R Data Types - part I

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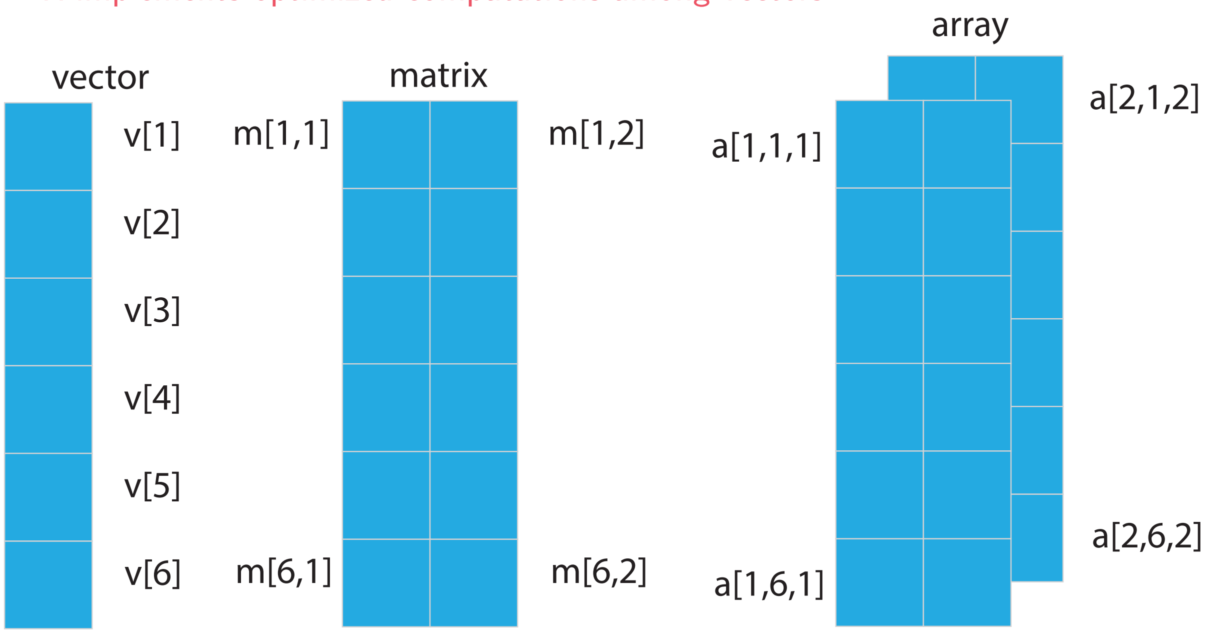
R data types: atomic vectors

- the basic data structure is a `vector` : a sequence of values stored in contiguous memory areas
- the `matrix` is a 2-dim representation of a vector
- the `array` is a multi-dimensional vector (with $\dim > 2$)
- `vector`, `matrix` and `array` are atomic types : all elements must be of same type

➜ R implements optimized computations among vectors



R is dynamically-typed language

- R is a dynamically-typed language

```
x <- 1L
y <- 2
x + y
# [1] 3

y <- 5.6
x + y
# [1] 6.6
```

→ Dynamic typing allows to assign a value of a different data type to the same variable at any time

```
y <- "Test"

x + y
# Error in x + y : non-numeric argument to binary operator
```

→ But the operation is acknowledged with an error if the data types of the two variables are not compatible

All variables do not need to be declared

R vectors

- scalar types do not exist, they are considered one-element vectors

```
x <-4.7; length(x)
# [1] 1
```

- longer vectors are usually created with the concatenate, `c()`, function

→ the size of a vector is determined at creation time

```
y <- c(1, 2, 5, 8)
str(y)
#  num [1:4] 1 2 5 8
```

- `c()` calls can be combined:

```
y <- c(y, 12, c(1, 7, 8))
str(y)
#  num [1:8] 1 2 5 8 12 1 7 8
```

