

A Gentle Introduction to R

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Debugging

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pandoc version: 3.1.1


knitr version: 1.43


rmarkdown version: 2.23

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Prerequisites

- Access to a copy of the ¹ software
 - ▶ i.e., a “binary executable”
 - ▶ Go to *www.r-project.org* to get a copy, or ask your system administrator.
- Knowledge of common mathematical operations: arithmetic, logarithms, etc.
- No previous experience with R or programming required.

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Section 1

Welcome

Pop Quiz

We will review these *at the end*, so you can see how much you have learned.

- What does 'CRAN' stand for?
- Why is it named 'R'?
- How can you use R *interactively*?
- How do you find out what a function does & how to use it?
- How do you store values to re-use later?
- True or False: Warnings can be ignored, but an Error means I made a mistake.
- True or False: Error messages will tell me how to fix the problem.

Answer in the chat:

What emoji best describes your current mood or state of mind?

Introductions

- Name
- Pronouns
- Job title, role
- *optional*: a hobby or activity you enjoy?
- Have you used R before?
- Have you used a programming language before?

Icebreaker activity

What is this?

1–3 word description, for example:

- “This is grey”
- “This looks uncomfortable”

OR caption this image?

On your turn:


- 1 Previous person's name
- 2 Their answer to the question
- 3 Your name
- 4 Your answer
- 5 Name of the person to go next



Figure 1: Caption this image.

© John Speirs/Comedywildlifephotography.com

Learning Objectives

- Get familiar with the  *interface*
- Use technical *terms* for R concepts
- Enter *commands*
 - ▶ use R interactively: understand input & output
 - ▶ use some common *functions*
- Get familiar with 'R objects'
 - ▶ store & retrieve values
- Understand *Errors*, *Warnings*, and *Messages*
- How to get Help

Why is it named 'R'?

- 1 R started as an *open-source* implementation of the S statistical computing language (S-PLUS)²
 - ▶ S was created at Bell Laboratories in 1976³
 - ▶ R was based on the S syntax (mostly v3), but works very differently “under the hood”.
- 2 R was created by **R**oss Ihaka and **R**obert Gentleman — aka “R & R”⁴ — at the University of Auckland in the early 1990s.

*Read more about the history of R on Wikipedia*⁵

²<https://www.r-project.org/about.html>

³[https://en.wikipedia.org/wiki/S_\(programming_language\)](https://en.wikipedia.org/wiki/S_(programming_language))

⁴<https://www.r-project.org/contributors.html>

⁵[https://en.wikipedia.org/wiki/R_\(programming_language\)#History](https://en.wikipedia.org/wiki/R_(programming_language)#History)

Section 2

Interacting with R (Interface)

The Interface

- ‘base R’ has a slightly different interface for each **O**perating **S**ystem (OS)
 - ▶ GUI = **G**raphical **U**ser **I**nterface
- R can also run inside of a terminal (no GUI) or other software (different GUI).

Integrated **D**evelopment **E**nvironment (IDE)

- An IDE is like an extra interface layer on top of ‘base R’
- IDEs often add convenient tools to make writing code easier (e.g., syntax highlighting), and for developing larger projects with multiple files.
- **RStudio** is one of the most popular cross-platform IDEs for R.
 - ▶ RStudio is available in open source (free/libre) and commercial^a editions.

^afor organizations not able to use software licensed with AGPL

A quick tour of the 'base R GUI'

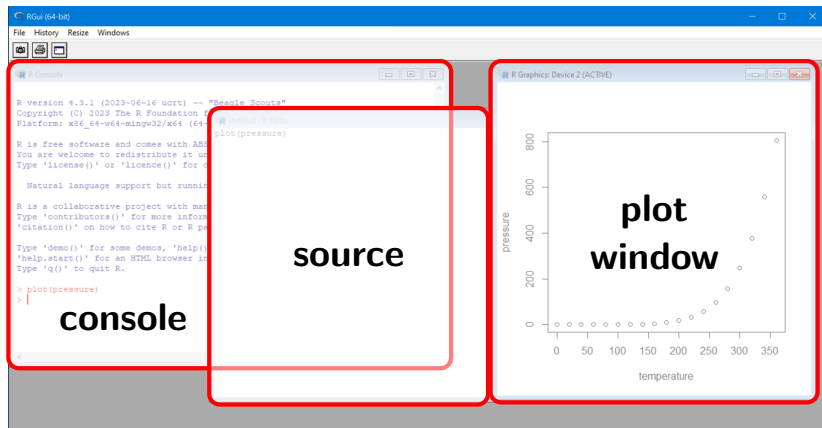
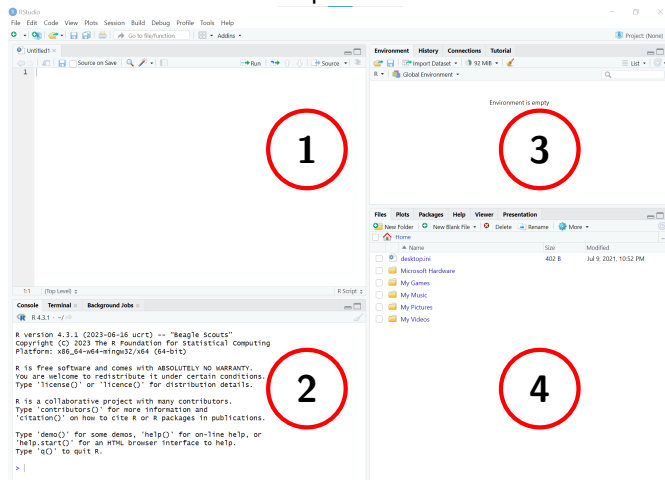


