INTRODUCTION TO DATA ANALYSIS

BASICS OF R

LEARNING GOALS

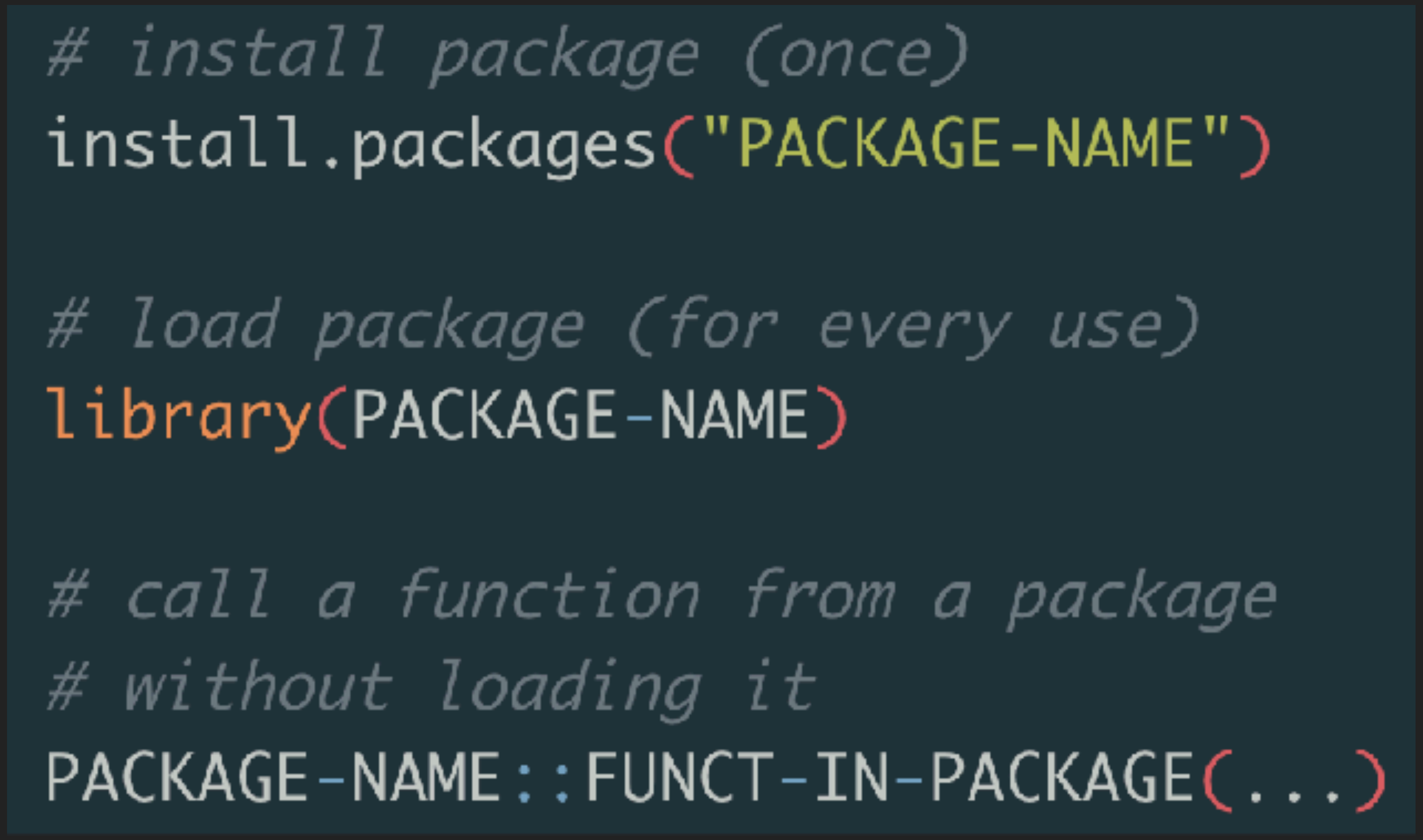
- become familiar with R, its syntax and basic notions
- become familiar with the key functionality from the tidyverse
- understand and write simple R scripts
- be able to write documents in Rmarkdown

BASE R

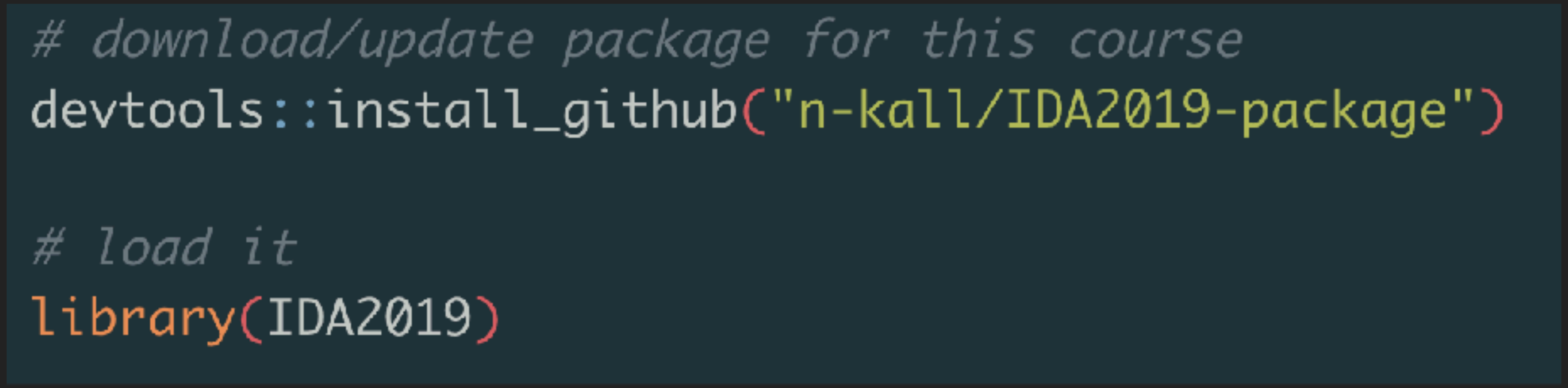
- special purpose programming language for statistical computing
  - statistics, data mining, visualization …
- first released in 1993 as a descendant of S
- free (GNU General Public License)
- authority says: do not treat R as a programming language
  - rather a tool optimized for manipulating, plotting and analyzing data

PACKAGES

- highly extensible via package
  - official package repository is CRAN
  - additional bleeding-edge packages, e.g., from GitHub

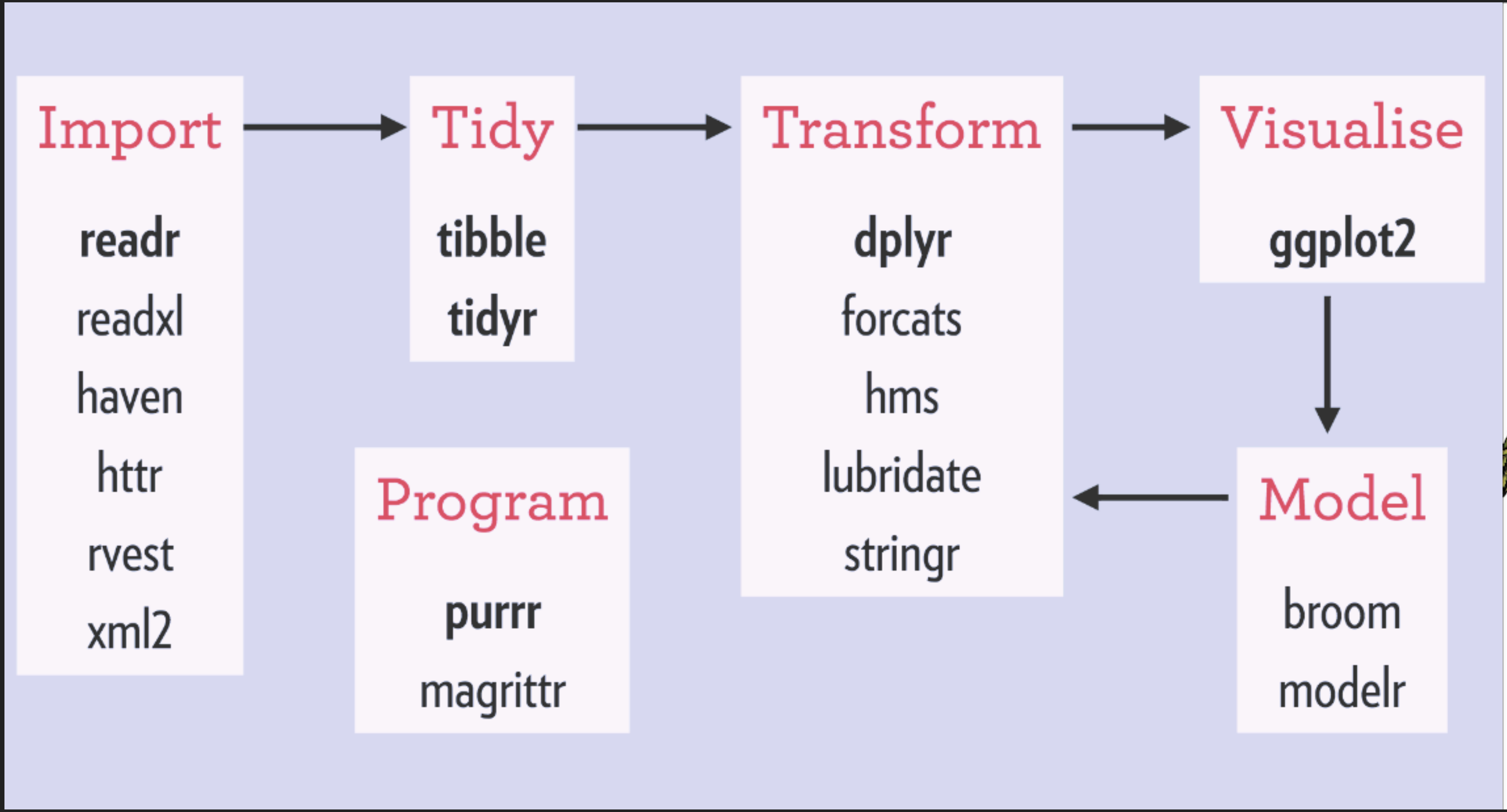


```r
# install package (once)
install.packages("PACKAGE-NAME")

# load package (for every use)
library(PACKAGE-NAME)

# call a function from a package
# without loading it
PACKAGE-NAME::FUNCT-IN-PACKAGE(...)
```



```r
# download/update package for this course
devtools::install_github("n-kall/IDA2019-package")

# load it
library(IDA2019)
```