Useful functions to inspect data types and storage

class()

- tell us what sort of data we have

```
x <- c(3, 7, 9)
class(x)
# [1] "numeric"
```

typeof() / storage.mode()

- get or set the mode (i.e. the type), or the storage mode of an R object

```
typeof(x)
# [1] "double"
```

length()

- returns the number of element in the object

```
length(3)
# [1] 3
```

str()

- Compactly display the internal structure of an R object

```
str(x)
# num [1:3] 3 7 9
```

Vector Maths

- several Maths functions are available for vectors

```
(x <- 3:1)
# [1] 3 2 1

str(x)
# int [1:3] 3 2 1

f1 <- 2.5
x*f1
# [1] 7.5 5.0 2.5


f2 <- c(4, 2)
x*f2
# [1] 12  4  4
# Warning message:
# In x * f2 : longer object length is not a multiple
#             of shorter object length
```

The shorter vector, f2, is duplicated to cover the length of x

```
f3 <- c(4, 2, 1)
x*f3
# [1] 12  4  1
```

Vector indexing - (1)

- the advantage of vector-based language is that it is simple to make computation involving all values in the vector

```
probe <- c(4, 7, 6, 5, 6, 7)
length(probe)
# [1] 6
mean(probe)
# [1] 5.833333
min(probe)
# [1] 4
max(probe)
# [1] 7
```

- sub-scripting is done through square brackets [] (indexing starts at '1')

```
probe[2]
# [1] 7
```

- sub-scripting can be done with vectors

```
index <- c(1, 3, 4, 6) # a vector of selected indexes
probe[index]
# [1] 4 6 5 7
probe[c(1, 3, 4, 6)] # this is also valid
# [1] 4 6 5 7
```

Generating sequences - :,seq()

- R provides and easy way to generate a sequence of numbers

```
0:10 # a sequence from 0 to 10, in steps of 1
#  [1]  0  1  2  3  4  5  6  7  8  9 10

10:-5 # a sequence from 15, down to -5
# [1] 10  9  8  7  6  5  4  3  2  1  0 -1 -2 -3 -4 -5
```

- the seq() function allows to generate sequences in steps other than 1

```
seq(-2, 3, 0.5)
#  [1] -2.0 -1.5 -1.0 -0.5  0.0  0.5  1.0  1.5  2.0  2.5  3.0

seq(6, 4.2, -0.2)
#  [1] 6.0 5.8 5.6 5.4 5.2 5.0 4.8 4.6 4.4 4.2
```

- or with a fixed vector length

```
seq(from=0.04, to=0.14, length=6)
# [1] 0.04 0.06 0.08 0.10 0.12 0.14

seq(from=0.04, to=0.14, length=7)
# [1] 0.04000000 0.05666667 0.07333333 0.09000000 0.10666667
# [6] 0.12333333 0.14000000
```

Vector indexing - (2)

- unwanted values can be dropped using negative indexes

```
probe <- c(4, 7, 6, 5, 6, 7) ; probe
# [1] 4 7 6 5 6 7

probe[-1] # remove the first element
# [1] 7 6 5 6 7

probe[-length(probe)] # remove the last element
# [1] 4 7 6 5 6
```

- write a function to remove the smallest two values (with index 1 and 2) and largest two values (which will have subscripts `length(x)` and `length(x)-1`)

```
trim <- function(x) sort(x)[-c(1,2,length(x)-1,length(x))]
trim(probe)
# [1] 6 6
```

- sequences can be used to extract values

```
probe[1:3]
# [1] 4 7 6
probe[seq(1,length(probe),2)]
# [1] 4 6 6
probe[seq(1,length(probe),2)] # get odd indexes values
# [1] 4 6 6
probe[seq(2,length(probe),2)] # get even indexes values
# [1] 7 5 7
```

Vectors and logical subscripts

```
(x <- 0:10)
# [1]  0  1  2  3  4  5  6  7  8  9 10

sum(x)
# [1] 55
```