Figure 2: Screenshot of the R GUI in Windows.

A quick tour of RStudio

The RStudio GUI has 4 'panes' that contain 'tabs'.



left:

- 1 top: **Source^a**
- 2 bottom: **Console, Terminal, ...**

right:

- 3 top: **Environment, History, ...**
- 4 bottom: **Files, Plots, Help, ...**

^aempty until you create or open a file

Figure 3: Screenshot of RStudio (default layout).

- Regardless of the GUI, you interact with R primarily using a *command line*
 - ▶ aka a command line interface (cli)
 - ▶ the command line is usually in the *console*
- “Question-and-Answer Model”
 - ▶ You ask R to do something (a *command*),
and R tells you the answer (*result*).
- Instructions are given to R using the *R language*.

The *console* is a window or pane where you will find:

- The *command line*
 - ▶ where you will enter commands for R to run
- Results of commands and other output
- Messages, *Warnings*, and **Errors**

The command-line

- The command *prompt* normally looks like this⁶:

```
>
```

- ▶ This is R's way of saying "I am ready to accept new commands".
- ▶ Type a new command on the line after this prompt (i.e., *input*).
- Press **return/enter** to *run the current command*
- If you can still edit the command next to the prompt, then it has not been submitted to R to execute (it is still waiting for input).
- If the last prompt is not empty (i.e., there is text beside it) *and* you cannot edit what is beside the prompt, it means R is still running the last command and is not ready to accept a new command yet.
 - ▶ Wait for a new empty prompt to appear before entering the next command.

⁶the colour of the prompt varies depending on the interface

The command-line (continued)

- If the prompt looks like this:

```
+
```

it means the last command was *incomplete* and R is waiting for more input.

R will not do anything until the command is completed or cancelled.

- ▶ This usually means you forgot a closing
quote `"`, parenthesis `(`, bracket `[`, or brace `{`
- You can *cancel* the current command at any time by pressing escape
(`esc`)

Section 3

Warming up: some early commands

Input & Output

In this presentation,

- *commands* that can be entered in the *command-line* look like this:

```
Input (commands)
```

▶ You can try these yourself!

- Expected output (results) look like this:

```
Output (results)
```

offers suggestions

Read the opening message carefully.

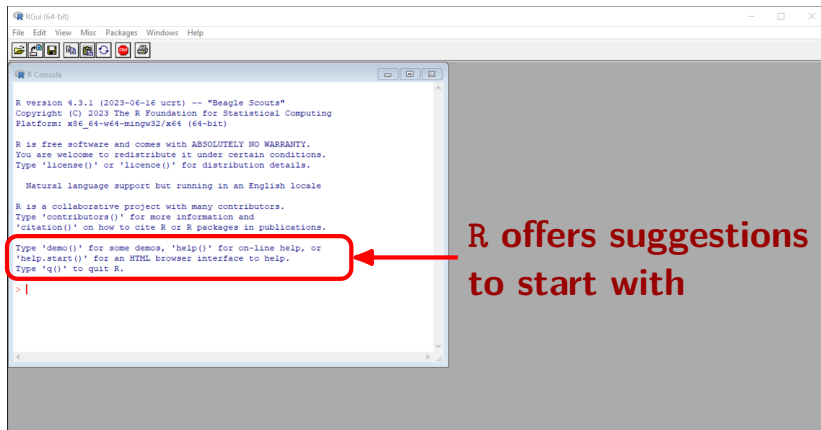


Figure 4: R offers suggestions of commands to **Type** in the console when it starts.

