **character/string** manipulation:
  - **nchar()**:
  - **paste()**:
  - **cat()**:
  - **sprintf()**:
  - **substr()**:
  - **strsplit()**:
  - Note: Specialized R libraries were developed to manipulate strings e.g. *stringr*
- explicit **cast**/conversion: https://data-flair.training/blogs/r-string-manipulation/
  - **as.{logical, integer, double, complex, character}()**
- explicit **test** of the type of a variable:
  - **is.{logical, integer, double, complex, character}()**

2.2.1 Examples

- Logical operators:

```
x <-3
y <-7
(x<=3) &&(y==7)
```

```
[1] TRUE
```

```
!(y<7)
```

```
[1] TRUE
```

- Mathematical operations

```
2**4
```

```
[1] 16
```

```
7%%4
```

```
[1] 3
```

```
7/4
```

```
[1] 1.75
```

```
7%/%4
```

```
[1] 1
```

- String operations

```r
s <- "Hello"
nchar(s)
```

```
[1] 5
```

```r
news <- paste(s,"World")
news
```

```
[1] "Hello World"
```

```r
sprintf("My new string:%20s\n", news)
```

```
[1] "My new string:          Hello World\n"
```

```r
city <- "Witwatersrand"
substr(city,4,8)
```

```
[1] "water"
```

- Conversion and testing of types

```r
s <- "Hello World"
is.character(s)
```

```
[1] TRUE
```

```r
s1 <- "-500"
is.character(s1)
```

```
[1] TRUE
```

```r
s2 <- as.double(s1)
is.character(s2)
```

```
[1] FALSE
```

```r
is.double(s2)
```

```
[1] TRUE
```

```r
s3 <- as.complex(s2)
s3
```

```
[1] -500+0i
```

```r
sqrt(s3)
```

```
[1] 0+22.36068i
```

2.3 Exercises

-
  - Calculate $\log_2(10)$ using R's **log()** function.
    The **default** version of **log()** is $\log_e() := \ln()$.
    Use **help(log)** to find the appropriate arguments for the **log()** function.
  - Perform the inverse operation (i.e. to obtain 10).

-
  - R's **round()** function rounds (by default) a real number to 0 decimal places. Round the number π to 4 decimal places.
  - **Note:**
    * You can generate the value for π as: $4.0 * \textbf{atan}(1.0)$.
    * Use **help(round)** to find the appropriate arguments for the **round()** function.
- Let $z = 3 + 4i$
  - Use R's **Re()**, **Im()** functions to extract the real and imaginary parts of z.
  - Calculate the modulus of z using R's **Mod()** function and check
    whether you the same answer using $\sqrt{\Re(z)^2 + \Im(z)^2}$.
  - Calculate the argument of z using R's **Arg()** function and check
    whether you have the same answer using $\arctan\left(\frac{\Im(z)}{\Re(z)}\right)$.

3 Atomic vectors

- An **atomic** vector is a data structure containing elements of **only one atomic** data type. Therefore, an atomic vector is **homogeneous**.
- Atomic vectors are stored in a **linear** fashion.
- R does **NOT** have scalars:
  - An atomic vector of **length 1** plays the role of a scalar.
  - Vectors of **length 0** also exist (and they have some use!).
- A **list** is a vector not necessarily of the atomic type.
  A list is also known as a **recursive/generic** vector (*vide infra*).

3.1 Creation of atomic vectors

Atomic vectors can be created in a multiple ways:

- Use of the **vector()** function.
- Use of the **c()** function (**c** stands for *combine*).
- Use of the column operator **:**
- Use of the **seq()** and **rep()** functions.

The length of a vector can be retrieved using the **length()** function.