- What is the result of `sum( x < 5 )` ?

```
sum(x<5)
# [1] 5
```

- the first `sum()` call sums up all the numbers in the vector
- the second call does not return the sum of the values which are lower than five

```
x<5
# [1] TRUE TRUE TRUE TRUE TRUE FALSE FALSE FALSE FALSE FALSE FALSE
```

- x<5 is a vector of logicals, but summing it up R converts logical `TRUE` to 1 and `FALSE` to 0
- we need vector sub-scripting to perform the desired sum

```
x[x<5]
# [1] 0 1 2 3 4

sum(x[x<5])
# [1] 10
```

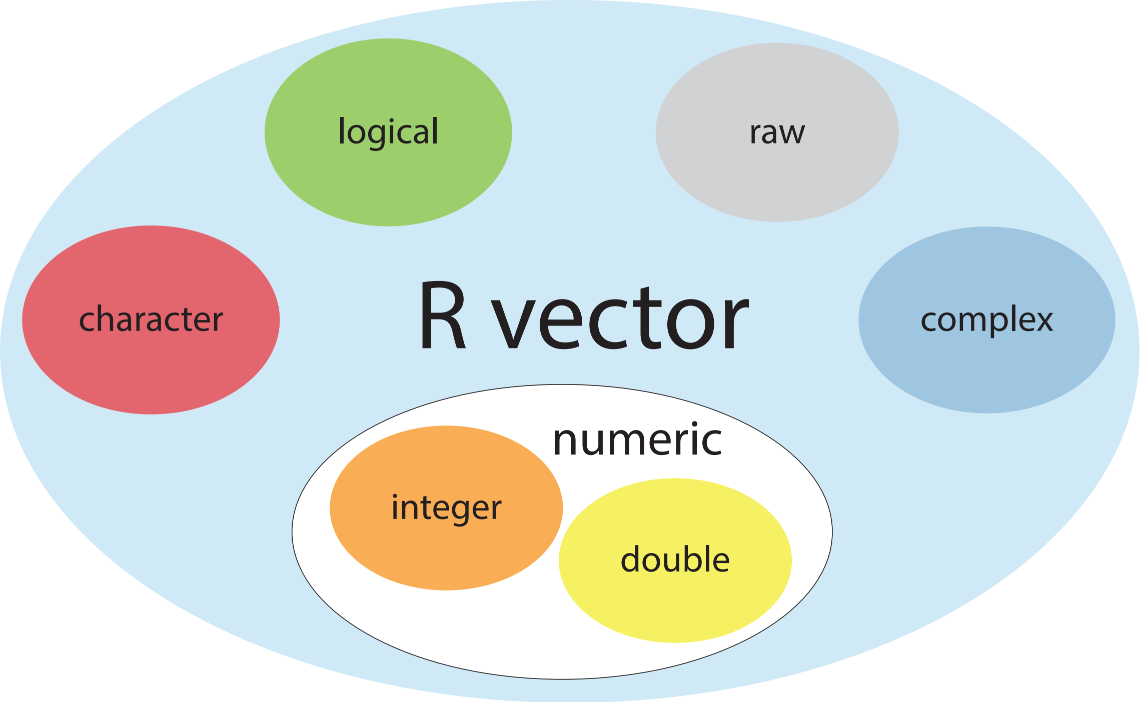
Generating replicated values - rep()

- the function rep() replicates the values in a vector

```
rep (9,5) # replicate 5 times the number 9
# [1] 9 9 9 9 9

rep(1:4, 2) # replicate twice the 1:4 sequence
# [1] 1 2 3 4 1 2 3 4

rep(1:4, each=2) # replicate twice each sequence number
# [1] 1 1 2 2 3 3 4 4

rep(1:4, each=2, times=3)
#  [1] 1 1 2 2 3 3 4 4 1 1 2 2 3 3 4 4 1 1 2 2 3 3 4 4


# replicate each sequence number a different number of times
rep(1:4, 1:4)
#  [1] 1 2 2 3 3 3 4 4 4 4

rep(c("cat","dog","mouse"), c(2,3,2))
# [1] "cat"   "cat"   "dog"   "dog"   "dog"   "mouse" "mouse"
```