THE TIDYVERSE



Import

readr

readxl

haven

httr

rvest

xml2

Tidy

tibble

tidyr

Transform

dplyr

forcats

hms

lubridate

stringr

Visualise

ggplot2

Model

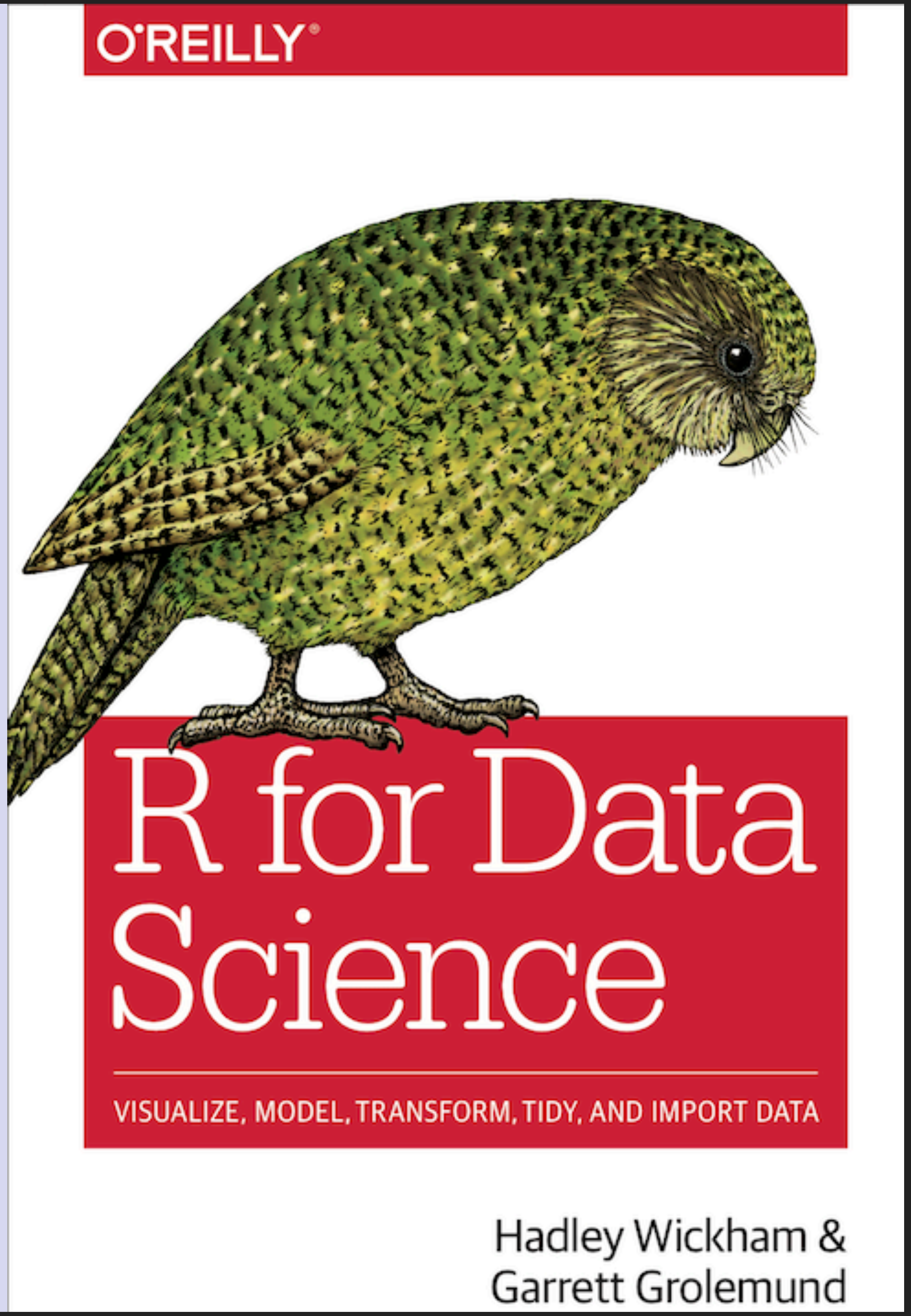
broom

modelr

Program

purrr

magrittr



O'REILLY®

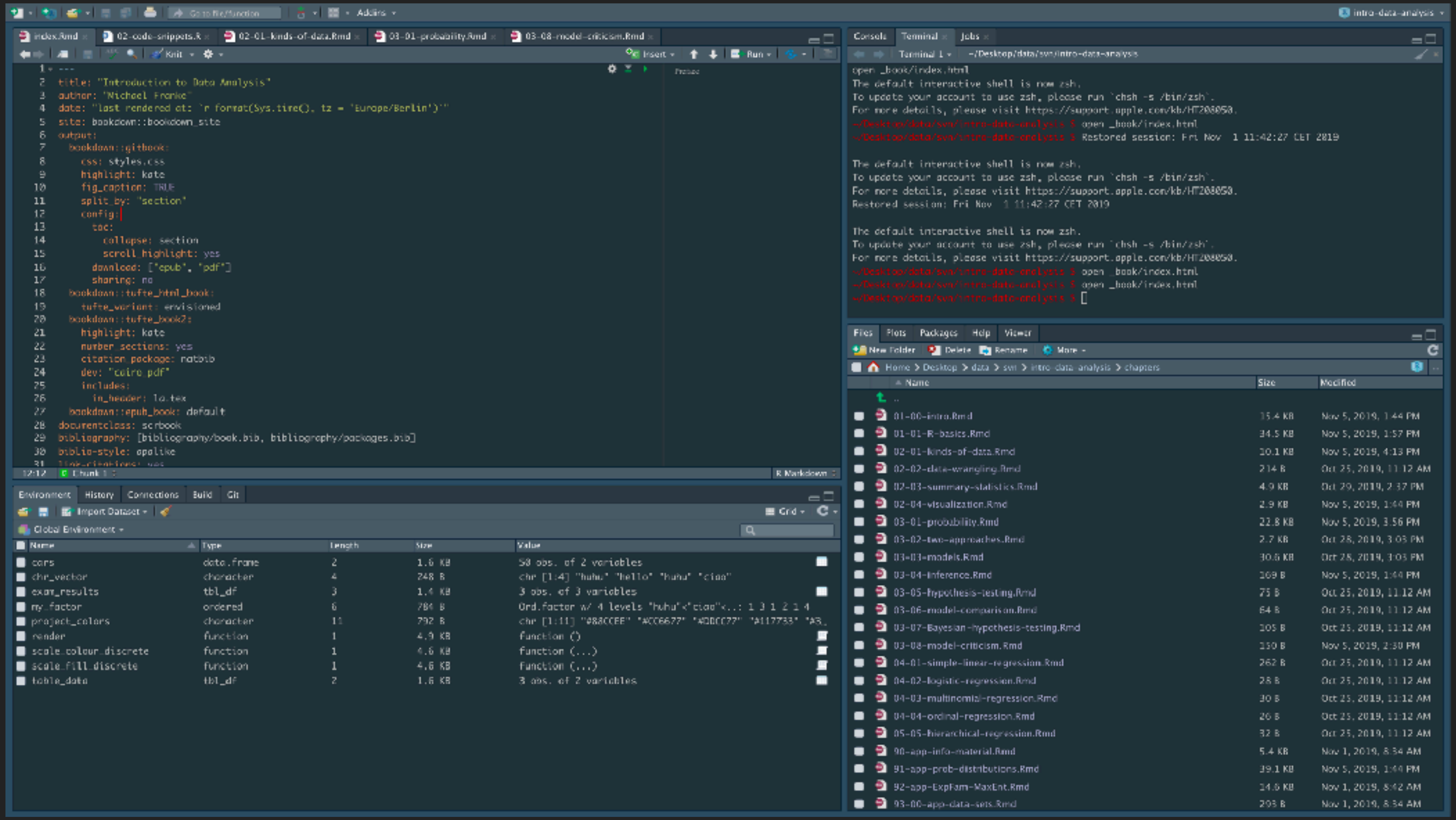
R for Data Science

VISUALIZE, MODEL, TRANSFORM, TIDY, AND IMPORT DATA

Hadley Wickham &
Garrett Grolemund

RSTUDIO

- use unless highly opinionated!



```
---
title: "Introduction to Data Analysis"
author: "Michael Franke"
date: "last rendered at: `r format(Sys.time(), tz = 'Europe/Berlin')`"
site: bookdown::bookdown_site
output:
  bookdown::gitbook:
    css: styles.css
    highlight: kate
    fig_caption: TRUE
    split_by: 'section'
    config:
      toc:
        collapse: section
        scroll_highlight: yes
      download: ["epub", "pdf"]
      sharing: no
  bookdown::tufte_html_book:
    tufte_variant: envisioned
  bookdown::tufte_book2:
    highlight: kate
    number_sections: yes
    citation_package: natbib
    dev: "cairo_pdf"
    includes:
      in_header: la.tex
  bookdown::epub_book: default
documentclass: scrbook
bibliography: [bibliography/book.bib, bibliography/packages.bib]
biblio-style: apalike
link-citations: yes
```

```
open _book/index.html
The default interactive shell is now zsh.
To update your account to use zsh, please run `chsh -s /bin/zsh`.
For more details, please visit https://support.apple.com/kb/HT208050.
~/Desktop/data/svn/intro-data-analysis $ open _book/index.html
~/Desktop/data/svn/intro-data-analysis $ Restored session: Fri Nov  1 11:42:27 CET 2019

The default interactive shell is now zsh.
To update your account to use zsh, please run `chsh -s /bin/zsh`.
For more details, please visit https://support.apple.com/kb/HT208050.
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~/Desktop/data/svn/intro-data-analysis $ open _book/index.html
~/Desktop/data/svn/intro-data-analysis $ 
```

Name	Type	Length	Size	Value
cars	data.frame	2	1.6 KB	50 obs. of 2 variables
chr_vector	character	4	248 B	chr [1:4] "huhu" "hello" "huhu" "ciao"
exam_results	tbl_df	3	1.4 KB	3 obs. of 3 variables
my_factor	ordered	6	784 B	Ord.factor w/ 4 levels "huhu"<"ciao"<..: 1 3 1 2 1 4
project_colors	character	11	792 B	chr [1:11] "#88CCEE" "#CC6677" "#DDCC77" "#117733" "#3…
render	function	1	4.9 KB	function ()
scale_colour_discrete	function	1	4.6 KB	function (...)
scale_fill_discrete	function	1	4.6 KB	function (...)
table_data	tbl_df	2	1.6 KB	3 obs. of 2 variables

