Vectors (part 1)

R Data Objects

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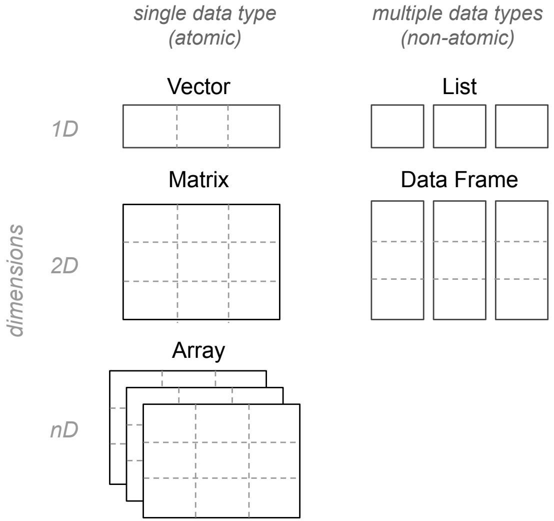
About

To make the best of the R language, you'll need a strong understanding of the basic **data types** and **data structures** and how to operate on them.

Basic Data Objects in R



Basic Data Objects in R

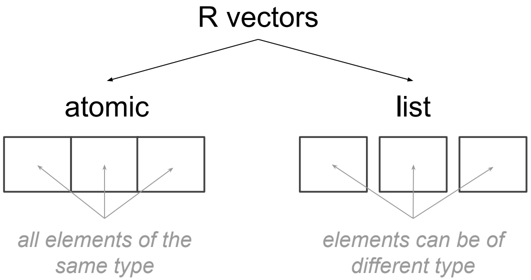
There are various data structures in R (we'll describe them in detail later):

- vectors and factors
- matrices (2-dimensional arrays)
- arrays (n-dim in general)
- lists
- data frames

Vectors

R Vectors

- A vector is the most basic data structure in R
- This is why I like to think of R as a *vector-based* language
- There are two flavors of vectors: **atomic** and **list**


R vectors
atomic
list
all elements of the same type
elements can be of different type

R Vectors

```r
# atomic vector
a = c(1, 2, 3)
a
```

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

```r
# list (non-atomic vector)
b = list(1, "two", TRUE)
b
```

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

[[2]]
[1] "two"

[[3]]
[1] TRUE
```

R Vectors

An atomic vector means that **all** its elements are of the same type.

In the R community, the term **vector** is typically associated with the atomic flavor of vectors.

Technically speaking, an R **list** is also a vector, although it's non-atomic in the sense that it can contain elements of different types.

To avoid confusion, unless otherwise noted, we'll use the term **vector** as a synonym for *atomic vector*, and we'll use the term **list** for a *non-atomic vector*.

Atomic Vectors

Atomic Vectors

The most simple type of atomic vectors are single values (i.e. vectors with just one element):

```r
# logical
a <- TRUE

# integer
x <- 1L

# double (real)
y <- 5

# character
b <- "yosemite"
```

Notice the appended `L` when specifying an `integer` type.

Basic Atomic Vectors

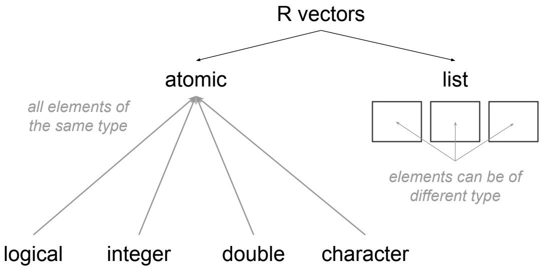
One way to create vectors with more than one element is with the function `c()` , short for **catenate** or **combine**:

```
# some vectors
x <- c(1, 2, 3, 4, 5)

y <- c("one", "two", "three")

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

Separate each element by a comma

Atomic Vectors

R has 4 (+ 2)* basic types of atomic vectors: `logical`, `integer`, `double` and `character`


R vectors
atomic
list
all elements of the same type
elements can be of different type
logical
integer
double
character

*There are two other (less used) data types: `complex` and `raw`.

Data types

- A **logical** vector holds `TRUE`, `FALSE` values
- An **integer** vector holds integers (no decimal component)
- A **double** vector holds double precision (“real”) numbers
- A **character** vector holds character strings
- *A **complex** vector holds complex numbers
- *A **raw** vector holds raw bytes

*We won’t be talking about complex and raw.

R Vectors

- Atomic vectors are contiguous cells containing data
- Can be of any length (including zero): `length()`
- They have a specific data type: `typeof()`
- Optionally, you can name their elements: `names()`
- Likewise, you can give them additional attributes with `attributes()`

Atomic Vectors

Use `typeof()` to find the data-type of an atomic vector:

```
a <- TRUE
typeof(a) # logical

x <- 1L
typeof(x)  # integer

y <- 5
typeof(y)  # double (real)

b <- "yosemite"
typeof(b)  # character
```

Notice the appended `L` when specifying an `integer` type.