`demo(graphics)`

- some plots and graphs that can be made with R

`demo(image)`

- image-like graphics and maps that can be produced with R

`demo(lm.glm)`

- a demonstration of linear modelling & GLMs

`demo()`

- a list of available demos

`help.start()`

- ← A great place to start, especially if you are comfortable reading documentation for a programming language.
More on this later.
-

Note

R will not only show the output, but also *the code used to produce it*.

is a calculator

```
1 + 1
```

```
[1] 2
```

```
2 * 2
```

```
[1] 4
```

```
2 ^ 3
```

```
[1] 8
```

```
10 - 1
```

```
[1] 9
```

```
8 / 2
```

```
[1] 4
```

```
sqrt(9)
```

```
[1] 3
```

- These are *expressions*
- *Expressions* are *evaluated*, and the *value* (result) is *returned* (sometimes *invisibly*)

- With the cursor next to the empty prompt (`>`), use the up & down **arrow keys** (`↑↓`) to re-produce previous commands.
- This lets you “scroll through your *command history*”.
- Press **up** (`↑`) once, and you get the last command you entered without having to copy & paste.

Section 4

Simple R objects

Vectors

- The most basic kind of *object* in R is a *vector*
- Think of a vector as a list of related values (data), which are *all the same type*
- A single value is an “*atomic vector*” (a vector with a length of 1)



Using vectors

- Vectors can be used in calculations
- Operations are applied to each item (*element-wise*)

```
sum( c(1, 2, 3, 4, 5) )  
1:10 + 2  
1:5 * 5:1
```

- Vectors can be used to plot data in a graph

```
plot( rnorm(1000) )  
hist( rnorm(1000) )
```

Some data types (of *atomic vectors*)

numeric

- Includes *integers*, *real* (decimal / *double*), and *complex* numbers.
- 1.23

character (*string*)

- in single ' or double " quotes.
- 'hello world'
- "1.23"

logical

- TRUE or FALSE

```
class(1.23)
class('hello')
class("1.23")
class(FALSE)
```

```
typeof(1.23)
typeof(1:10)
```

```
as.character(c(1,2,NA,4))
```

↑
as.*(): converting from one type to another = *coercion*

Section 5

Storing & retrieving values

Symbolic variables

- You can store values (*objects*) in symbolic variables (*names*) using an *assignment operator*.

`<-` assign the *value* on the **right** to the *name* on the **left**

- Names can include:

letters	a-z A-Z
numbers	0-9
periods	.
underscores	_

```
A <- 10
B <- 10 * 10
A_log <- log(A)
B.seq <- 1:B

assign('x', 3)
```

- Names *should begin with a letter*.

Retrieve values

When a variable *name* is evaluated, it returns the stored *value*.

A

```
[1] 10
```

B

```
[1] 100
```

A_log

```
[1] 2.303
```

x

```
[1] 3
```

B.seq

```
[1] 1 2 3 4 5 6 7 8 9 10 11 12 13
[14] 14 15 16 17 18 19 20 21 22 23 24 25 26
[27] 27 28 29 30 31 32 33 34 35 36 37 38 39
[40] 40 41 42 43 44 45 46 47 48 49 50 51 52
[53] 53 54 55 56 57 58 59 60 61 62 63 64 65
[66] 66 67 68 69 70 71 72 73 74 75 76 77 78
[79] 79 80 81 82 83 84 85 86 87 88 89 90 91
[92] 92 93 94 95 96 97 98 99 100
```

Built-in variables

Some words and letters already have values in R
and should **never be used as variable names**.

```
pi
```

```
[1] 3.142
```

```
version
```

```
... information about  
this version of R ...
```

```
letters
```

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

```
LETTERS
```

```
[1] "A" "B" "C" "D" "E" "F" "G" "H" "I" "J" "K" "L" "M" "N"  
[15] "O" "P" "Q" "R" "S" "T" "U" "V" "W" "X" "Y" "Z"
```

Reserved words

Some words and letters already have special meaning in the R language (*keywords*) and should **never be used as variable names**.

NA	“Not Available”	placeholder for unknown or missing values
NaN	“Not a Number”	placeholder for <i>undefined</i> numeric values
NULL	<i>a special object</i>	placeholder for missing <i>objects</i>
Inf	Infinity	
TRUE	Logical value	
FALSE	Logical value	
T	short for TRUE	
F	short for FALSE	
c, q, t, C, D, I	R functions	
diff, df, pt	R functions	

is case-sensitive

<code>R.version</code>	a variable	<code>pi</code>
------------------------	------------	-----------------

<code>R.Version()</code>	a <i>function</i>	<i><code>PI</code></i>
--------------------------	-------------------	------------------------

<code>letters</code>	a-z	<code>NA</code>
----------------------	-----	-----------------

<code>LETTERS</code>	A-Z	<i><code>na</code></i>
----------------------	-----	------------------------

