

Logic and types in R

Lecture 01

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**In R (almost)
everything is a vector**

Vectors

The fundamental building block of data in R are vectors (collections of related values, objects, etc).

R has two types of vectors (that everything is built on):

- atomic vectors (*vectors*)
 - homogeneous collections of the *same* type (e.g. all `true/false` values, all numbers, or all character strings).
- generic vectors (*lists*)
 - heterogeneous collections of *any* type of R object, even other lists (meaning they can have a hierarchical/tree-like structure).

Atomic Vectors

Atomic Vectors

R has six atomic vector types, we can check the type of any object in R using the `typeof()` function

<code>typeof()</code>	<code>mode()</code>
logical	logical
double	numeric
integer	numeric
character	character
complex	complex
raw	raw

Mode is a higher level abstraction, we will discuss this in detail a bit later.

There are additional types in R, e.g. `list`, `closure`, `environment`, etc. We will see these in the next couple of weeks. Check `?typeof` for more information.

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logical - boolean values (TRUE and FALSE)

```
1 typeof(TRUE)
```

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

```
1 typeof(FALSE)
```

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

```
1 mode(TRUE)
```

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

```
1 mode(FALSE)
```

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

R will let you use `T` and `F` as shortcuts to `TRUE` and `FALSE`, this is a bad practice as these values are actually **global variables** that can be overwritten.

R Code ↺ Start Over ▶ Run Code

```
1 T
```

character - text strings

Either single or double quotes are fine, the opening and closing quote must match.

```
1 typeof("hello")
```

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

```
1 typeof('world')
```

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

```
1 mode("hello")
```

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

```
1 mode('world')
```

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

Quote characters can be included by escaping or using a non-matching quote.

```
1 "abc'123"
```

```
[1] "abc'123"
```

```
1 'abc"123'
```

```
[1] "abc\"123"
```

```
1 "abc\"123"
```

```
[1] "abc\"123"
```

```
1 'abc\'123'
```

```
[1] "abc'123"
```

RStudio's syntax highlighting is helpful here to indicate where it thinks a string begins and ends.

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Numeric types

`double` - floating point values (these are the default numerical type)

```
1 typeof(1.33)
```

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

```
1 typeof(7)
```

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

```
1 mode(1.33)
```

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

```
1 mode(7)
```

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

`integer` - integer values (literals are indicated by an `L` suffix)

```
1 typeof( 7L )
```

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

```
1 typeof( 1:3 )
```

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

```
1 mode( 7L )
```

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

```
1 mode( 1:3 )
```

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


Combining / Concatenation

Atomic vectors can be constructed using the combine `c()` function.

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

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

```
1 c("Hello", "World!")
```

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

```
1 c(1, 1:10)
```

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

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

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

Note - atomic vectors are inherently flat / 1d.

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Inspecting types

- `typeof(x)` - returns a character vector (length 1) of the *type* of object `x`.
- `mode(x)` - returns a character vector (length 1) of the *mode* of object `x`.

```
1 typeof(1)
```

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

```
1 typeof(1L)
```

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

```
1 typeof("A")
```

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

```
1 typeof(TRUE)
```

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

```
1 mode(1)
```

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

```
1 mode(1L)
```

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

```
1 mode("A")
```

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

```
1 mode(TRUE)
```

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

Type predicates

- `is.logical(x)` - returns `TRUE` if `x` has *type* `logical`.
- `is.character(x)` - returns `TRUE` if `x` has *type* `character`.
- `is.double(x)` - returns `TRUE` if `x` has *type* `double`.
- `is.integer(x)` - returns `TRUE` if `x` has *type* `integer`.
- `is.numeric(x)` - returns `TRUE` if `x` has *mode* `numeric`.

```
1 is.integer(1)
```

```
[1] FALSE
```

```
1 is.integer(1L)
```

```
[1] TRUE
```

```
1 is.integer(3:7)
```

```
[1] TRUE
```

```
1 is.double(1)
```

```
[1] TRUE
```

```
1 is.double(1L)
```

```
[1] FALSE
```

```
1 is.double(3:8)
```

```
[1] FALSE
```

```
1 is.numeric(1)
```

```
[1] TRUE
```

```
1 is.numeric(1L)
```

```
[1] TRUE
```

```
1 is.numeric(3:7)
```

```
[1] TRUE
```