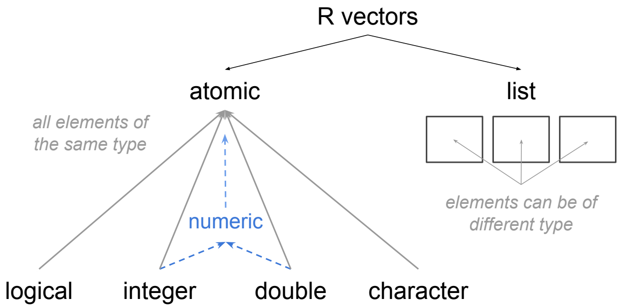
Special Values

There are some special values

- `NULL` is the null object (it has length zero); it is not a vector but it often plays the role of a zero-length vector.
- Missing values are referred to by the symbol `NA` ; there various flavors:
  - `NA` (“plain vanilla” logical missing value)
  - `NA_integer_` (integer missing value)
  - `NA_real_` (double missing value)
  - `NA_character_` (character missing value)
- `Inf` indicates positive infinite
- `-Inf` indicates negative infinite
- `NaN` indicates *Not a Number*

Atomic Vectors

For historical reasons (i.e. compatibility with S) R considers `integer` and `double` vectors as `numeric` types:


R vectors
atomic
list
all elements of the same type
elements can be of different type
numeric
logical
integer
double
character

Atomic Vectors

Both `integer` and `double` are grouped together under the `numeric` umbrella

```r
# integer
x <- 1L
is.numeric(x)
```

```
[1] TRUE
```

```r
# double (real)
y <- 5
is.numeric(y)
```

```
[1] TRUE
```

Atomic Vectors

Among useRs, it is common to refer to the **mode** of a vector, and to use the `mode()` function as a pseudo-equivalent of data-type:

value	example	mode	storage
logical	`TRUE, FALSE`	`logical`	`logical`
integer	`1L, 2L`	`numeric`	`integer`
double	`1, -0.5`	`numeric`	`double`
complex	`3 + 5i`	`complex`	`complex`
character	`"hello"`	`character`	`character`

This notion of `mode` in R also has its historical roots to have a compatible syntax with the S language.

Atomic Vectors

To summarize:

- vectors are **atomic** structures
- the values in a vector must be **ALL** of the same type
- atomic vectors are contiguous cells containing data
- can be of any length (including zero)
- either all integers, or doubles, or complex, or characters, or logicals
- you **cannot** have an atomic vector of different data types

Coercion

Coercion

What happens if you mix different data types in a vector?

```r
x <- c(1, 2, 3, "four", "five")

y <- c(TRUE, FALSE, 3, 4)

z <- c(TRUE, 1L, 2 + 3i, pi)
```

What will the data-types of x, y and z be?

Atomic Vectors: Implicit Coercion

If you mix different data values, R will **implicitly coerce** them so they are all of the same type

```
# mixing numbers and characters
x <- c(1, 2, 3, "four", "five")
x
```

```
[1] "1"    "2"    "3"    "four" "five"
```

```
# mixing numbers and logical values
y <- c(TRUE, FALSE, 3, 4)
y
```

```
[1] 1 0 3 4
```

Atomic Vectors

```r
# mixing numbers and logical values
z <- c(TRUE, FALSE, "TRUE", "FALSE")
z
```

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

```r
# mixing integer, real, and complex numbers
w <- c(1L, -0.5, 3 + 5i)
w
```

```
[1]  1.0+0i -0.5+0i  3.0+5i
```

How does R coerce data types?

There is a hierarchy of data-types used by R to apply its implicit coercion rules:

$$\texttt{logical} < \texttt{integer} < \texttt{double} < \texttt{character}$$

`character` type is the dominant one in the sense that if a character is present, R will coerce everything else to characters.

Then we have `double` (or `real`): assuming a non-character vector, if it has at least one `double` element, then all other elements will be coerced as doubles. And so on with `integer` and `logical`.

Coercion

The following table shows the resulting data-types from mixing two or more different flavors of atomic vectors:

	`logical`	`integer`	`double`	`character`
`logical`	`logical`	`integer`	`double`	`character`
`integer`	`integer`	`integer`	`double`	`character`
`double`	`double`	`double`	`double`	`character`
`character`	`character`	`character`	`character`	`character`

Explicit Coercion functions

R provides a set of **explicit** coercion functions that allow us to "convert" one type of data into another

- `as.character()`
- `as.integer()`
- `as.double()`
- `as.numeric()`
- `as.logical()`

Depending on what kind of input vector you are trying to coerce to, sometimes the explicit coercion may fail.