3.1.1 Examples

- use of the **vector()** function:

```
x <- vector()  # Empty vector (Default:'logical')
x
```

```
logical(0)
```

```
length(x)
```

```
[1] 0
```

```
typeof(x)
```

```
[1] "logical"
```

```
x <- vector(mode="complex", length=4)
x
```

```
[1] 0+0i 0+0i 0+0i 0+0i
```

```
length(x)
```

```
[1] 4
```

```
x
```

```
[1] 0+0i 0+0i 0+0i 0+0i
```

```
x[1] <- 4
x
```

```
[1] 4+0i 0+0i 0+0i 0+0i
```

- use of the **c()** function:

```
x1 <- c(3, 2, 5.2, 7)
x1
```

```
[1] 3.0 2.0 5.2 7.0
```

```
x2 <- c(8, 12, 13)
x2
```

```
[1]  8 12 13
```

```
x3 <- c(x2, x1)
x3
```

```
[1]  8.0 12.0 13.0  3.0  2.0  5.2  7.0
```

```
x4 <- c(FALSE,TRUE,FALSE)
x4
```

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

```
x5 <- c("Hello", "Salt", "Lake", "City")
x5
```

```
[1] "Hello" "Salt"  "Lake"  "City"
```

- use of the column operator:

```
y1 <- 1:10
y1
```

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

```
y2 <- 5:-5
y2
```

```
 [1]  5  4  3  2  1  0 -1 -2 -3 -4 -5
```

```
y3 <- 2.3:10
y3
```

```
[1] 2.3 3.3 4.3 5.3 6.3 7.3 8.3 9.3
```

```
y4 <- 2.0*(7:1)
y4
```

```
[1] 14 12 10  8  6  4  2
```

```r
y5 <- (1:7) - 1
y5
```

```
[1] 0 1 2 3 4 5 6
```

- **seq()** and **rep()** functions

```r
z1 <- seq(from=1, to=15, by=3)
z1
```

```
[1]  1  4  7 10 13
```

```r
z2 <- seq(from=-2,to=5,length=4)
z2
```

```
[1] -2.0000000  0.3333333  2.6666667  5.0000000
```

```r
z3 <- rep(c(3,2,4), time=2)
z3
```

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

```r
z4 <- rep(c(3,2,4), each=3)
z4
```

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

```r
z5 <- rep(c(1,7), each=2, time=3)
z5
```

```
 [1] 1 1 7 7 1 1 7 7 1 1 7 7
```

```r
length(z5)
```

```
[1] 12
```

3.1.2 Exercises

- Use the **seq()** function to generate the following sequence:
  6 13 20 27 34 41 48
- Create the following R vector using **only** the **seq()** and **rep()** functions:
  -8 -8 -8 -8 0 8 8 8 16 16 16 16 16

3.2 Operations on vectors: element-wise

- All operations on vectors in R happen **element by element** (cfr. *NumPy*).
- **Vector Recycling**:

  If 2 vectors of **different** lengths are involved in an operation, the **shortest vector** will be repeated until all elements of the longest vector are matched.
  A *warning* message will be sent to the stdout.

3.2.1 Examples

```
x <- -3:3
x
```

```
[1] -3 -2 -1  0  1  2  3
```

```
y <- 1:7
y
```

```
[1] 1 2 3 4 5 6 7
```

```
xy <- x*y
xy
```

```
[1] -3 -4 -3  0  5 12 21
```

```
xpy <- x^y
xpy
```

```
[1]   -3    4   -1    0    1   64 2187
```

```
x <- 0:10
y <- 1:2
length(x)
```

```
[1] 11
```

```
length(y)
```

```
[1] 2
```

```
x
```

```
 [1]  0  1  2  3  4  5  6  7  8  9 10
```

```
y
```

```
[1] 1 2
```

```
x+y
```

```
Warning in x + y: longer object length is not a multiple of shorter object
length

 [1]  1  3  3  5  5  7  7  9  9 11 11
```

3.2.2 Exercises

- Create the following vector (do **not** use **c()**!):
  -512 -216 -64 -8 0 8 64 216 512 1000