Other useful predicates

- `is.atomic(x)` - returns `TRUE` if `x` is an *atomic* vector.
- `is.list(x)` - returns `TRUE` if `x` is a *list* (generic vector).
- `is.vector(x)` - returns `TRUE` if `x` is either an *atomic* or *generic* vector.

```
1 is.atomic(c(1,2,3))
```

```
[1] TRUE
```

```
1 is.list(c(1,2,3))
```

```
[1] FALSE
```

```
1 is.vector(c(1,2,3))
```

```
[1] TRUE
```

```
1 is.atomic(list(1,2,3))
```

```
[1] FALSE
```

```
1 is.list(list(1,2,3))
```

```
[1] TRUE
```

```
1 is.vector(list(1,2,3))
```

```
[1] TRUE
```

Type Coercion

R is a dynamically typed language – it will automatically convert between most types without raising warnings or errors. Keep in mind that atomic vectors must always contain values of the same type.

```
1 c(1, "Hello")
```

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

```
1 c(FALSE, 3L)
```

```
[1] 0 3
```

```
1 c(1.2, 3L)
```

```
[1] 1.2 3.0
```

```
1 c(FALSE, "Hello")
```

```
[1] "FALSE" "Hello"
```

Operator coercion

Builtin operators and functions (e.g. `+`, `&`, `log()`, etc.) will generally attempt to coerce values to an appropriate type for the given operation (numeric for math, logical for logical, etc.)

```
1 3.1+1L
```

```
[1] 4.1
```

```
1 5 + FALSE
```

```
[1] 5
```

```
1 TRUE & FALSE
```

```
[1] FALSE
```

```
1 TRUE & 7
```

```
[1] TRUE
```

```
1 log(1)
```

```
[1] 0
```

```
1 log(TRUE)
```

```
[1] 0
```

```
1 TRUE | FALSE
```

```
[1] TRUE
```

```
1 FALSE | !5
```

```
[1] FALSE
```

Explicit Coercion

Most of the `is` functions we just saw have an `as` variant which can be used for *explicit* coercion.

```
1 as.logical(5.2)
```

```
[1] TRUE
```

```
1 as.character(TRUE)
```

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

```
1 as.integer(pi)
```

```
[1] 3
```

```
1 as.numeric(FALSE)
```

```
[1] 0
```

```
1 as.double("7.2")
```

```
[1] 7.2
```

```
1 as.double("one")
```

```
Warning: NAs introduced by coercion
```

```
[1] NA
```

Missing Values

Missing Values

R uses `NA` to represent missing values in its data structures, what may not be obvious is that there are different `NA`s for the different atomic types.

```
1 typeof(NA)
```

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

```
1 typeof(NA+1)
```

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

```
1 typeof(NA+1L)
```

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

```
1 typeof(c(NA,""))
```

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

```
1 typeof(NA_character_)
```

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

```
1 typeof(NA_real_)
```

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

```
1 typeof(NA_integer_)
```

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

```
1 typeof(NA_complex_)
```

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

This should make sense as `NA` values can appear along over values in atomic vectors.

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NA stickiness”

Because NAs represent missing values it makes sense that most calculations using them will also be missing.

```
1 1 + NA
```

```
[1] NA
```

```
1 1 / NA
```

```
[1] NA
```

```
1 NA * 5
```

```
[1] NA
```

```
1 sqrt(NA)
```

```
[1] NA
```

```
1 3^NA
```

```
[1] NA
```

```
1 sum(c(1, 2, 3, NA))
```

```
[1] NA
```

Aggregation / summarization functions (e.g. `sum()`, `mean()`, `sd()`, etc.) will often have a `na.rm` argument which will allow you to *drop* missing values.

```
1 sum(c(1, 2, 3, NA), na.rm = TRUE)
```

```
[1] 6
```

```
1 mean(c(1, 2, 3, NA), na.rm = TRUE)
```

```
[1] 2
```

NAs are not always sticky

A useful mental model for **NAs** is to consider them as a unknown value that could take any of the possible values for a type.