Properties of Vectors

- all vectors have a length
- vector elements can have associated names
- vectors are objects of class `"vector"`
- vectors have a mode (storage mode)

Properties of Vectors

```r
# vector with named elements
x <- c(a = 1, b = 2.5, c = 3.7, d = 10)
x
```

```
   a    b    c    d 
 1.0  2.5  3.7 10.0 
```

```r
length(x)
```

```
[1] 4
```

```r
mode(x)
```

```
[1] "numeric"
```

Vectorization and Recycling

Vectorized Operations

You've probably operated with vectors like so:

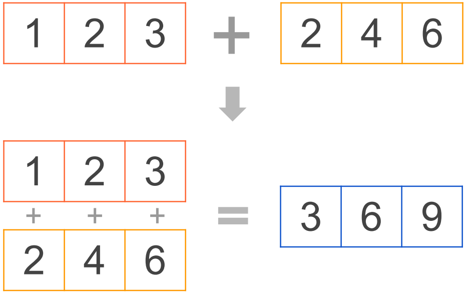
```r
vec1 <- c(1, 2, 3)

vec2 <- c(2, 4, 6)

vec1 + vec2
```

```
[1] 3 6 9
```

This is an example of **vectorized code**

Vectorization

Vectorized code in pictures:



Vectorized code refers to operations that are performed on the contents of `vec1` and `vec2`, **element-by-element** at the same time.

Vectorized Operations

A vectorized computation is any computation that when applied to a vector operates on all of its elements (same computation applied to each element)

```
c(1, 2, 3) + c(3, 2, 1)
```

```
[1] 4 4 4
```

```
c(1, 2, 3) * c(3, 2, 1)
```

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

```
c(1, 2, 3) ^ c(3, 2, 1)
```

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

Vectorization

All arithmetic, trigonometric, math and other vector functions are vectorized:

```r
log(c(1, 2, 3))
```

```
[1] 0.0000000 0.6931472 1.0986123
```

```r
cos(seq(1, 3))
```

```
[1]  0.5403023 -0.4161468 -0.9899925
```

```r
sqrt(1:3)
```

```
[1] 1.000000 1.414214 1.732051
```

Recycling and Vectorization

What happens if you operate on two vectors of different length, in which one of them is a one element ("scalar") vector?

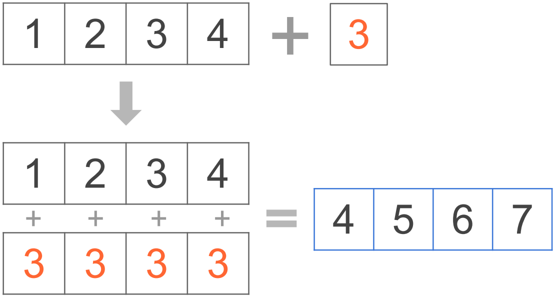
```r
vec <- c(1, 2, 3, 4)


vec + 3
```

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

This is an example of recycling and vectorization. The value 3 gets recycled as many times as the length of longer vector `vec`, and then vectorization applies.

Recycling and Vectorization

Recycling and vectorization in pictures



Recycling Rule

The recycling rule can be very useful, like when operating between a vector and a "scalar" (ie. one-element vector)

```
x <- c(2, 4, 6, 8)
x + 3  # add 3 to all elements in x
```

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

```
x / 3  # divide all elemnts by 3
```

```
[1] 0.6666667 1.3333333 2.0000000 2.6666667
```

```
x ^ 3  # all elements to the power of 3
```

```
[1]   8  64 216 512
```

Recycling

What happens if you operate on two vectors (of length > 1) that have different lengths?

```r
c(1, 3, 5, 7) + c(2, 4)
```

```
[1]  3  7  7 11
```

The same **recycling rule** applies: the shorter vector is replicated enough times so that the result has the length of the longer vector

Recycling

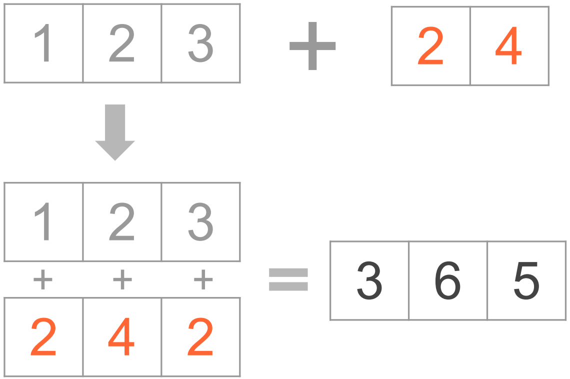
When vectorized computations are applied, some “issues” may occur when the length of the shorter vector is not a multiple of the length of the longer vector:

```
c(1, 2, 3) + c(2, 4)
```

```
Warning in c(1, 2, 3) + c(2, 4): longer object length is no
shorter object length
```

```
[1] 3 6 5
```

Recycling



Recycling Rule

The recycling rule states that the shorter vector is replicated enough times so that the result has the length of the longer vector

```
c(1, 2, 3, 4) + c(2, 1)
```

```
[1] 3 3 5 5
```

```
1:10 * 1:5
```

```
 [1]  1  4  9 16 25  6 14 24 36 50
```

General Functions

Functions for inspecting a vector

- `typeof(x)`
- `str(x)`
- `class(x)`
- `length(x)`
- `head(x)`
- `tail(x)`
- `summary(x)`

General Functions

```r
ages <- c(21, 28, 23, 25, 24, 26, 27, 21)

typeof(ages)
str(ages)
class(ages)
length(ages)
head(ages)
tail(ages)
summary(ages)
```