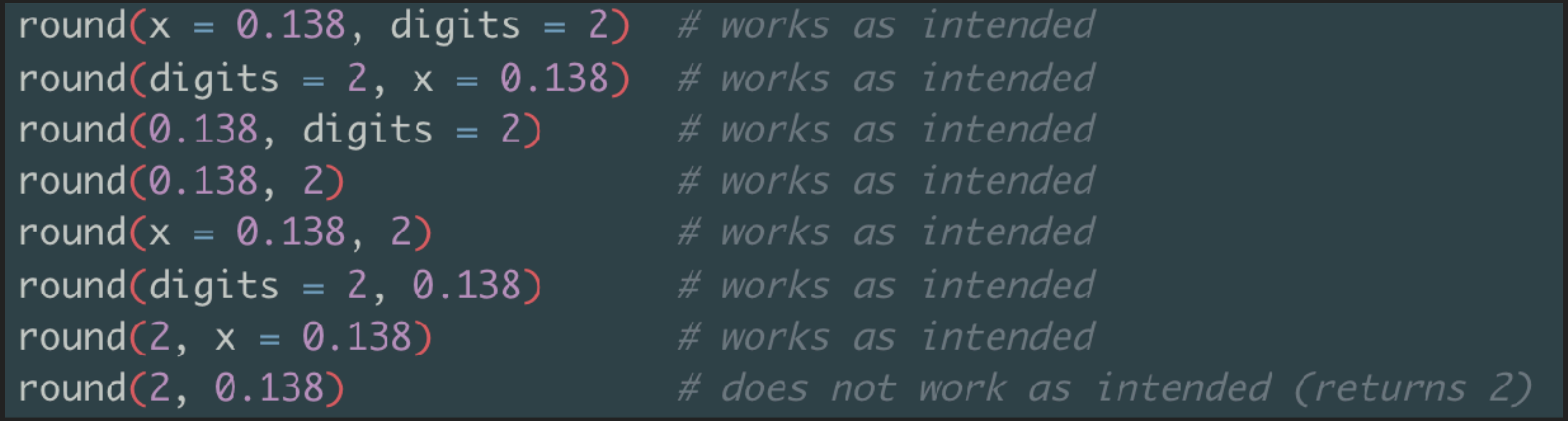
Name	Size	Modified
..		
01-00-intro.Rmd	15.4 KB	Nov 5, 2019, 1:44 PM
01-01-R-basics.Rmd	34.5 KB	Nov 5, 2019, 1:57 PM
02-01-kinds-of-data.Rmd	10.1 KB	Nov 5, 2019, 4:13 PM
02-02-data-wrangling.Rmd	214 B	Oct 25, 2019, 11:12 AM
02-03-summary-statistics.Rmd	4.9 KB	Oct 29, 2019, 2:37 PM
02-04-visualization.Rmd	2.9 KB	Nov 5, 2019, 1:44 PM
03-01-probability.Rmd	22.8 KB	Nov 5, 2019, 3:56 PM
03-02-two-approaches.Rmd	2.7 KB	Oct 28, 2019, 3:03 PM
03-03-models.Rmd	30.6 KB	Oct 28, 2019, 3:03 PM
03-04-inference.Rmd	169 B	Nov 5, 2019, 1:44 PM
03-05-hypothesis-testing.Rmd	75 B	Oct 25, 2019, 11:12 AM
03-06-model-comparison.Rmd	64 B	Oct 25, 2019, 11:12 AM
03-07-Bayesian-hypothesis-testing.Rmd	105 B	Oct 25, 2019, 11:12 AM
03-08-model-criticism.Rmd	130 B	Nov 5, 2019, 2:30 PM
04-01-simple-linear-regression.Rmd	262 B	Oct 25, 2019, 11:12 AM
04-02-logistic-regression.Rmd	28 B	Oct 25, 2019, 11:12 AM
04-03-multinomial-regression.Rmd	30 B	Oct 25, 2019, 11:12 AM
04-04-ordinal-regression.Rmd	26 B	Oct 25, 2019, 11:12 AM
05-05-hierarchical-regression.Rmd	32 B	Oct 25, 2019, 11:12 AM
90-app-info-material.Rmd	5.4 KB	Nov 1, 2019, 8:34 AM
91-app-prob-distributions.Rmd	39.1 KB	Nov 5, 2019, 1:44 PM
92-app-ExpFam-MaxEnt.Rmd	14.6 KB	Nov 1, 2019, 8:42 AM
93-00-app-data-sets.Rmd	293 B	Nov 1, 2019, 8:34 AM

FIRST STEPS IN R

- interpreted language
  - evaluate code line-by-line when developing
  - store code in scripts for reuse
- multi-paradigmatic language
  - supports object-oriented programming (but we will not use it (much))
  - supports functional programming (and we will use it a lot)

FUNCTIONS

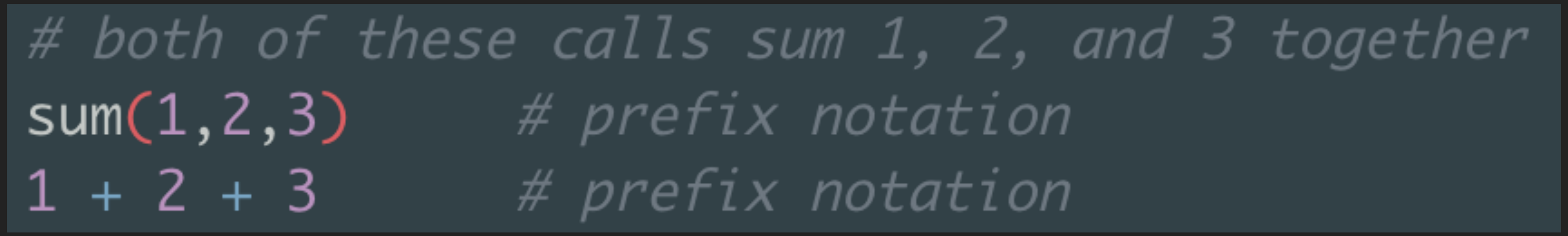
- function calls
  - named and unnamed arguments
  - default values



```
round(x = 0.138, digits = 2)   # works as intended
round(digits = 2, x = 0.138)   # works as intended
round(0.138, digits = 2)       # works as intended
round(0.138, 2)                # works as intended
round(x = 0.138, 2)            # works as intended
round(digits = 2, 0.138)       # works as intended
round(2, x = 0.138)            # works as intended
round(2, 0.138)                # does not work as intended (returns 2)
```

FUNCTIONS

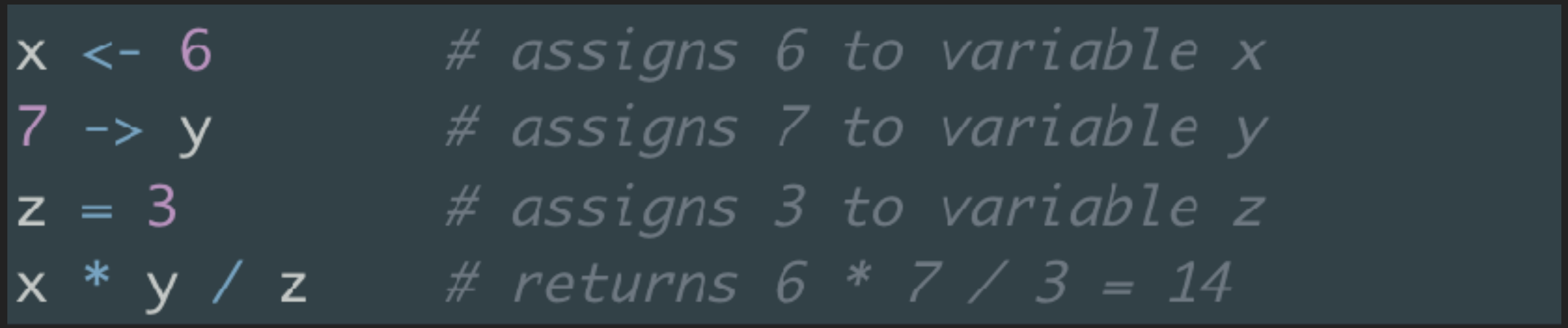
- function calls
  - prefix vs infix notation



```
# both of these calls sum 1, 2, and 3 together
sum(1,2,3)      # prefix notation
1 + 2 + 3       # prefix notation
```

VARIABLES

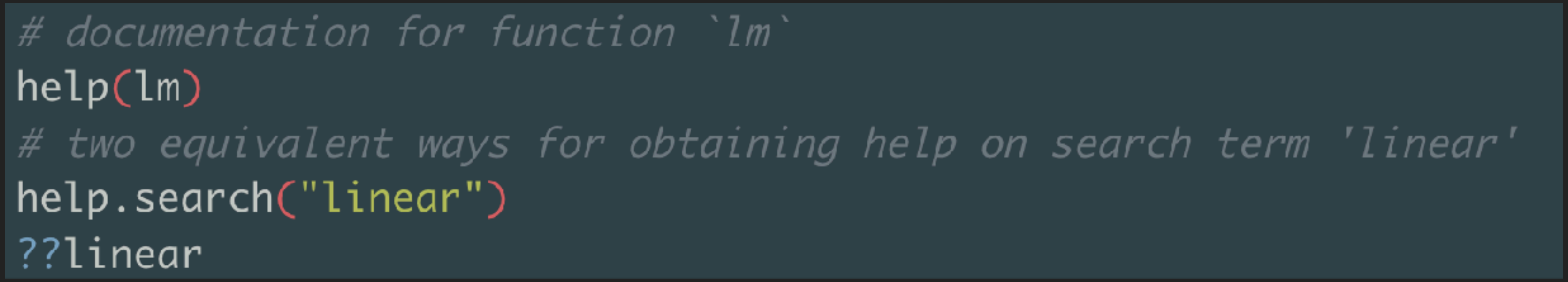
- variable variable assignment
  - use of `=` is discouraged



```
x <- 6        # assigns 6 to variable x
7 -> y        # assigns 7 to variable y
z = 3         # assigns 3 to variable z
x * y / z     # returns 6 * 7 / 3 = 14
```

GETTING HELP

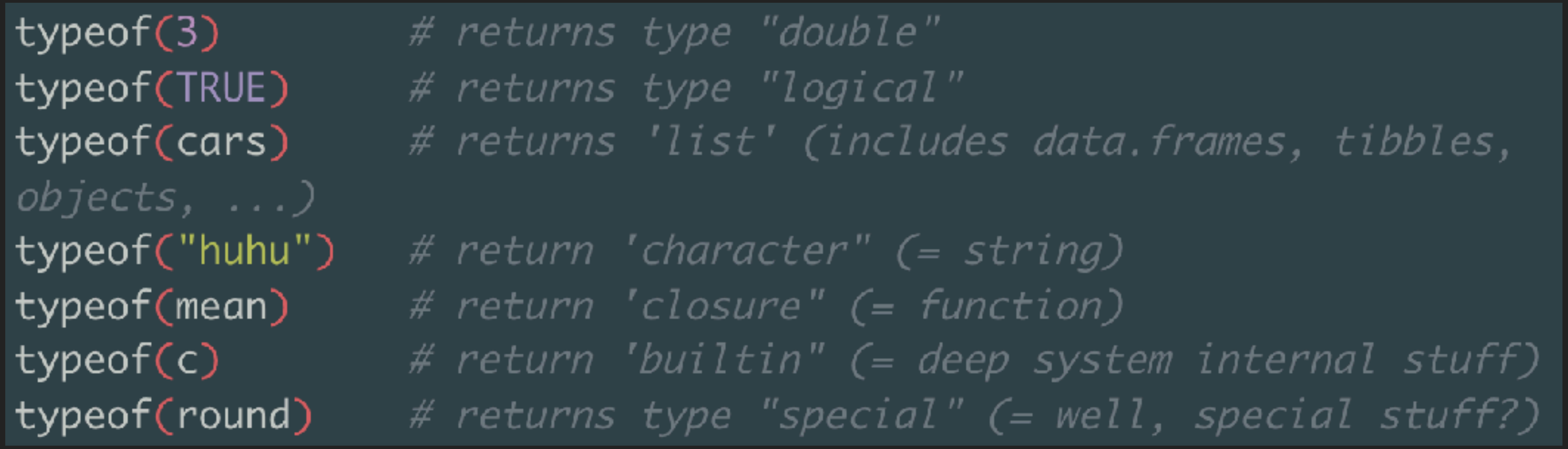
- internal documentation



```
# documentation for function `lm`
help(lm)
# two equivalent ways for obtaining help on search term 'linear'
help.search("linear")
??linear
```