For numbers or characters this isn't very helpful, but for a logical value we know that the value must either be **TRUE** or **FALSE** and we can use that when deciding what value to return.

```
1 TRUE & NA
```

```
[1] NA
```

```
1 FALSE & NA
```

```
[1] FALSE
```

```
1 TRUE | NA
```

```
[1] TRUE
```

```
1 FALSE | NA
```

```
[1] NA
```

Other Special values (double)

These are defined as part of the IEEE floating point standard (not unique to R)

- `NaN` - Not a number
- `Inf` - Positive infinity
- `-Inf` - Negative infinity

```
1 pi / 0
```

```
[1] Inf
```

```
1 0 / 0
```

```
[1] NaN
```

```
1 1/0 + 1/0
```

```
[1] Inf
```

```
1 Inf - Inf
```

```
[1] NaN
```

```
1 NaN / NA
```

```
[1] NA
```

```
1 NaN * NA
```

```
[1] NA
```

Testing for `Inf` and `NaN`

`NaN` and `Inf` there are convenience functions for testing for these types of values

```
1 is.finite(Inf)
```

```
[1] FALSE
```

```
1 is.infinite(-Inf)
```

```
[1] TRUE
```

```
1 is.nan(Inf)
```

```
[1] FALSE
```

```
1 Inf > 1
```

```
[1] TRUE
```

```
1 is.finite(NaN)
```

```
[1] FALSE
```

```
1 is.infinite(NaN)
```

```
[1] FALSE
```

```
1 is.nan(NaN)
```

```
[1] TRUE
```

```
1 -Inf > 1
```

```
[1] FALSE
```

```
1 is.finite(NA)
```

```
[1] FALSE
```

```
1 is.infinite(NA)
```

```
[1] FALSE
```

```
1 is.nan(NA)
```

```
[1] FALSE
```

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Coercion for infinity and NaN

First remember that `Inf`, `-Inf`, and `NaN` are doubles, however their coercion behavior is not the same as other doubles

```
1 as.integer(Inf)
```

Warning: NAs introduced by coercion to integer range

```
[1] NA
```

```
1 as.integer(NaN)
```

```
[1] NA
```

```
1 as.logical(Inf)
```

```
[1] TRUE
```

```
1 as.logical(-Inf)
```

```
[1] TRUE
```

```
1 as.logical(NaN)
```

```
[1] NA
```

```
1 as.character(Inf)
```

```
[1] "Inf"
```

```
1 as.character(-Inf)
```

```
[1] "-Inf"
```

```
1 as.character(NaN)
```

```
[1] "NaN"
```

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Exercise 1

Part 1

What is the type of the following vectors? Explain why they have that type.

```
1 c(1, NA+1L, "C")
2 c(1L / 0, NA)
3 c(1:3, 5)
4 c(3L, NaN+1L)
5 c(NA, TRUE)
```

Part 2

Considering only the four (common) data types, what is R's implicit type conversion hierarchy (from highest priority to lowest priority)?

Hint - think about the pairwise interactions between types.

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Conditionals & Control Flow

Logical (boolean) operators

Operator	Operation	Vectorized?
<code>x y</code>	or	Yes
<code>x & y</code>	and	Yes
<code>!x</code>	not	Yes
<code>x y</code>	or	No
<code>x && y</code>	and	No
<code>xor(x, y)</code>	exclusive or	Yes

Vectorized?

```
1 x = c(TRUE, FALSE, TRUE)
2 y = c(FALSE, TRUE, TRUE)
```

```
1 x | y
```

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

```
1 x & y
```

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

```
1 x || y
```

```
Error in x || y: 'length = 3'
in coercion to 'logical(1)'
```

```
1 x && y
```

```
Error in x && y: 'length = 3'
in coercion to 'logical(1)'
```

& and | are almost always going to be the right choice, the only time we use && or || is when you need to take advantage of [short-circuit evaluation](#).