Use variables in calculations

```
A + 5
```

```
[1] 15
```

```
B/A
```

```
[1] 10
```

```
Weight <- c(60 , 72 , 57 , 90 , 95 , 72 )
```

```
Height <- c(1.7, 1.8, 1.6, 1.9, 1.7, 1.9)
```

```
BMI <- Weight / Height^2
```

```
BMI
```

```
[1] 20.76 22.22 22.27 24.93 32.87 19.94
```

```
plot(Height, Weight)
```

Housekeeping

`ls()`

List all variables you have created

`rm(x)`

Remove the variable 'x' from memory

`rm(list=ls())`

Remove *all variables* from memory
(clear memory)

```
pi
pi <- "pie"
pi
rm(pi)
pi
```

Section 6

Operators

Operators

Operators are special symbols that go between two values, to perform an *operation* on both values (the *operands*) and return the *result*.

- For example: `2 * 3` is a way of saying “*multiply* 2 and 3 together”
- Operations are evaluated one pair at a time, according to precedence (*order of operations*).

Arithmetic Operators

The usual math symbols:

`+`, `-`, `*`, `/`, `^`, etc.

Assignment Operators

Assign values to symbolic variables:

`<-`, `->`, `=`, etc.

Comparison (*Relational*) Operators

For comparing two values:

`==`, `!=`, `>`, `<`, etc.

Boolean Operators

Combining logical values

(`TRUE`, `FALSE`): `!`, `&`, `|`, etc.

Comparisons

Comparison of 2 values results in *logical values*: **TRUE** or **FALSE**

==	“equal” — Note the two equals signs. Not to be confused with a single equals sign (used to <i>assign</i> values).
!=	“not equal”
>	“greater than”
<	“less than”
>=	“greater than or equal to”
<=	“less than or equal to”

Comparisons: examples

```
1 == 2
```

```
[1] FALSE
```

```
1 <= 2
```

```
[1] TRUE
```

```
1 < "a"
```

```
[1] TRUE
```

```
1 < 2
```

```
[1] TRUE
```

```
1 != "foo"
```

```
[1] TRUE
```

```
0 == FALSE
```

```
[1] TRUE
```

Comparing decimals ('floating point' arithmetic)

Computers can't represent *all* values accurately, and there is often some rounding that occurs (even at 50+ decimal places).

As a result, 'floating point' values may not be *reliably equal*.^{7 8}

This is a common source of confusion, but it is a fact of how computers handle floating point arithmetic, and not specific to R.

Two common solutions:

- 1 `round()` decimal values when comparing them
- 2 use a function with a tolerance for small differences, such as `all.equal()`

```
a <- sqrt(2)
a * a == 2 # should be TRUE
```

```
[1] FALSE
```

```
a * a - 2
```

```
[1] 4.441e-16
```

```
round(a * a, 8) == 2 #(1)
```

```
[1] TRUE
```

```
all.equal(a * a, 2) #(2)
```

```
[1] TRUE
```

⁷R FAQ: "Why doesn't R think these numbers are equal?"

⁸See Stackoverflow: "Why are these numbers not equal?" for other solutions

Section 7

Functions

Functions

- *Functions* are special commands that can do more than simple operators⁹.
- They are the main instructions you give to R.
- To use (or *call*) a function, the command must be structured properly, following the “grammar rules” of the R language (*syntax*).

```
log( 8 , base = 2 )
```

⁹technically, operators are special functions with exactly 1 (*unary*) or 2 (*binary*) *arguments*. See section 3.1.4 “Operators” in the R Language Definition.

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function name `log(8 , base = 2)`

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parentheses

function name

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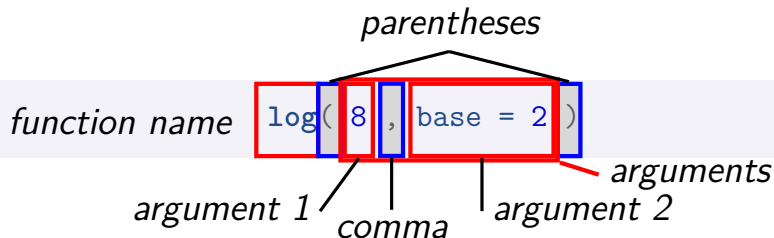
parentheses

function name `log(8 , base = 2)` *arguments*

The diagram illustrates the syntax of an R function call. The function name 'log' is enclosed in a red box. The opening parenthesis '(' is enclosed in a blue box. The arguments '8 , base = 2' are enclosed in a red box. The closing parenthesis ')' is enclosed in a blue box. A black line labeled 'parentheses' connects the two parentheses. A red line labeled 'arguments' points to the argument box.