3.3 Retrieving elements of vectors

- Indexing: starts at **1** (**not 0** like C/C++, Python, Java, ….) see also: Edsger Dijkstra: Why numbering should start at zero
- Use of vector with indices to extract values.
- Advanced features:
  - use of boolean values to extract values.
  - the membership operator: **%in%**.
  - the deselect/omit operator: **-**
  - **which()**: returns the indices for which the condition is true.
  - **any()**/**all()** functions.
    - **any()** : **TRUE** if at least 1 value is true
    - **all()** : **TRUE** if all values are true

3.3.1 Examples

- Use of a simple index:

```
x <- seq(2,100,by=15)
x
```

```
[1]  2 17 32 47 62 77 92
```

```
x[4]
```

```
[1] 47
```

```
x[1]
```

```
[1] 2
```

- Select several indices at once using vectors:

```
x
```

```
[1]  2 17 32 47 62 77 92
```

```
x[3:5]
```

```
[1] 32 47 62
```

```
x[c(1,3,5,7)]
```

```
[1]  2 32 62 92
```

```
x[seq(1,7,by=2)]
```

```
[1]  2 32 62 92
```

- Extraction via booleans (i.e. retain only those values that are equal to **TRUE**):

```r
x
```

```
[1]  2 17 32 47 62 77 92
```

```r
x>45
```

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

```r
x[x>45]
```

```
[1] 47 62 77 92
```

- Use of the **%in%** operator:

```r
x
```

```
[1]  2 17 32 47 62 77 92
```

```r
10 %in% x
```

```
[1] FALSE
```

```r
62 %in% x
```

```
[1] TRUE
```

```r
c(32,33,43) %in% x
```

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

```r
!(c(32,33,43) %in% x)
```

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

- Negate/filter out the elements with **negative** indices:

```r
x <- c(1,13,17,27,49,91)
x
```

```
[1]  1 13 17 27 49 91
```

```r
x[-c(2,4,6)]
```

```
[1]  1 17 49
```

```r
z <- x[-1] - x[-length(x)]
z
```

```
[1] 12  4 10 22 42
```

- The **which()** function returns **only those indices** of which the condition/expression is **true**.

```r
# Sample 10 numbers from N(0,1)
vecnum <- rnorm(n=10)
vecnum
```

```
 [1] -0.21762551  0.05462450  0.06989174  0.91250665  0.56312441 -0.21607659
 [7] -2.04680647 -1.79808294 -0.74705420 -1.25622359
```

```r
which(vecnum>1.0)
```

```
integer(0)
```

- Use of the **any()**/**all()** functions.

```r
y <- seq(0,100,by=10)
x
```

```
[1]  1 13 17 27 49 91
```

```r
y
```

```
 [1]   0  10  20  30  40  50  60  70  80  90 100
```

```r
any(x<y)
```

```
Warning in x < y: longer object length is not a multiple of shorter object
length
```

```
[1] TRUE
```

```r
all(x[6:7]>y[2:3])
```

```
[1] NA
```

3.3.2 Exercises

- R has the its own inversion function, **rev()**, e.g.:

  ```r
  x <- seq(from=2,to=33,by=3)
  x
  ```

  ```
   [1]  2  5  8 11 14 17 20 23 26 29 32
  ```

  ```r
  y <- rev(x)
  y
  ```

  ```
   [1] 32 29 26 23 20 17 14 11  8  5  2
  ```

  Invert the vector x without invoking the **rev()** function.

- The `Taylor series` for $\ln(1+x)$ is converging when $|x| < 1$ and is given by:

$$\ln(1+x) = x - \frac{x^2}{2} + \frac{x^3}{3} - \frac{x^4}{4} + \frac{x^5}{5} - \frac{x^6}{6} + \ldots$$

Calculate the sum of the first 5, 10, 15 terms in the above expression to approximate $\ln(1.2)$. Compare with `R`'s value i.e.: **log(1.2)**.