Note previously (before R 4.3) both || and && only used the *first* value in the vector, all other values are ignored and there was no warning about the ignored values.

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Vectorization and math

Almost all of the basic mathematical operations (and many other functions) in R are vectorized.

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

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

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

```
[1] 0.3333333 1.0000000  
3.0000000
```

```
1 log(c(1, 3, 0))
```

```
[1] 0.000000 1.098612 -Inf
```

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

```
[1] 0.8414710 0.9092974  
0.1411200
```

Length coercion (aka recycling)

If the lengths of the vector do not match, then the shorter vector has its values recycled to match the length of the longer vector.

```
1 x = c(TRUE, FALSE, TRUE)
2 y = c(TRUE)
3 z = c(FALSE, TRUE)
```

```
1 x | y
```

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

```
1 x & y
```

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

```
1 y | z
```

```
[1] TRUE TRUE
```

```
1 y & z
```

```
[1] FALSE TRUE
```

```
1 x | z
```

```
Warning in x | z: longer object length is not a multiple of
shorter object
length
```

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

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Length coercion and math

The same length coercion rules apply for most basic mathematical operators,

```
1 x = c(1, 2, 3)
2 y = c(5, 4)
3 z = 10L
```

```
1 x + x
```

```
[1] 2 4 6
```

```
1 x + z
```

```
[1] 11 12 13
```

```
1 y / z
```

```
[1] 0.5 0.4
```

```
1 log(x)+z
```

```
[1] 10.00000 10.69315 11.09861
```

```
1 x %% y
```

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

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

Comparison operators

Operator	Comparison	Vectorized?
<code>x < y</code>	less than	Yes
<code>x > y</code>	greater than	Yes
<code>x <= y</code>	less than or equal to	Yes
<code>x >= y</code>	greater than or equal to	Yes
<code>x != y</code>	not equal to	Yes
<code>x == y</code>	equal to	Yes
<code>x %in% y</code>	contains	Yes (over <code>x</code>)*

*over `x` means the returned value will have the length of `x` regardless of the length of `y`

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Comparisons

```
1 x = c("A","B","C")
2 y = c("A")
```

```
1 x == y
```

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

```
1 x != y
```

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

```
1 x %in% y
```

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

```
1 y %in% x
```

```
[1] TRUE
```

Type coercion also applies for comparison operators which can result in *interesting* behavior

```
1 TRUE == "TRUE"
```

```
[1] TRUE
```

```
1 FALSE == 1
```

```
[1] FALSE
```

```
1 TRUE == 1
```

```
[1] TRUE
```

```
1 TRUE == 5
```

```
[1] FALSE
```

> & < with characters

While maybe somewhat unexpected, these comparison operators can be used character values.

```
1 "A" < "B"
```

```
[1] TRUE
```

```
1 "A" > "B"
```

```
[1] FALSE
```

```
1 "A" < "a"
```

```
[1] FALSE
```

```
1 "a" > "!"
```

```
[1] TRUE
```

```
1 "Good" < "Goodbye"
```

```
[1] TRUE
```

```
1 c("Alice", "Bob", "Carol") <
```

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

Note - to better understand how this works, i.e. the ordering used, see [ASCII code](#)

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Conditional Control Flow

Conditional execution of code blocks is achieved via `if` statements.

```
1 x = c(1, 3)
```

```
1 if (3 %in% x) {  
2   print("Contains 3!")  
3 }
```

[1] "Contains 3!"

```
1 if (5 %in% x) {  
2   print("Contains 5!")  
3 }
```

```
1 if (1 %in% x)  
2   print("Contains 1!")
```

[1] "Contains 1!"

```
1 if (5 %in% x) {  
2   print("Contains 5!")  
3 } else {  
4   print("Does not contain 5!")  
5 }
```

[1] "Does not contain 5!"

if is not vectorized

```
1 x = c(1, 3)
```

```
1 if (x == 1)
2   print("x is 1!")
```

Error in if (x == 1) print("x is 1!"): the condition has length > 1

```
1 if (x == 3)
2   print("x is 3!")
```

Error in if (x == 3) print("x is 3!"): the condition has length > 1

Note that the behavior seen above (thrown errors) is new in R 4.2, previous versions will only throw warnings (using only the first value in the condition vector).