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Function arguments

- *arguments* are the values passed to a function when it is *called*
 - ▶ these are values the function needs to do its thing
 - ▶ some change *how* the function operates (these are usually optional)
- arguments are separated by a comma (,)
- arguments can be *passed by order* or *passed by name*
 - ▶ *passed by order* means the arguments are specified in the correct order, without a name
 - ▶ *passed by name* means the arguments can be in any order, but must be declared by name: `argument = value`

!

Note the **single** equals sign (`=`), used to assign values to function arguments by name

Calling Functions

- Some functions can be called without arguments.
- **You still need the parentheses()** !
- The same word without **()** refers to an *object* (*variable*):
adding the **()** specifies a *function call*
- Typing a function name without brackets usually outputs the *raw code* for that function (unless another object has been defined with the same name).
 - ▶ i.e., the *value* of the function object itself.

```
ls()
```

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

```
ls
```

```
function (name, pos = -1L, envir =  
  pattern, sorted = TRUE)  
{  
  if (!missing(name)) {  
    pos <- tryCatch(name, error=  
      if (inherits(pos, "error")  
        name <- substitute(na  
        if (!is.character(name
```


A complex example

```
Var <- sum( ((x <- 1:20) - mean(x))^2 / (length(x) - 1) )
```

- Try breaking this up and run each piece one at a time to see all the steps.

A complex example

```
Var <- sum( ((x <- 1:20) - mean(x))^2 / (length(x) - 1) )
```

- Try breaking this up and run each piece one at a time to see all the steps.
- The shorter version:

```
var(1:20)
```

```
[1] 35
```

Section 8

Errors, Warnings, and Messages

Errors

- When R receives a command it does not understand, or cannot execute, it outputs an **error** to the *console*.
 - ▶ This is a message that begins with the word “**Error**”.
- A command that produces an *error* is **not** executed.

```
Fail <- 1 + "2"
```

```
Error in 1 + "2" : non-numeric argument to binary operator
```

```
Fail
```

```
Error in eval(expr, envir, enclos) : object 'Fail' not found
```

- Error messages tell you what went wrong, not how to fix it: that's up to you to figure out.
- When an error occurs, R **stops running** commands and returns to the command-line.
 - ▶ Your *session* is still active: R didn't quit, and you can enter more commands.

Warnings

- Some commands still work, but did not run exactly as R (or the developers) think is “ideal”, and may produce a **warning** instead.
 - ▶ This is a message that begins with the word “**Warning**”.
- These do not interrupt what R is doing: it will keep running, but tell you that there were warnings.
 - ▶ *It is up to you to review the warnings and decide if they are important.*
 - ▶ Use the `warnings()` command to review them.

```
oops <- log(-1)
```

Warning in log(-1): NaNs produced

Errors, Warnings, and Messages

- **Errors** indicate something is wrong, and R had to stop. You'll have to figure out what caused the error, fix it, and try again.
 - ▶ Think of errors as a red traffic light: stop — something is wrong!
- **Warnings** indicate something unusual happened, but R is able to continue. You'll have to assess if it's worth worrying about.
 - ▶ Think of warnings as a yellow traffic light: you can go, but be careful and pay attention, in case there is a problem.
- Other **Messages** are for information, and a sign that things are working fine (at least, according to the programmers who created the function).
 - ▶ Think of messages as a green traffic light: you are safe to continue.

Section 9

Help & documentation

HELP

- R *documentation* (help files)
- Books
- Web sites
- Cheat sheets / Reference cards
- Each Other

HELP: Books

- Springer publishing: “**Use R!**” series
 - ▶ Some older: A Beginner’s Guide to R (2009)
 - ▶ Some more recent: Data Wrangling with R (2016)
 - ▶ Some focus on specific methods, e.g.:
 - Numerical Ecology with R (2018)
 - Applied Spatial Data Analysis with R (2013)
- Other suggestions on the R web site:
www.r-project.org/doc/bib/R-books.html
- R packages can change quickly: be careful if older content refers to old versions of packages, or packages that are deprecated.
 - ▶ Concepts or general methods may still be relevant.
- Many are available in physical or digital formats (or both)

HELP: Web Sites

- R web site: www.r-project.org
 - ▶ especially the “Documentation” section
 - ▶ e-mail lists
- RStudio Education: education.rstudio.com
- R-bloggers.com www.r-cookbok.com
- Stack Overflow (stackoverflow.com)
 - ▶ Q&A site: search for your question, or ask your own
- Cookbook for R (www.cookbook-r.com)
- Your preferred search engine ...