- The `logarithmic` return in finance is defined as:

$$R_t = \ln\left(\frac{P_t}{P_{t-1}}\right)$$

  - Generate a financial time series using the following `R` code:

```
price <- abs(rcauchy(1000))+1.E-6
```

  - Calculate the `logarithmic return` for the financial time series `price`. The newly created time series will be 1 element shorter in length than the original one. Compare your result with **diff(log(price))**.

- `Monte-Carlo` approximation of π

Let `S1` be the square spanned by the following 4 vertices: $\{(0,0),(0,1),(1,0),(1,1)\}$. Let `S2` be the first quadrant of the unit-circle $\mathcal{C} : x^2 + y^2 = 1$.

The ratio ρ defined as:

$$\rho := \frac{\text{Area S2}}{\text{Area S1}} = \frac{\#\text{Points in S2}}{\#\text{Points in S1}}$$

allows us to estimate $\frac{\pi}{4}$ numerically.

Therefore:

  - Sample 100000 independent x-coordinates from `Unif`.
  - Sample 100000 independent y-coordinates from `Unif`.
  - Calculate an approximate value for π using the Monte-Carlo approach.

Note: The uniform distribution $[0, 1)$ (`Unif`) can be sampled using **runif()**.

3.4 Hash tables

A **hash table** is a data structure which implements an associative array or dictionary. It is an abstract data which maps data to keys.

- There are several ways to create one:
  - Map names to an existing vector
  - Add names when creating the vector
- To remove the map, map the names to NULL

3.4.1 Examples

- Creation of 2 independent vectors

```
capitals <- c("Albany", "Providence", "Hartford", "Boston", "Montpelier",
              "Concord", "Augusta")
states <- c("NY", "RI", "CT", "MA", "VT", "NH", "ME")
capitals
```

```
[1] "Albany"     "Providence" "Hartford"   "Boston"     "Montpelier"
[6] "Concord"    "Augusta"
```

```r
states
```

```
[1] "NY" "RI" "CT" "MA" "VT" "NH" "ME"
```

```r
capitals[3]
```

```
[1] "Hartford"
```

- Create the hashtable/dictionary

```r
# Method 1
names(capitals) <- states
capitals
```

```
          NY           RI           CT           MA           VT           NH 
    "Albany" "Providence"   "Hartford"     "Boston" "Montpelier"    "Concord" 
          ME 
   "Augusta" 
```

```r
capitals["MA"]
```

```
      MA 
"Boston" 
```

```r
names(capitals)
```

```
[1] "NY" "RI" "CT" "MA" "VT" "NH" "ME"
```

```r
# Method 2
phonecode <- c("801"="SLC", "206"="Seattle", "307"="Wyoming")
phonecode
```

```
      801       206       307 
    "SLC" "Seattle" "Wyoming" 
```

```r
phonecode["801"]
```

```
  801 
"SLC" 
```

- Dissociate the 2 vectors

```r
names(capitals) <- NULL
capitals
```

```
[1] "Albany"      "Providence" "Hartford"   "Boston"      "Montpelier"
[6] "Concord"     "Augusta"
```

3.5 NA (Not Available values)

- **NA**: stands for 'Not Available'/Missing values and has a length of 1.
  There are in essence 4 versions depending on the type:
  - **NA** (logical - **default**)
  - **NA_integer** (integer)
  - **NA_real** (double precision)
  - **NA_character** (string)

  Under the hood, the version of NA is subjectd to **coercion**:
  logical → *integer* → *double* → *character*
- some functions e.g. **mean()** return (by default) NA if
  1 or more instances NA are present in a vector.
- **is.na()**: test a vector (element-wise) for NA values.
  Do NOT use:

  ```
  x == NA
  ```

  but use INSTEAD:

  ```
  is.na(x)
  ```

3.5.1 Examples

- Types of NA

```
x <- NA
typeof(x)
```

```
[1] "logical"
```

```
# logical NA coerced to double precision NA
x <- c(3.0, 5.0, NA)
typeof(x[3])
```