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Collapsing logical vectors

There are a couple of helper functions for collapsing a logical vector down to a single value: `any`, `all`

```
1 x = c(3,4,1)
```

```
1 x >= 2
```

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

```
1 any(x >= 2)
```

```
[1] TRUE
```

```
1 all(x >= 2)
```

```
[1] FALSE
```

```
1 x <= 4
```

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

```
1 any(x <= 4)
```

```
[1] TRUE
```

```
1 all(x <= 4)
```

```
[1] TRUE
```

```
1 if (any(x == 3))  
2   print("x contains 3!")
```

```
[1] "x contains 3!"
```

else if and else

```
1 x = 3
2
3 if (x < 0) {
4   "x is negative"
5 } else if (x > 0) {
6   "x is positive"
7 } else {
8   "x is zero"
9 }
```

[1] "x is positive"

```
1 x = 0
2
3 if (x < 0) {
4   "x is negative"
5 } else if (x > 0) {
6   "x is positive"
7 } else {
8   "x is zero"
9 }
```

[1] "x is zero"

if return values

R's `if` conditional statements return a value (invisibly), the two following implementations are equivalent.

```
1 x = 5
```

```
1 s = if (x %% 2 == 0) {  
2   x / 2  
3 } else {  
4   3*x + 1  
5 }
```

```
1 s
```

```
[1] 16
```

```
1 x = 5
```

```
1 if (x %% 2 == 0) {  
2   s = x / 2  
3 } else {  
4   s = 3*x + 1  
5 }
```

```
1 s
```

```
[1] 16
```

Notice that conditional expressions are evaluated in the parent scope.

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Exercise 2

Take a look at the following code below on the left, without running it in R what do you expect the outcome will be for each call on the right?

```
1 f = function(x) {  
2   # Check small prime  
3   if (x > 10 || x < -10) {  
4     stop("Input too big")  
5   } else if (x %in% c(2, 3,  
6     cat("Input is prime!\n")  
7   } else if (x %% 2 == 0) {  
8     cat("Input is even!\n")  
9   } else if (x %% 2 == 1) {  
10    cat("Input is odd!\n")  
11  }  
12 }
```

```
1 f(1)  
2 f(3)  
3 f(8)  
4 f(-1)  
5 f(-3)  
6 f(1:2)  
7 f("0")  
8 f("3")  
9 f("zero")
```

More on functions next time

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Conditionals and missing values

NAs can be particularly problematic for control flow,

```
1 if (2 != NA) {  
2   "Here"  
3 }
```

Error in if (2 != NA) {: missing value
where TRUE/FALSE needed

```
1 2 != NA
```

[1] NA

```
1 if (all(c(1,2,NA,4) >= 1)) {  
2   "There"  
3 }
```

Error in if (all(c(1, 2, NA, 4) >= 1)) {:
missing value where TRUE/FALSE needed

```
1 all(c(1,2,NA,4) >= 1)
```

[1] NA

```
1 if (any(c(1,2,NA,4) >= 1)) {  
2   "There"  
3 }
```

[1] "There"

```
1 any(c(1,2,NA,4) >= 1)
```

[1] TRUE

Testing for NA

To explicitly test if a value is missing it is necessary to use `is.na` (often along with `any` or `all`).

```
1 NA == NA
```

```
[1] NA
```

```
1 is.na(NA)
```

```
[1] TRUE
```

```
1 is.na(1)
```

```
[1] FALSE
```

```
1 is.na(c(1,2,3,NA))
```

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

```
1 any(is.na(c(1,2,3,NA)))
```

```
[1] TRUE
```

```
1 all(is.na(c(1,2,3,NA)))
```

```
[1] FALSE
```