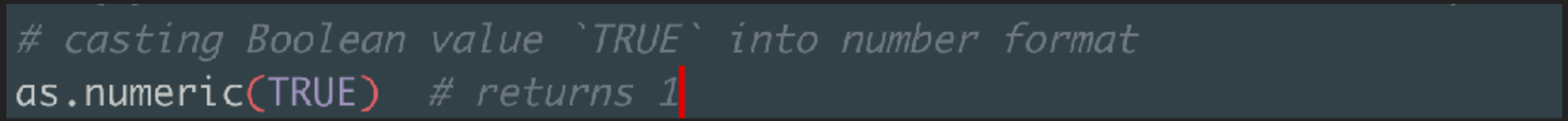
DATA TYPES

- numeric
  - integer, double, complex
- logical (= Boolean)
- special values
  - `NA`, `NaN`, `Inf`, `NULL`
- character (= string)
- factor
- list
- data frame / tibble



```
typeof(3)          # returns type "double"
typeof(TRUE)       # returns type "logical"
typeof(cars)       # returns 'list' (includes data.frames, tibbles,
objects, ...)
typeof("huhu")     # return 'character" (= string)
typeof(mean)       # return 'closure" (= function)
typeof(c)          # return 'builtin" (= deep system internal stuff)
typeof(round)      # returns type "special" (= well, special stuff?)
```

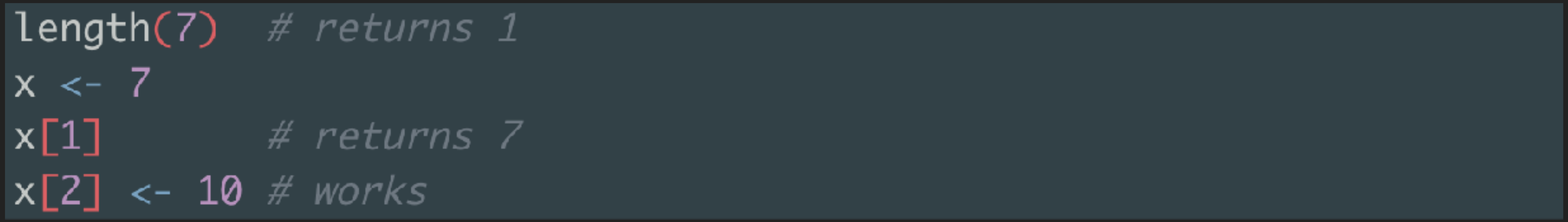
- casting



```
# casting Boolean value `TRUE` into number format
as.numeric(TRUE)  # returns 1
```

VECTORS

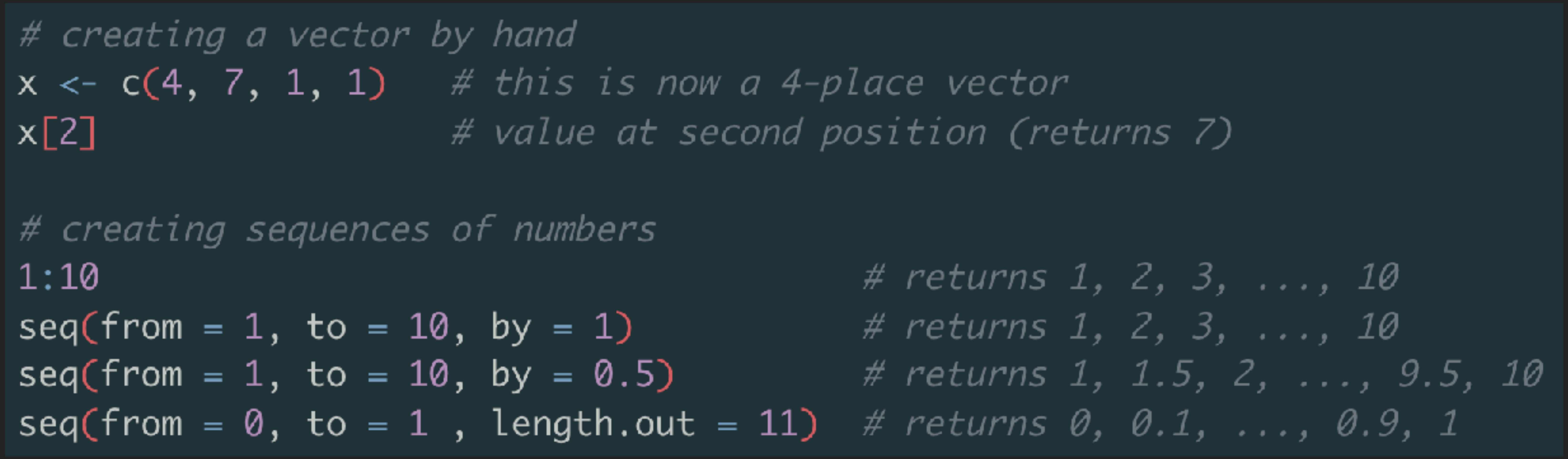
- as violable default, expect everything to be a vector-like
  - single numbers have a `length`
  - you can access index [2] of a variable storing a single number



```
length(7)  # returns 1
x <- 7
x[1]       # returns 7
x[2] <- 10 # works
```

VECTORS

- creating numeric vectors
  - indexing starts at 1

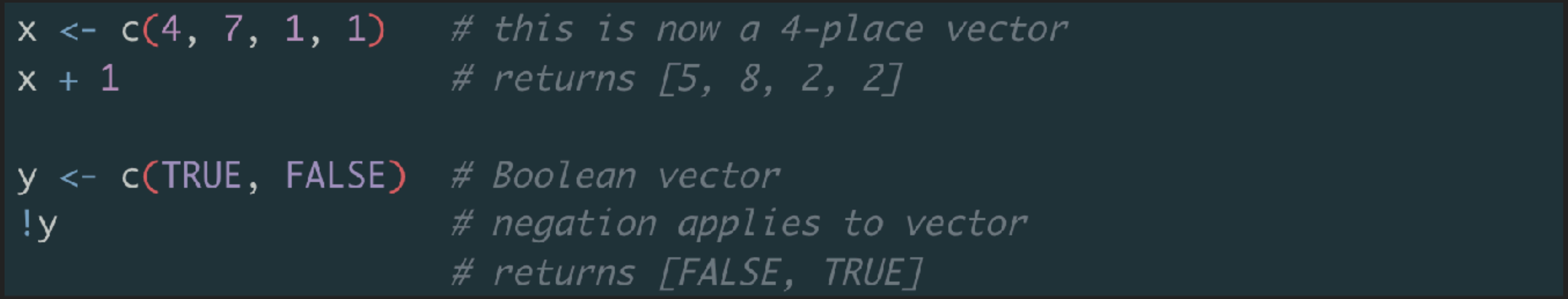


```
# creating a vector by hand
x <- c(4, 7, 1, 1)   # this is now a 4-place vector
x[2]                 # value at second position (returns 7)

# creating sequences of numbers
1:10                                     # returns 1, 2, 3, ..., 10
seq(from = 1, to = 10, by = 1)           # returns 1, 2, 3, ..., 10
seq(from = 1, to = 10, by = 0.5)         # returns 1, 1.5, 2, ..., 9.5, 10
seq(from = 0, to = 1 , length.out = 11)  # returns 0, 0.1, ..., 0.9, 1
```

VECTORS

- as violable default, expect every operation to apply to vectors

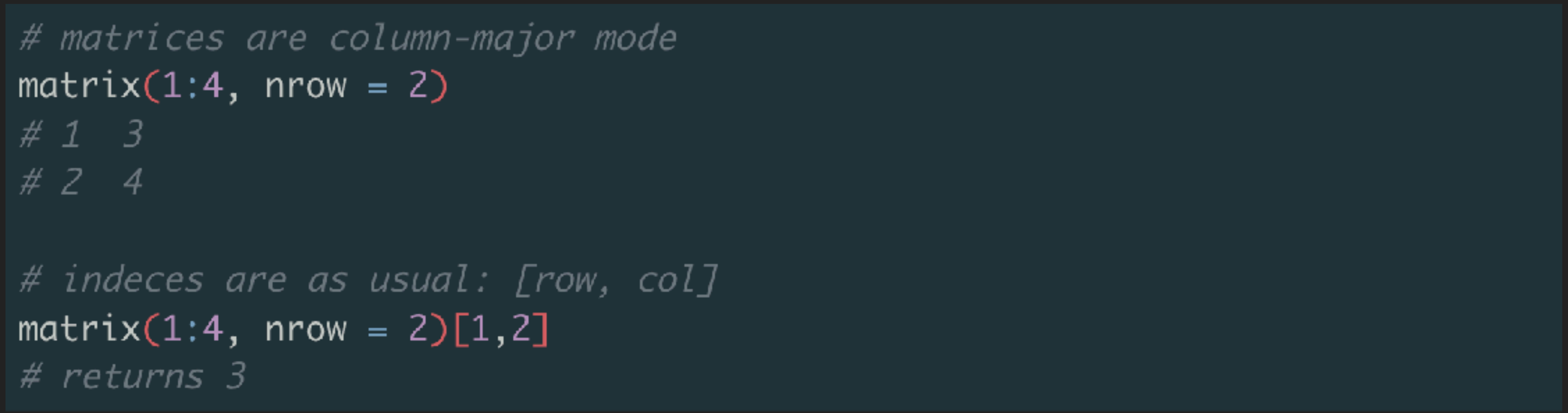


```
x <- c(4, 7, 1, 1)    # this is now a 4-place vector
x + 1                 # returns [5, 8, 2, 2]

y <- c(TRUE, FALSE)   # Boolean vector
!y                    # negation applies to vector
                      # returns [FALSE, TRUE]
```