HELP: Reference cards / cheat sheets

- <https://cran.r-project.org/doc/contrib/Short-refcard.pdf>
- <https://cran.r-project.org/doc/contrib/refcard.pdf>
- RStudio IDE cheat sheet
- Search the internet for
 - ▶ “R cheat sheet”
 - ▶ “R reference card”

R Documentation

```
help.start()
```

Statistical Data Analysis 

Manuals

[An Introduction to R](#)

[The R Language Definition](#)

[Writing R Extensions](#)

[R Installation and Administration](#)

[R Data Import/Export](#)

[R Internals](#)

Reference

[Packages](#)

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[Technical papers](#)

- A great place to start
- HTML documentation with tutorials, concepts, and examples.
- Browse or search for something specific, or just explore.
- Click on “packages” to see a list of installed packages,
 - ▶ documentation about each package (e.g., “vignettes”),
 - ▶ functions included in a package

R Documentation: find it

```
?help
```

```
?c
```

```
help.search("c")
```

```
?seq
```

```
?help.search
```

```
help.search("t-test")
```

```
?? 't-test'
```

- Documentation about documentation, and how to search it
- read about the often-used 'combine' *function*
- read about a function for making a *sequence*
- use `help.search("")` or `??` to search for a term when you don't know the name of the function, but you know what you want to do.

R Documentation: find it

```
?help
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- Documentation about documentation, and how to search it

```
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- read about the often-used 'combine' *function*

```
?seq
```

- read about a function for making a *sequence*

```
?help.search
```

```
help.search("t-test")
```

```
?? 't-test'
```

- use `help.search("")` or `??` to search for a term when you don't know the name of the function, but you know what you want to do.

function name → `seq {base}` ← *package*
(or topic)

Sequence Generation *title*

Description

Generate regular sequences. `seq` is a standard generic with a default method. `seq.int` is a primitive which can be much faster but has a few restrictions. `seq_along` and `seq_len` are very fast primitives for two common cases.

Usage

```
seq(...)  
  
## Default S3 method:  
seq(from = 1, to = 1, by = ((to - from)/(length.out - 1)),  
    length.out = NULL, along.with = NULL, ...)  
seq.int(from, to, by, length.out, along.with, ...)  
  
seq_along(along.with)  
seq_len(length.out)
```

arguments

Arguments

...

arguments passed to or from methods.

`from, to`

the starting and (maximal) end values of the sequence. Of length 1 unless just `from` is supplied as an unnamed argument.

`by`

number: increment of the sequence.

`length.out`

desired length of the sequence. A non-negative number, which for `seq` and `seq.int` will be rounded up if fractional.

`along.with`

take the length from the length of this argument.

Details

Numerical inputs should all be [finite](#) (that is, not infinite, `NaN` or `NA`).

The interpretation of the unnamed arguments of `seq` and `seq.int` is *not* standard, and it is recommended always to name the

arguments followed by '=' have a *default value*: if you don't include these in your function call, they are automatically assigned the default value shown here, after the '='.

default values

*details on
how the func-
tion works*

The third form generates the integer sequence 1, 2, ..., length(along.with). (along.with is usually abbreviated to along, and seq_along is much faster.)

The fifth form generates the sequence 1, 2, ..., length(from) (as if argument along.with had been specified), *unless* the argument is numeric of length 1 when it is interpreted as 1:from (even for seq(0) for compatibility with S). Using either seq_along or seq_len is much preferred (unless strict S compatibility is essential).

The final form generates the integer sequence 1, 2, ..., length.out unless length.out = 0, when it generates integer(0).

Very small sequences (with from - to of the order of 10^{-14} times the larger of the ends) will return from.

For seq (only), up to two of from, to and by can be supplied as complex values provided length.out or along.with is specified. More generally, the default method of seq will handle classed objects with methods for the Math, Ops and Summary group generics.

seq.int, seq_along and seq_len are [primitive](#).

Value

seq.int and the default method of seq for numeric arguments return a vector of type "integer" or "double": programmers should not rely on which.

seq_along and seq_len return an integer vector, unless it is a [long vector](#) when it will be double.

References

Becker, R. A., Chambers, J. M. and Wilks, A. R. (1988) *The New S Language*. Wadsworth & Brooks/Cole.

See Also

The methods [seq.Date](#) and [seq.POSIXt](#).

[i](#), [rep](#), [sequence](#), [row](#), [col](#).

Examples

[Run examples](#)

```
seq(0, 1, length.out = 11)
seq(stats::rnorm(20)) # effectively 'along'
seq(1, 9, by = 2)      # matches 'end'
seq(1, 9, by = pi)     # stays below 'end'
seq(1, 6, by = 3)
seq(1.575, 5.125, by = 0.05)
seq(17) # same as 1:17, or even better seq_len(17)
```

You can also click the "Run examples" link or use 'example(seq)' in the console to run all the example code in this section.

[Package base version 4.3.1 [Index](#)]

details

value returned

publications that describe the function or algorithm (theory & concepts)

Copy & paste **Examples** into the console to try them out. Try changing the example code to do what you want.