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

* Functions on a vector containing NA

```
mean(x)
```

```
[1] NA
```

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

```
[1] 4
```

* Check of the NA availability

```
x <- c(NA, 1, 2, NA)
is.na(x)
```

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

* Functions on a vector containing NA

```
mean(x)
```

```
[1] NA
```

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

```
[1] 1.5
```

3.5.2 Exercises

- A family has installed a device to monitor their daily energy consumption (in kWh). When a measurement fails or is unavailable NA is recorded.

  You can invoke the following code to generate the measurements generated by the device.

  ```
  dailyusage <- 30.0 + runif(365, min=0, max=5.0)
  dailyusage[sample(1:365, sample(1:50,1), replace=FALSE)] <- NA
  ```

  - How many measurements failed?
  - What is the average daily energy consumption (based on the non-failed) measurements?

3.6 NaN and infinities

- **NaN** (only for numeric types!), and the infinties **Inf** and **-Inf** are part of the IEEE 754 floating-point standard.
- To test whether you have:
  - finite numbers: use **is.finite()**
  - infinite numbers: use **is.infinite()**
  - NaNs: use **is.nan()**
- Further:
  - a **NaN** will return **TRUE** only when tested by **is.nan()**
  - a **NA** will return **TRUE** when tested by either **is.nan()** or **is.na()**

3.6.1 Examples

- Infinities:

```
x <- 5.0/0.0
x
```

```
[1] Inf
```

```r
is.finite(x)
```

```
[1] FALSE
```

```r
is.infinite(x)
```

```
[1] TRUE
```

```r
is.nan(x)
```

```
[1] FALSE
```

```r
y <- -5.0/0.0
y
```

```
[1] -Inf
```

```r
is.finite(y)
```

```
[1] FALSE
```

```r
is.infinite(y)
```

```
[1] TRUE
```

```r
is.nan(y)
```

```
[1] FALSE
```

```r
z <- x + y
z
```

```
[1] NaN
```

```r
typeof(z)
```

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

```r
is.finite(z)
```

```
[1] FALSE
```

```r
is.infinite(z)
```

```
[1] FALSE
```

```r
is.nan(z)
```

```
[1] TRUE
```

- **is.na()** vs. **is.nan()**:

```r
# is.nan
v <- c(NA, z, 5.0, log(-1.0))
```

```
Warning in log(-1): NaNs produced
```

```r
is.nan(v)
```

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

```r
# is.na(): also includes NaN!
v <- c(NA, z, 5.0, log(-1.0))
```

```
Warning in log(-1): NaNs produced
```

```r
is.na(v)
```

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

3.7 Note on logical operators

- **&**, **|**, **!**, **xor()**: **element-wise** operators on vectors (cfr. arithmetic operators)
- **&&**, **||**: evaluated from **left** to **right** until result is determined.

3.7.1 Examples

- Vector operators (**&**, **|**, **!** and **xor()**)

```r
x <- sample(x=1:10, size=10, replace=TRUE)
x
```

```
 [1]  5  1 10  3  4  6  3  4 10  6
```

```r
y <- sample(x=1:10, size=10, replace=TRUE)
y
```

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

```r
v1 <- (x<=3)
v1
```

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

```r
v2 <- (y>=7)
v2
```

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

```r
v1 & v2
```

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

```r
v1 | v2
```

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

```r
xor(v1, v2)
```

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

```r
!v1
```

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

3.7.2 Exercises

- Generate a random vector of integers using the following code:

  ```r
  x <- sample(x=0:1000,size=100, replace=TRUE)
  ```

  - Invoke the above code to generate the vector `x`
  - Find if there are any integers in the vector `x` which can be divided by 4 and 6
  - Find those numbers and their corresponding indices in the vector `x`.