MATRICES

- numeric matrices are two-dimensional vectors
  - column-major mode



```
# matrices are column-major mode
matrix(1:4, nrow = 2)
# 1  3
# 2  4

# indeces are as usual: [row, col]
matrix(1:4, nrow = 2)[1,2]
# returns 3
```

MATRICES

- numeric matrices are two-dimensional vectors
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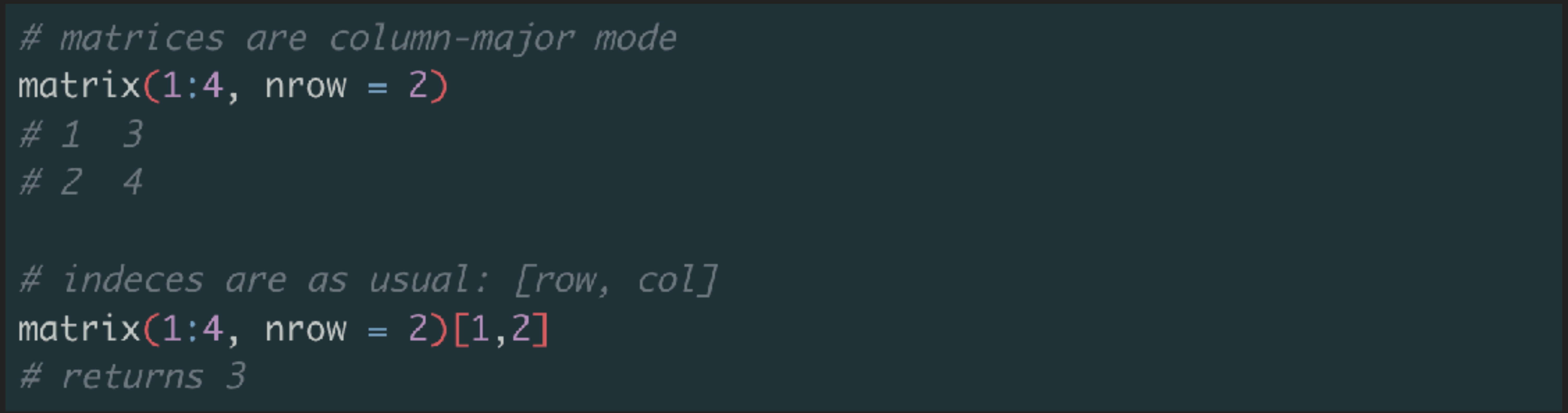

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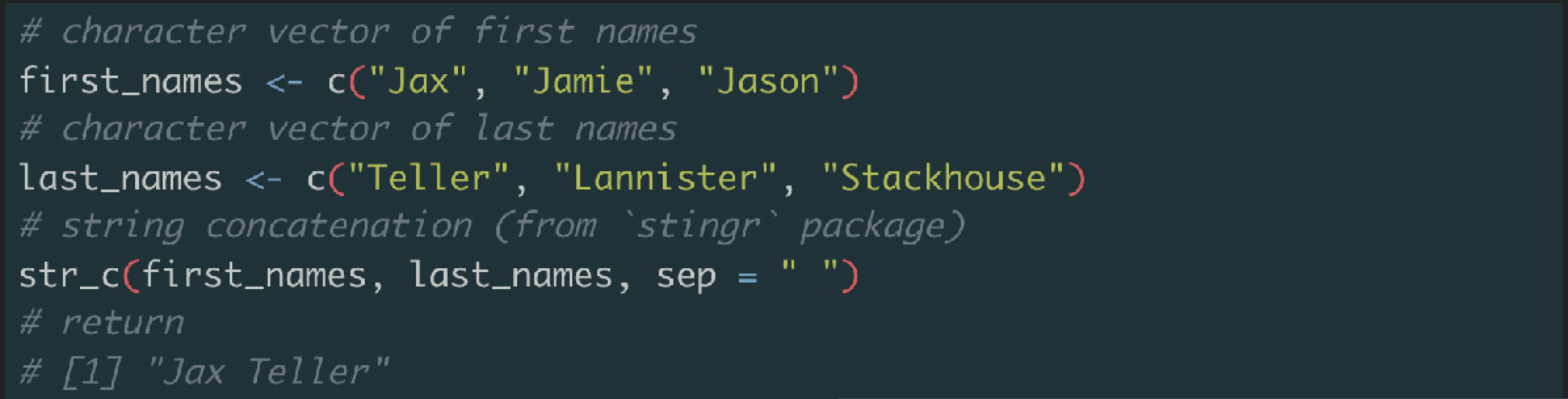
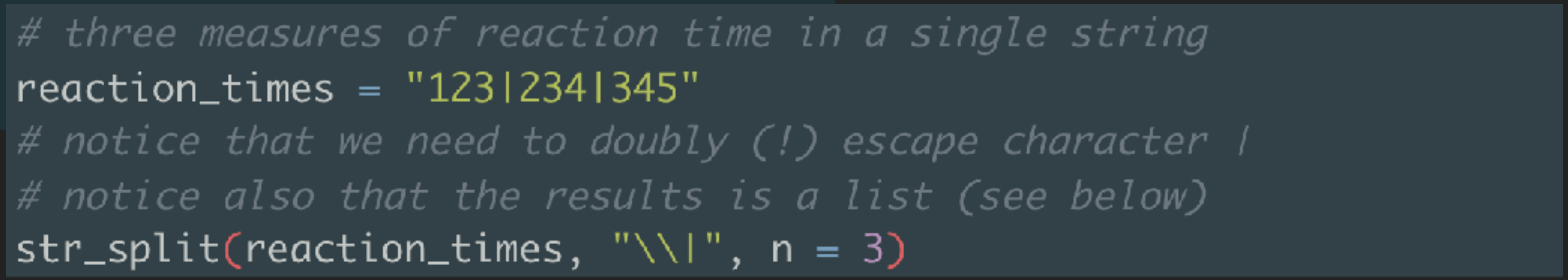
CHARACTER VECTORS

- check `stingr` package for useful character functions



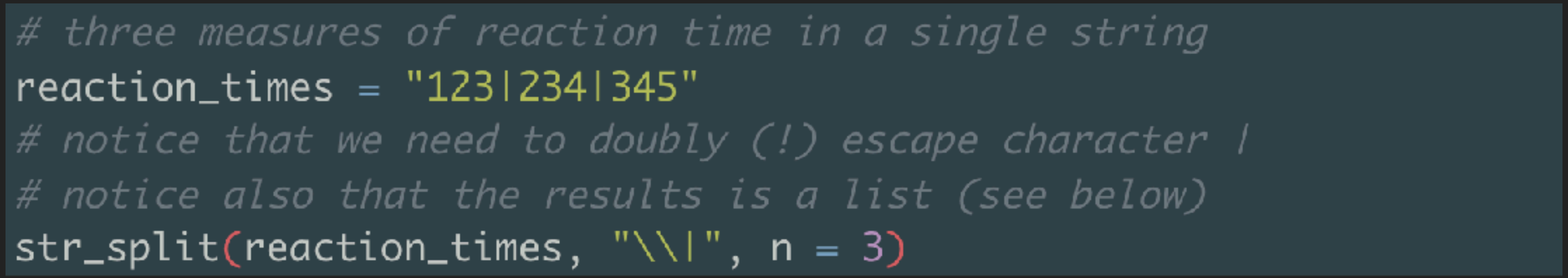
```r
# character vector of first names
first_names <- c("Jax", "Jamie", "Jason")
# character vector of last names
last_names <- c("Teller", "Lannister", "Stackhouse")
# string concatenation (from `stingr` package)
str_c(first_names, last_names, sep = " ")
# return
# [1] "Jax Teller"
# [2] "Jamie Lannister"
# [3] "Jason Stackhouse"
```



```r
# three measures of reaction time in a single string
reaction_times = "123|234|345"
# notice that we need to doubly (!) escape character |
# notice also that the results is a list (see below)
str_split(reaction_times, "\\|", n = 3)
```