R vector types

- 4 standard vector types are commonly used: double and integer (under the numeric class), character, and logical
- plus two rare types: complex and raw



Vector - numeric

- double is the default type for all numbers

```
n <- c(1, 3, 12)

class(n)
[1] "numeric"

typeof(n)
# [1] "double"

str(n)
# num [1:3] 1 3 12
```

- integer is assumed for all sequences
  or for numbers with the L suffix

```
n <- c(1L, 3L, 12L)

class(n)
# [1] "integer"

typeof(n)
# [1] "integer"

str(n)
# int [1:3] 1 3 12
```

Vector - logical

- logical vectors can assume two possible values:
  TRUE or FALSE
- it can be abbreviated with T and F

```
x <- -5:5
# Select the positive numbers in the vector
l.positive <- x > 0

# Select all even numbers
l.even <- x %% 2 == 0

# and the odd numbers
l.odd <- x %% 2 > 0

# Get all odd, positive numbers
x[l.odd & l.positive]
# [1] 1 3 5

# and all even, positive numbers
x[l.even & l.positive]
# [1] 2 4
```

Vector - character

- logical vectors can assume two possible values:

```
k <- c("one", "two", "three", "one")
class(k)
# [1] "character"

typeof(k)
# [1] "character"

str(k)
# chr [1:4] "one" "two" "three" "one"
```

Infinity - Inf

- calculations can lead to results which go to ±∞ or are indeterminate

```
4/0
# [1] Inf

-15/0
# [1] -Inf
```

- but calculations involving ±∞ are properly evaluated

```
exp(-Inf)
# [1] 0

exp(Inf)
# [1] Inf

0/Inf
# [1] 0

(0:3)^Inf
# [1]   0   1 Inf Inf
```

Not a Number: NaN

- some calculations may lead to results which are indeterminate, i.e. not numbers

```
0/0
# [1] NaN

Inf - Inf
# [1] NaN

Inf/Inf
# [1] NaN
```

- there are functions to test weather a number is finite or infinite

```
v1 <- c(-4.5, 0/0, exp(Inf))

is.finite(v1)
# [1]  TRUE FALSE FALSE

is.infinite(v1)
# [1] FALSE FALSE  TRUE

is.nan(v1)
# [1] FALSE  TRUE FALSE
```

Missing or unknown values: NA

- R represents missing or unknown values with the sentinel NA
- but most computations with NA will return NA

```
NA > 0; 2.7*NA; ! NA
# [1] NA
# [1] NA
# [1] NA
```

- exception: when some identity holds for all possible inputs

```
NA ^ 0
# [1] 1
NA | TRUE
# [1] TRUE
NA & FALSE
# [1] FALSE
```

- but, how do we check for NA values ?

```
y <- c(4, NA, -8)
y == NA  # it does not work, sets all to NA
# [1] NA NA NA

y == "NA" # this does not work, either
# [1] FALSE    NA FALSE

is.na(y) # this is the proper way
# [1] FALSE  TRUE FALSE

y[! is.na(y)] # produce a vector with NAs removed
# [1]  4 -8
```

Factors

- Factors are categorical variables that have a fixed number of levels

```
gender <- c("Male", "Female", "Male", "Male", "Female", "Female")
class(gender)
# [1] "character"

mode(gender)
# [1] "character"

str(gender)
# chr [1:6] "Male" "Female" "Male" "Male" "Female" "Female"
```