Help: example

- Create an unsorted vector of numbers
- Find out how to sort it

```
unsorted_vector <- c(1, 6, -2, 9.5, 4)  
help.search("sort")
```

Help: example

- Create an unsorted vector of numbers
- Find out how to sort it

```
unsorted_vector <- c(1, 6, -2, 9.5, 4)
help.search("sort")
```

- Now try including a character string in the vector
 - ▶ Sort again
- Try to sort it in reverse order

Section 10

Working with objects

Some *object* types

An “object” is a way of packaging information in R.

vector

- a collection of *values*, all of the **same** *type*.

list

- a collection of **different** *types* of values, or even *objects*.

factor

- a collection of values (*vector*)
from a finite list of possible values (*levels*)

data frame

- a list of *vectors*, *factors*, or other objects of the same length (# rows)
- *columns* = “variables” ; *rows* = “cases”

Working with *objects*

the object *class*

```
class(pi)
```

the object *type*

```
typeof(pi)
```

the object's *structure*

```
str(pi)
```

the object's *attributes*

```
attributes(pi)
```

is it a *vector*?

```
is.vector(pi)
```

Replace 'pi' in the
above statements with
one of these examples

```
letters  
1:10  
version
```

Working with a *data frame*

load a built-in data file `data(CO2)`

peek at the first few rows `head(CO2)`

the object's **structure** `str(CO2)`

names of items in the object `names(CO2)`

the object *class* `class(CO2)`

the object *type* `typeof(CO2)`

the object's *attributes* `attributes(CO2)`

summary statistics `summary(CO2)`

plot of all variable combinations `plot(CO2)`

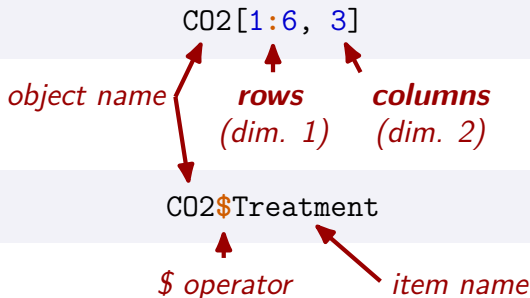
Structure of a data frame

```
str(CO2)
```

```
Classes 'nfnGroupedData', 'nfGroupedData', 'groupedData' and 'data.frame': 84 obs. of 5 variables:
 $ Plant      : Ord.factor w/ 12 levels "Qn1"<"Qn2"<"Qn3"<...: 1 1 1 1 1 1 1 2 2 2 ...
 $ Type       : Factor w/ 2 levels "Quebec","Mississippi": 1 1 1 1 1 1 1 1 1 1 ...
 $ Treatment: Factor w/ 2 levels "nonchilled","chilled": 1 1 1 1 1 1 1 1 1 1 ...
 $ conc       : num  95 175 250 350 500 675 1000 95 175 250 ...
 $ uptake     : num  16 30.4 34.8 37.2 35.3 39.2 39.7 13.6 27.3 37.1 ...
 - attr(*, "formula")=Class 'formula' language uptake ~ conc | Plant
 .. ..- attr(*, ".Environment")=<environment: R_EmptyEnv>
 - attr(*, "outer")=Class 'formula' language ~Treatment * Type
 .. ..- attr(*, ".Environment")=<environment: R_EmptyEnv>
 - attr(*, "labels")=List of 2
 .. $ x: chr "Ambient carbon dioxide concentration"
 .. $ y: chr "CO2 uptake rate"
 - attr(*, "units")=List of 2
 .. $ x: chr "(uL/L)"
 .. $ y: chr "(umol/m^2 s)"
```

Indexing

- You can refer to parts of an object by their *index* or *name* (if they have one)



Indexing examples

```
names(CO2)
```

- available *names*

```
CO2$Treatment  
CO2[["Treatment"]]
```

- "Treatment" column (name)

```
CO2[,3]
```

- all rows, column 3

```
CO2[3,]
```

- row 3, all columns

```
CO2[3]
```

- element 3

```
CO2[1:6,]
```

- rows 1-6, all columns

```
CO2[c(1,2,3,4,5,6),3]
```

- rows 1-6, column 3

```
CO2$Treatment[1:6]
```

- elements 1-6 of Treatment column

```
CO2[CO2$conc>100,]
```

- rows where `conc > 100`

```
CO2[CO2$Treatment=="chilled",]
```

- rows where
Treatment == "chilled"

```
CO2[sample(nrow(CO2), 10),]
```

- 10 random rows

Section 11

Installing packages

Intalling *packages*

- R is extensible & modular
 - ▶ you can add features (*functions*) and capabilities by *installing* and *loading* extra components called “*packages*”
- You can do this within R, using simple functions
- This keeps R lean, fast, and avoids “feature bloat”: load only the packages you need.