CHARACTER VECTORS

- check `stingr` package for useful character functions



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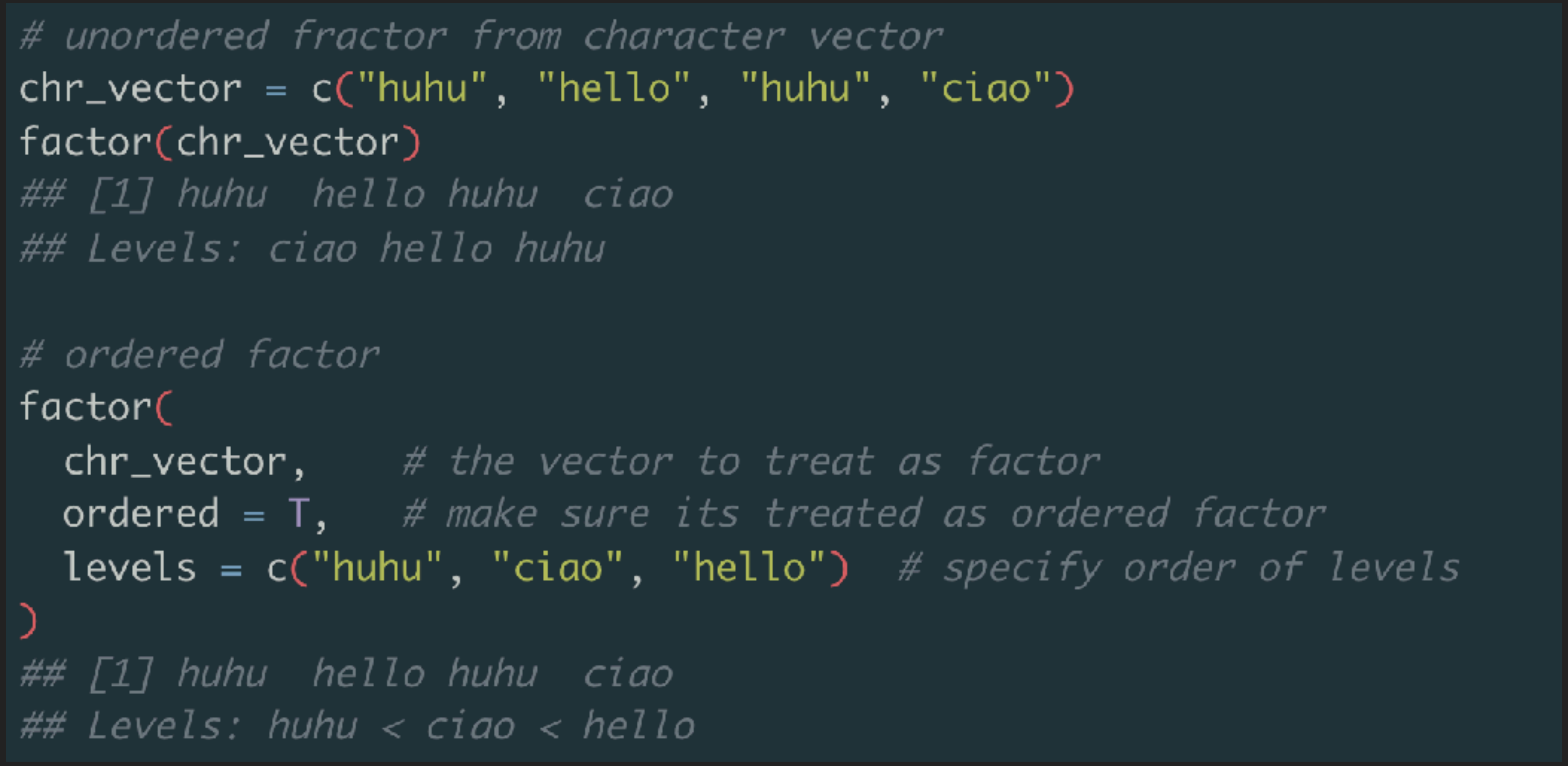
```

MIA

- gmzzlyoiyrnmhjeigrewiytdyloopcfokjhgfpoiupoipipiphgfhgnjfghnbfjkakaaggrsjuytrewpoiuytrewqlkjhgfdsalyasdpopopapamkkrtyuiopoiuytrewq

FACTORS

- factors store information about instances from a finite set of discrete categories (ordered or unordered)

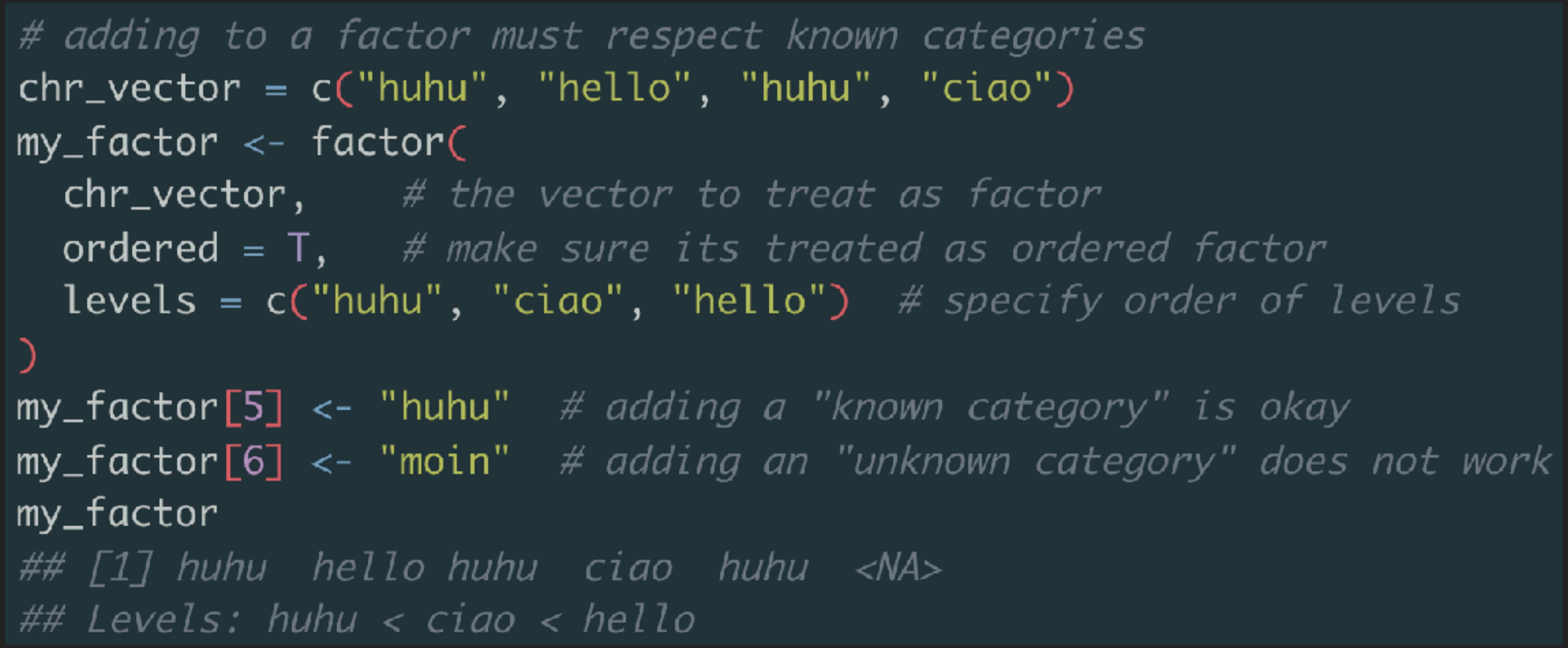


```
# unordered fractor from character vector
chr_vector = c("huhu", "hello", "huhu", "ciao")
factor(chr_vector)
## [1] huhu  hello huhu  ciao
## Levels: ciao hello huhu

# ordered factor
factor(
  chr_vector,    # the vector to treat as factor
  ordered = T,   # make sure its treated as ordered factor
  levels = c("huhu", "ciao", "hello")  # specify order of levels
)
## [1] huhu  hello huhu  ciao
## Levels: huhu < ciao < hello
```

FACTORS

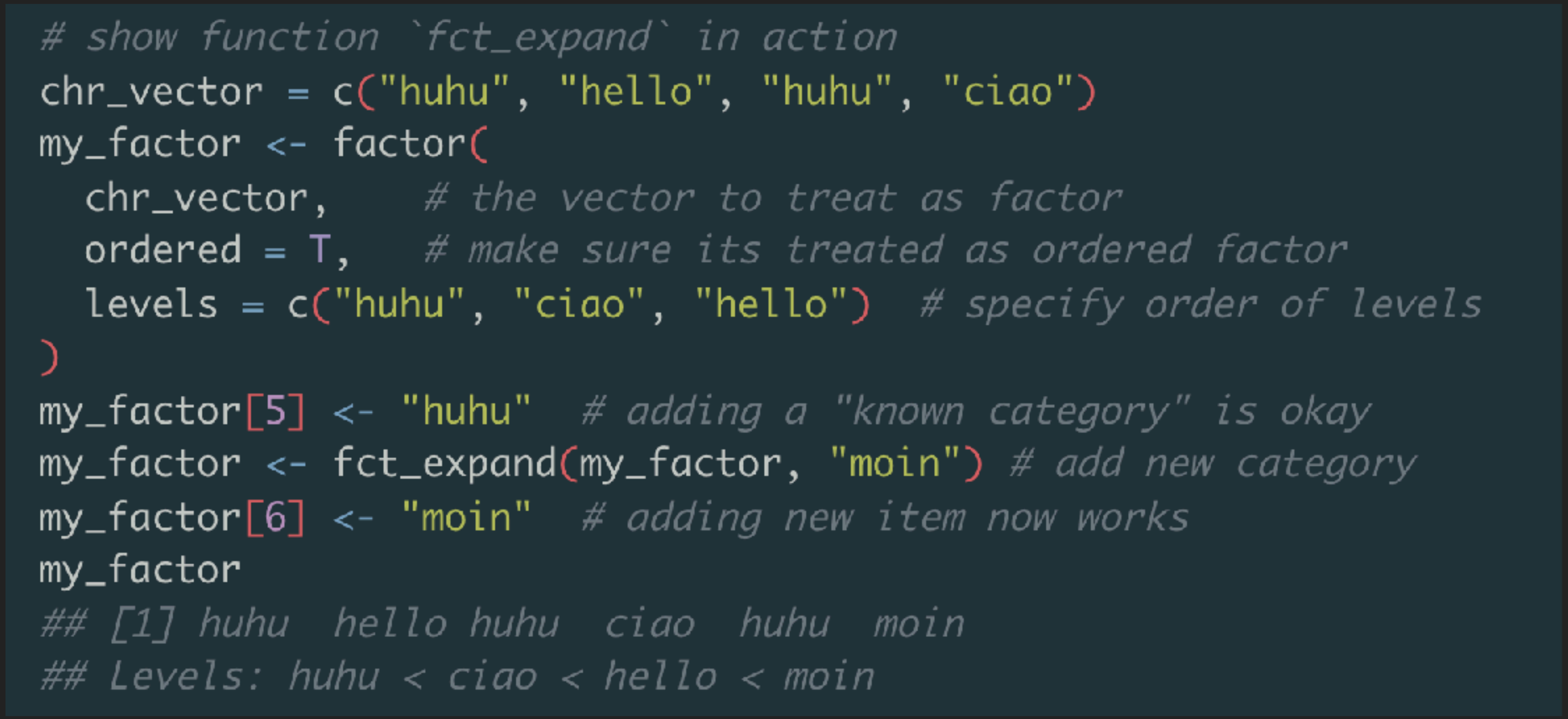
- adding elements to a factor must respect known categories



```
# adding to a factor must respect known categories
chr_vector = c("huhu", "hello", "huhu", "ciao")
my_factor <- factor(
  chr_vector,    # the vector to treat as factor
  ordered = T,   # make sure its treated as ordered factor
  levels = c("huhu", "ciao", "hello")  # specify order of levels
)
my_factor[5] <- "huhu"  # adding a "known category" is okay
my_factor[6] <- "moin"  # adding an "unknown category" does not work
my_factor
## [1] huhu  hello huhu  ciao  huhu  <NA>
## Levels: huhu < ciao < hello
```

FACTORS

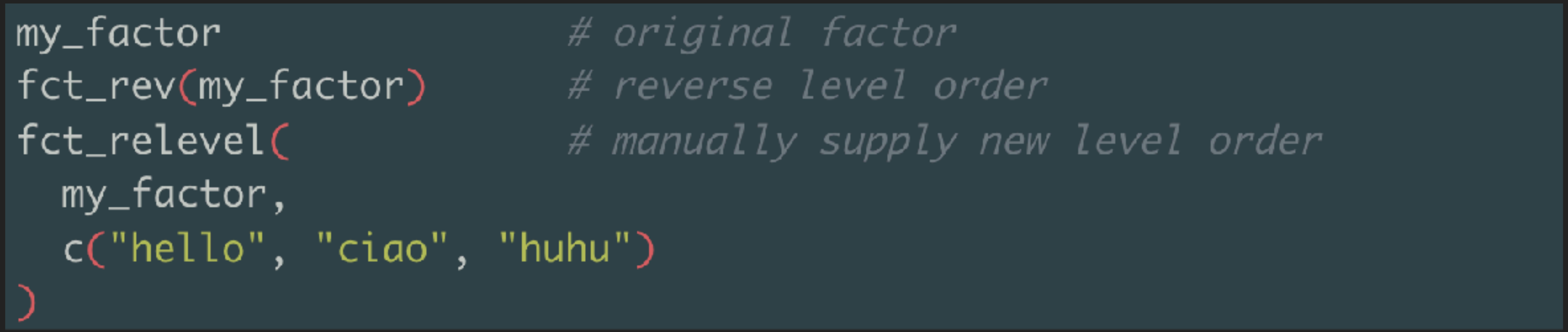
- useful functions for factors from `forcats` package