- Factors are stored internally as numbers

```
gender <- factor(gender)
class(gender)
# [1] "factor"

mode(gender)
# [1] "numeric"

str(gender)
Factor w/ 2 levels "Female","Male": 2 1 2 2 1 1

levels(gender)
# [1] "Female" "Male"
```

R vector functions

Function	Description
`max(x)`	the maximum value in `x`
`min(x)`	the minimum value in `x`
`sum(x)`	the sum of all values in `x`
`mean(x)`	arithmetic average of the values in `x`
`median(x)`	median value in `x`
`range(x)`	a vector with `min(x)` and `max(x)`
`var(x)`	sample variance of `x`
`cor(x,y)`	correlation between `x` and `y` vectors
`sort(x)`	a sorted version of `x`
`rank(x)`	a vector with the ranks of the `x` values
`order(x)`	a vector with the permutations to sort `x` in asc order
`quantile(x)`	a vector with: minimum, lower quantile, median, upper quantile and maximum of `x`
`cumsum(x)`	a running sum of the vector elements
`cumprod(x)`	a running product of the vector elements
`cummax(x)`	a vector of non-decreasing numbers with the cumulative maxima
`cummin(x)`	a vector of non-decreasing numbers with the cumulative minima
`pmax(x, y, z)`	vector containing the maximum of `x, y` or `z` for each position
`pmin(x, y, z)`	vector containing the minimum of`x, y` or `z` for each position
`colMeans(x)`	column means of a dataframe or matrix
`colSums(x)`	column sums of a dataframe or matrix
`rowMeans(x)`	row means of a dataframe or matrix
`rowSums(x)`	row sums of a dataframe or matrix

Vector attribute: names

- a vector can be given a name in three ways

```
# When creating it
x <- c(a = 1, b = 2, c = 3)


# By assigning a character vector to names()
x <- 1:3
names(x) <- c("a", "b", "c")


# Inline, with the function setNames()
(x<- setNames(1:3, c("a", "b", "c")))
# a b c
# 1 2 3
```

- vector names can be retrieved with the function names()

```
names(x)
# [1] "a" "b" "c"
```

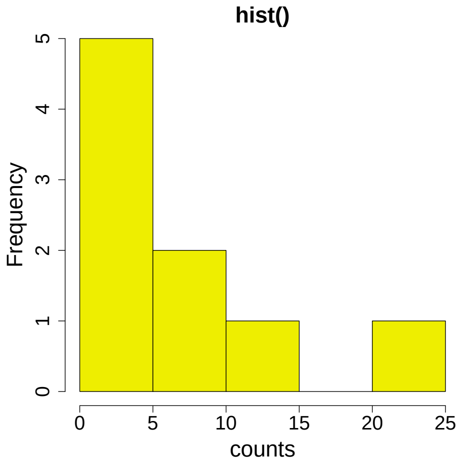
- and removed with uname(), or setting names(x) <- NULL

```
unname(x)
# [1] 1 2 3
names(x) <- NULL
x
# [1] 1 2 3
```

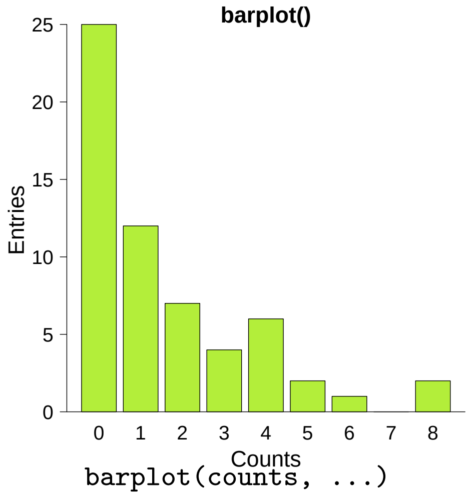
Example : naming vector elements

- sometimes is is useful to have values in a vector labeled
- for instance, we have a vector of counts occurrence of 0, 1, 2, ...

```
counts <- c(25,12,7,4,6,2,1,0,2)

names(counts) <- 0:(length(counts)-1)
str(counts)
# Named num [1:9] 25 12 7 4 6 2 1 0 2
# - attr(*, "names")= chr [1:9] "0" "1" "2" "3" ...

names(counts) <- NULL  # names can be easily removed
str(counts)
# num [1:9] 25 12 7 4 6 2 1 0 2
```



hist(counts, ...)



barplot(counts, ...)