Try a function that does not exist (yet)

```
?recode  
recode(CO2$Type, "'Quebec'='QC'; else='MS'")
```

```
Error in recode(CO2$Type, "'Quebec'='QC'; else='MS'") :  
could not find function "recode"
```

- This often happens when you forget to *load* a *package* that contains the *function* you are trying to use.
- or there's a typo in the *function name*

Trying to load a *package* that is not installed

- If you try to load a package that is not installed, you will get an **Error**

```
library(car)
```

Error in library(car) : there is no package called 'car'

- This often happens when you run R code written on a different computer, or written by someone else (on a different computer).
- You have to *install* the package before you can *load* it.

Installing the 'car' package

- car = “Companion to Applied Regression”
 - ▶ includes the `recode()` function

```
install.packages("car")
```

- Download & install the package
- You may have to select a “CRAN mirror” (server) to use.

You only need to do this *once* per R installation.

```
library(car)
```

- Load the package, to make all contained *functions*, data, and *documentation* available.

This is all you need to do when you want to use it.

```
help(package="car")
```

- Information about your new package.
- See also `help.start()`, and click on the “Packages” link.

Installing package into '/Users/jaw/Library/R/arm64/4.3/library'
(as 'lib' is unspecified)

Loading required package: carData

Try out your new package

```
?recode  
recode(CO2$Type, "'Quebec'='QC'; else='MS'")
```

```
[1] QC QC QC QC QC QC QC QC QC QC QC QC QC QC QC QC QC QC  
[19] QC QC QC QC QC QC QC QC QC QC QC QC QC QC QC QC QC QC  
[37] QC QC QC QC QC QC MS MS MS MS MS MS MS MS MS MS MS MS  
[55] MS MS MS MS MS MS MS MS MS MS MS MS MS MS MS MS MS MS  
[73] MS MS MS MS MS MS MS MS MS MS MS MS MS  
Levels: MS QC
```

Section 12

Review

Let's play “Command-R”

- 2 (or more) players
 - ▶ If you have 2 computers, use one to play and the other to consult the help files.
- **Start with:**

```
x <- 0
```

- Take turns using the variable ‘x’ as an *argument* in a *function* or *expression*
- Assign the *result* to the same variable ‘x’
- You may not use the same command twice in a chain
- You may use the same *function* or *mathematical operator*, but you have to use more, fewer, or different *arguments* each time.
- How long can you keep the chain going without getting errors or breaking the rules?

“Command-R”

Challenges

- Change the object *type* of `x` into a :
 - ▶ vector of multiple items
 - ▶ data frame
- Use `x` in a graph or `plot()`
 - ▶ Careful! Some plotting functions do not return a result and may break your chain.

Sample commands

```
x <- x + 1
x <- x * (x+10)
x <- log(x)
x <- exp(x)
x <- 1:x
x <- seq(from=x[1], to=100,
         by=2)
x <- rnorm(x)
x <- x[1:3]
x <- x[2]
x <- data.frame(
  foo = rnorm(length(x)),
  x
)
```

Today's Commands

<code>+</code>	<code>-</code>	<code>*</code>	<code>/</code>	<code>^</code>	<code>min</code>	<code>max</code>	<code>install.packages</code>
<code><-</code>	<code>=</code>	<code>assign</code>			<code>sum</code>	<code>mean</code>	<code>library</code>
<code>==</code>	<code>!=</code>	<code><</code>	<code>></code>	<code><=</code>	<code>>=</code>	<code>rnorm</code>	<code>var</code>
<code>:</code>						<code>summary</code>	<code>plot</code>
<code>seq</code>							<code>hist</code>
<code>c</code>						<code>head</code>	
						<code>length</code>	<code>demo</code>
<code>sqrt</code>						<code>str</code>	<code>example</code>
<code>log</code>						<code>names</code>	
<code>exp</code>						<code>typeof</code>	<code>help</code> <code>?</code>
						<code>class</code>	<code>help.search</code> <code>??</code>
<code>ls</code>						<code>attributes</code>	<code>help.start</code>
<code>rm</code>						<code>is.vector</code>	

Section 13

Saving code (files)

Saving code (files)

Section 14

Backmatter

Quiz Review



References & More Information

```
help.start()
```

Accessible from the screen above (offline):

- An Introduction to R
- The R Language Definition

Online:

- RStudio Education (education.rstudio.com)
 - ▶ tutorials, workshop materials, and other resources.
-  Manuals (<https://cran.r-project.org/manuals.html>)
-  Contributed Documentation
 - ▶ e.g., <http://cran.r-project.org/doc/contrib/usingR.pdf>
- Internet search
 - ▶ Stack Overflow (stackoverflow.com)
 - ▶ Cookbook for R (www.cookbook-r.com)