```
# show function `fct_expand` in action
chr_vector = c("huhu", "hello", "huhu", "ciao")
my_factor <- factor(
  chr_vector,     # the vector to treat as factor
  ordered = T,    # make sure its treated as ordered factor
  levels = c("huhu", "ciao", "hello")  # specify order of levels
)
my_factor[5] <- "huhu"  # adding a "known category" is okay
my_factor <- fct_expand(my_factor, "moin") # add new category
my_factor[6] <- "moin"  # adding new item now works
my_factor
## [1] huhu  hello huhu  ciao  huhu  moin
## Levels: huhu < ciao < hello < moin
```

FACTORS

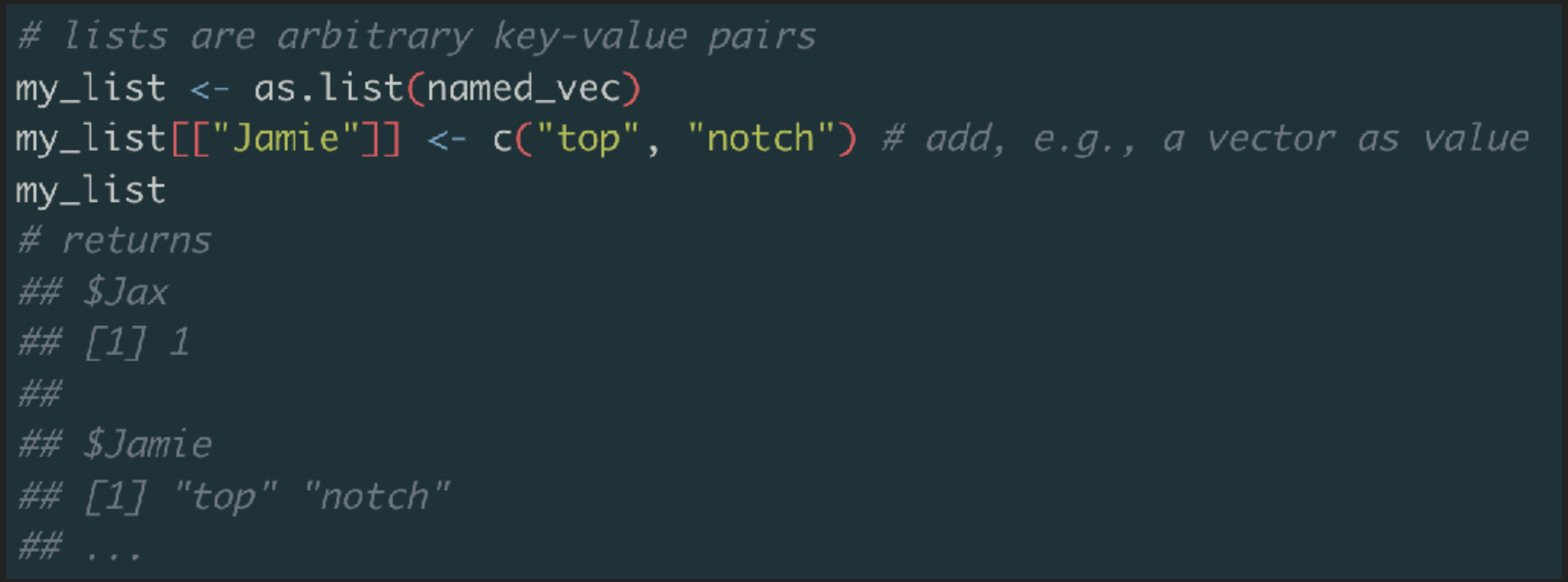
- useful functions for factors from `forcats` package



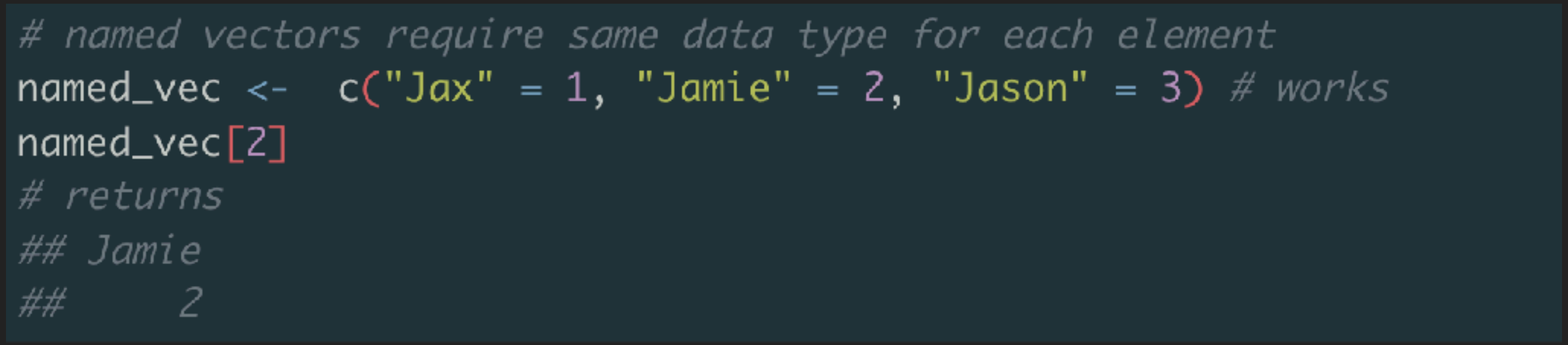
```
my_factor               # original factor
fct_rev(my_factor)      # reverse level order
fct_relevel(            # manually supply new level order
  my_factor,
  c("hello", "ciao", "huhu")
)
```

LISTS

- named vectors ≠ lists



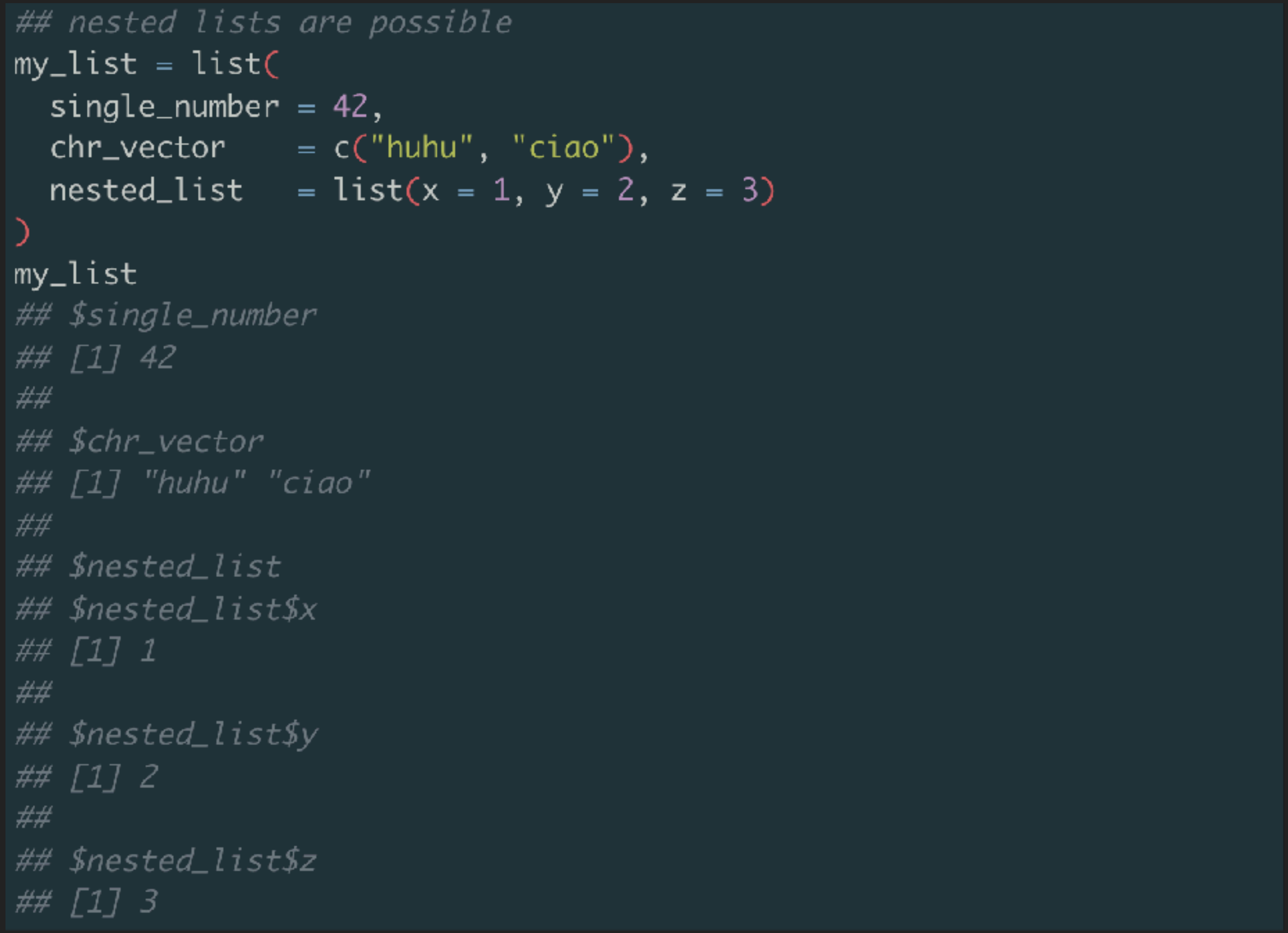
```r
# lists are arbitrary key-value pairs
my_list <- as.list(named_vec)
my_list[["Jamie"]] <- c("top", "notch") # add, e.g., a vector as value
my_list
# returns
## $Jax
## [1] 1
##
## $Jamie
## [1] "top" "notch"
## ...
```