Vector attribute: dimensions

- adding a dim attribute to a vector, changes it behavior to

- a 2D matrix dim = c(nrow, ncol)

```
v1 <- c(1:20)  ;   v1
 [1]  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20

class(v1)
# [1] "integer"

str(v1)
# int [1:20] 1 2 3 4 5 6 7 8 9 10 ...

# We transform the vector to a matrix 4 x 5:
dim(v1) <- c(4,5)

class(v1)
# [1] "matrix"

str(v1)
# int [1:4, 1:5] 1 2 3 4 5 6 7 8 9 10 ...

v1
#      [,1] [,2] [,3] [,4] [,5]
# [1,]    1    5    9   13   17
# [2,]    2    6   10   14   18
# [3,]    3    7   11   15   19
# [4,]    4    8   12   16   20
```

Vector attribute: dimensions

- adding a dim attribute to a vector, changes it behavior to

- a multi-dimensional array dim = c(dim1, dim2, ... dimn)

```
v1 <- c(1:20)

dim(v1) <- c(2,5,2)

class(v1)
# [1] "array"

str(v1)
# int [1:2, 1:5, 1:2] 1 2 3 4 5 6 7 8 9 10 ...

v1
# , , 1
#      [,1] [,2] [,3] [,4] [,5]
# [1,]    1    3    5    7    9
# [2,]    2    4    6    8   10
#
# , , 2
#      [,1] [,2] [,3] [,4] [,5]
# [1,]   11   13   15   17   19
# [2,]   12   14   16   18   20
```

Matrix

- An `matrix` is a bi-dimensional array where all the entries have the same class

```
(m1 <- matrix(1:12, nrow=3))
#      [,1] [,2] [,3] [,4]
# [1,]    1    4    7   10
# [2,]    2    5    8   11
# [3,]    3    6    9   12
```

- the default filling (by column) can be changed (`byrow = TRUE`)

```
(m2 <- matrix(1:12, nrow=4, byrow=T))
#      [,1] [,2] [,3]
# [1,]    1    2    3
# [2,]    4    5    6
# [3,]    7    8    9
# [4,]   10   11   12

class(m2)
# [1] "matrix" "array"
attributes(m2)
# $dim
# [1] 4 3
```

- we can "rearrange" the matrix by changing the number of rows and columns

```
dim(m2) <- c(2,6)
m2
#      [,1] [,2] [,3] [,4] [,5] [,6]
# [1,]    1    7    2    8    3    9
# [2,]    4   10    5   11    6   12
```

Matrix element access

- A `matrix` element is accessed with the syntax:

`A[row, col]`

```
(m1 <- matrix(1:12, nrow=3))
#      [,1] [,2] [,3] [,4]
# [1,]    1    4    7   10
# [2,]    2    5    8   11
# [3,]    3    6    9   12

print(m1[1,3])
# [1] 7
```

- it is possible to access a single row

`A[row, ]`

```
m1[1,]
# [1]  1  4  7 10
```

- and column

`A[, col]`

```
m1[,2]
# [1] 4 5 6
```

- and a subset of the full matrix (rows 1 2 and columns 2 and 3)

```
m1[1:2,2:3]
#      [,1] [,2]
# [1,]    4    7
# [2,]    5    8
```

Matrix Maths - product

- Let's define two matrices

```
(A <- matrix (c (1, 0, 4, 2, -1, 1), nrow = 3))
#      [,1] [,2]
# [1,]    1    2
# [2,]    0   -1
# [3,]    4    1

(B <- matrix (c (1, -1, 2, 1, 1, 0), ncol = 3))
#      [,1] [,2] [,3]
# [1,]    1    2    1
# [2,]   -1    1    0
```

- we can multiply them since (`nrows(A) = ncol(B)`)

```
A %*% B
#      [,1] [,2] [,3]
# [1,]   -1    4    1
# [2,]    1   -1    0
# [3,]    3    9    4

B %*% A
#      [,1] [,2]
# [1,]    5    1
# [2,]   -1   -3
```

Square Matrix Maths - diag() / det() / solve()

- we can define a 3×3 diagonal matrix

```
(I <- diag (1, nrow = 3, ncol = 3))
#      [,1] [,2] [,3]
# [1,]    1    0    0
# [2,]    0    1    0
# [3,]    0    0    1
```

- and compute the determinant of a square matrix

```
C <- matrix (c (1, 2, 4, 2, 1, 1, 3, 1, 2), nrow = 3)
det(C)
# [1] -5
```

- since the determinant is $\neq 0$ we can compute the inverse, C^{-1}

```
Cinv <- solve(C)
C %*% Cinv
#      [,1]         [,2]          [,3]
# [1,]    1 8.881784e-16 -2.220446e-16
# [2,]    0 1.000000e+00 -1.110223e-16
# [3,]    0 0.000000e+00  1.000000e+00
```

Solving system of linear equations with matrices

- Let's suppose we have the following linear system:

$$\begin{cases} 3x + 4y & = & 12 \\ x + 2y & = & 8 \end{cases}$$

```
(A <- matrix (c (3, 1, 4, 2), nrow = 2))
#      [,1] [,2]
# [1,]    3    4
# [2,]    1    2
(k <- matrix (c (12, 8), nrow = 2))
#      [,1]
# [1,]   12
# [2,]    8

v <- solve(A, k)
#       [,1]
# [1,]   -4
# [2,]    6
```

- the solution is $x = -4$ and $y = 6$

```
A %*% v
#      [,1]
# [1,]   12
# [2,]    8
```

Array

- An array is a multi-dimensional object where all the entries have the same class
- The dimensions of an array are specified by its `dim` argument

```
(ar <- array (1:24, dim = c (2, 4, 3)))
#
# , , 1
#      [,1] [,2] [,3] [,4]
# [1,]    1    3    5    7
# [2,]    2    4    6    8
#
# , , 2
#      [,1] [,2] [,3] [,4]
# [1,]    9   11   13   15
# [2,]   10   12   14   16
#
# , , 3
#      [,1] [,2] [,3] [,4]
# [1,]   17   19   21   23
# [2,]   18   20   22   24
```

- we can change it to a matrix by modifying the `dim` attribute

```
dim(ar) <- c(4,6)
ar
#      [,1] [,2] [,3] [,4] [,5] [,6]
# [1,]    1    5    9   13   17   21
# [2,]    2    6   10   14   18   22
# [3,]    3    7   11   15   19   23
# [4,]    4    8   12   16   20   24
```

Data Types testing and coercing

- we can always test whether objects are a particular type
- and also coerce them to a different type

```
lv <- c (T, F, T)

is.logical(lv)
# [1] TRUE

as.numeric(lv)
# [1] 1 0 1

as.character(lv)
# [1] "TRUE"  "FALSE" "TRUE"
```

Type	Testing	Coercing
Array	is.array()	as.array()
Character	as.character()	as.character()
Complex	is.complex()	as.complex()
Dataframe	is.data.frame()	as.data.frame()
Double	is.double()	as.double()
Factor	is.factor()	as.factor()
List	is.list()	as.list()
Logical	is.logical()	as.logical()
Matrix	is.matrix()	as.matrix()
Numeric	is.numeric()	as.numeric()
Raw	is.raw()	as.raw()
Time series	is.ts()	as.ts()
Vector	as.vector()	as.vector()