```r
# named vectors require same data type for each element
named_vec <-  c("Jax" = 1, "Jamie" = 2, "Jason" = 3) # works
named_vec[2]
# returns
## Jamie
##     2
```

LISTS

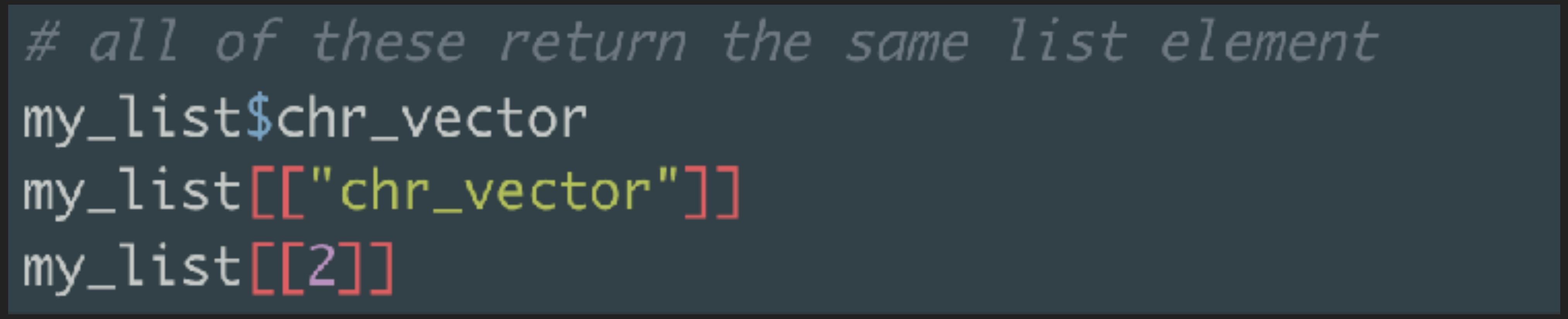
- nested lists are possible



```
## nested lists are possible
my_list = list(
  single_number = 42,
  chr_vector    = c("huhu", "ciao"),
  nested_list   = list(x = 1, y = 2, z = 3)
)
my_list
## $single_number
## [1] 42
##
## $chr_vector
## [1] "huhu" "ciao"
##
## $nested_list
## $nested_list$x
## [1] 1
##
## $nested_list$y
## [1] 2
##
## $nested_list$z
## [1] 3
```

LISTS

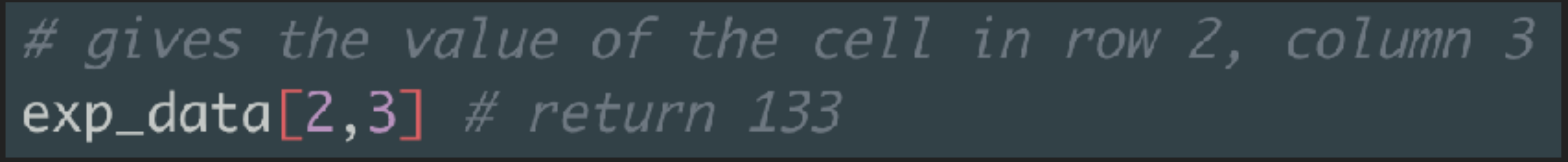
- ways of accessing list elements



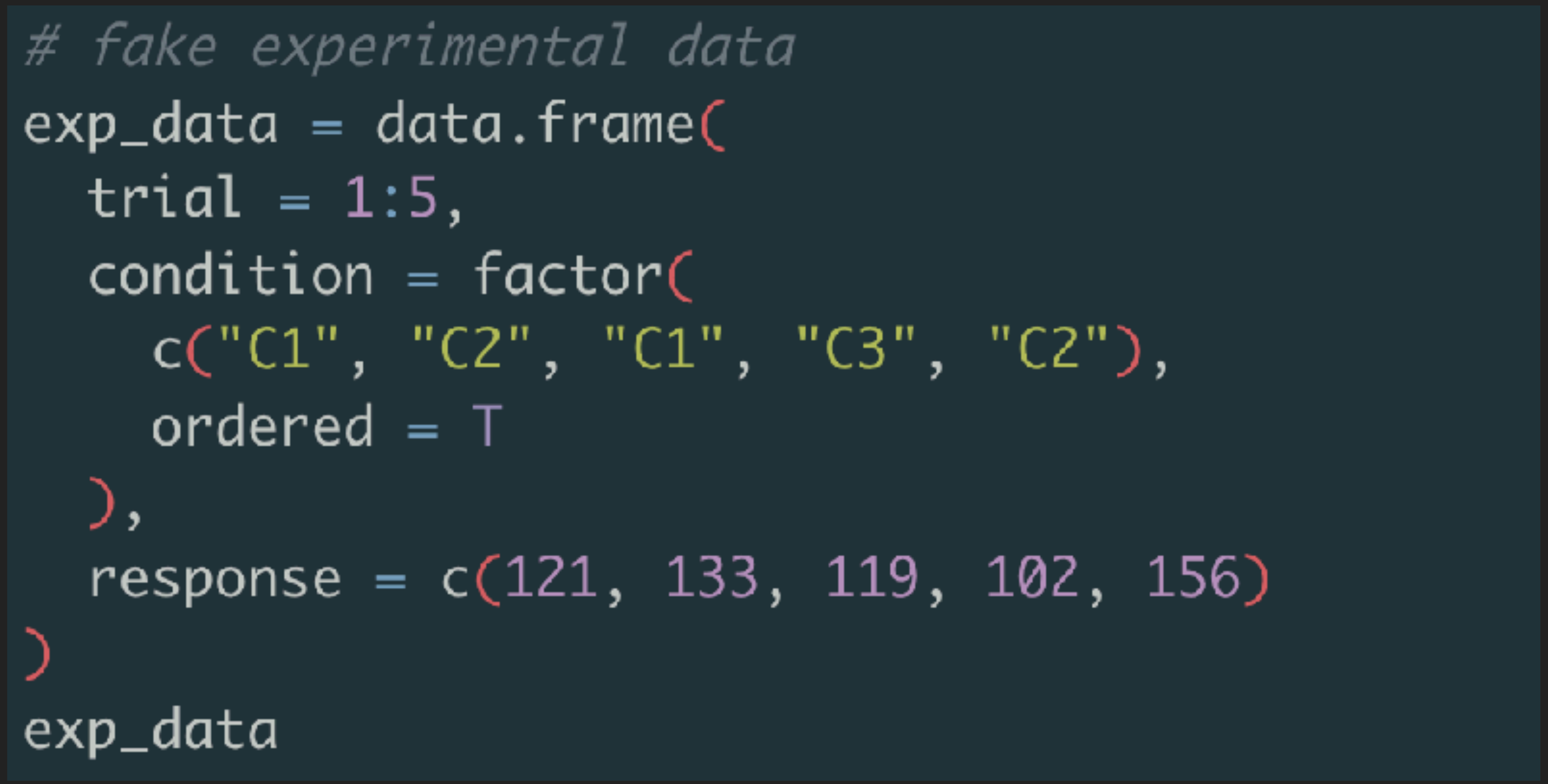
```
# all of these return the same list element
my_list$chr_vector
my_list[["chr_vector"]]
my_list[[2]]
```

DATA FRAMES

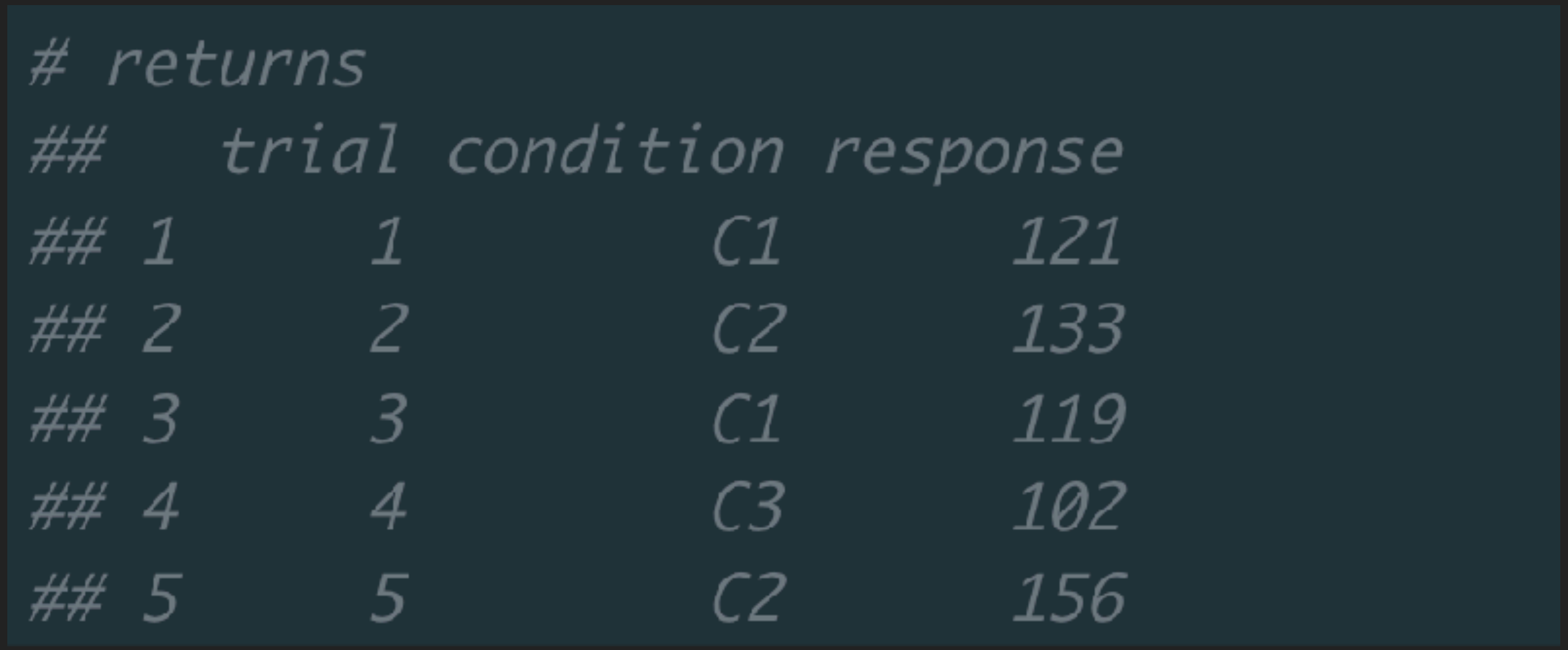
- data frames store data
  - data frames are essentially lists where all elements have the same length
    - “rectangular data”
  - we can use indexing like in a matrix



```r
# gives the value of the cell in row 2, column 3
exp_data[2,3] # return 133
```



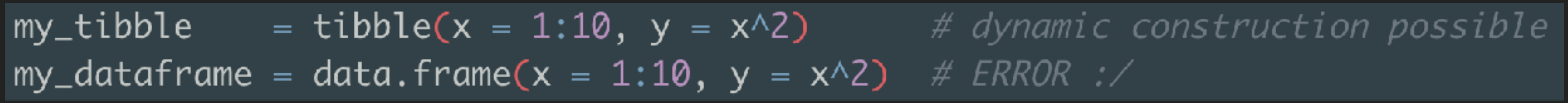
```r
# fake experimental data
exp_data = data.frame(
  trial = 1:5,
  condition = factor(
    c("C1", "C2", "C1", "C3", "C2"),
    ordered = T
  ),
  response = c(121, 133, 119, 102, 156)
)
exp_data
```



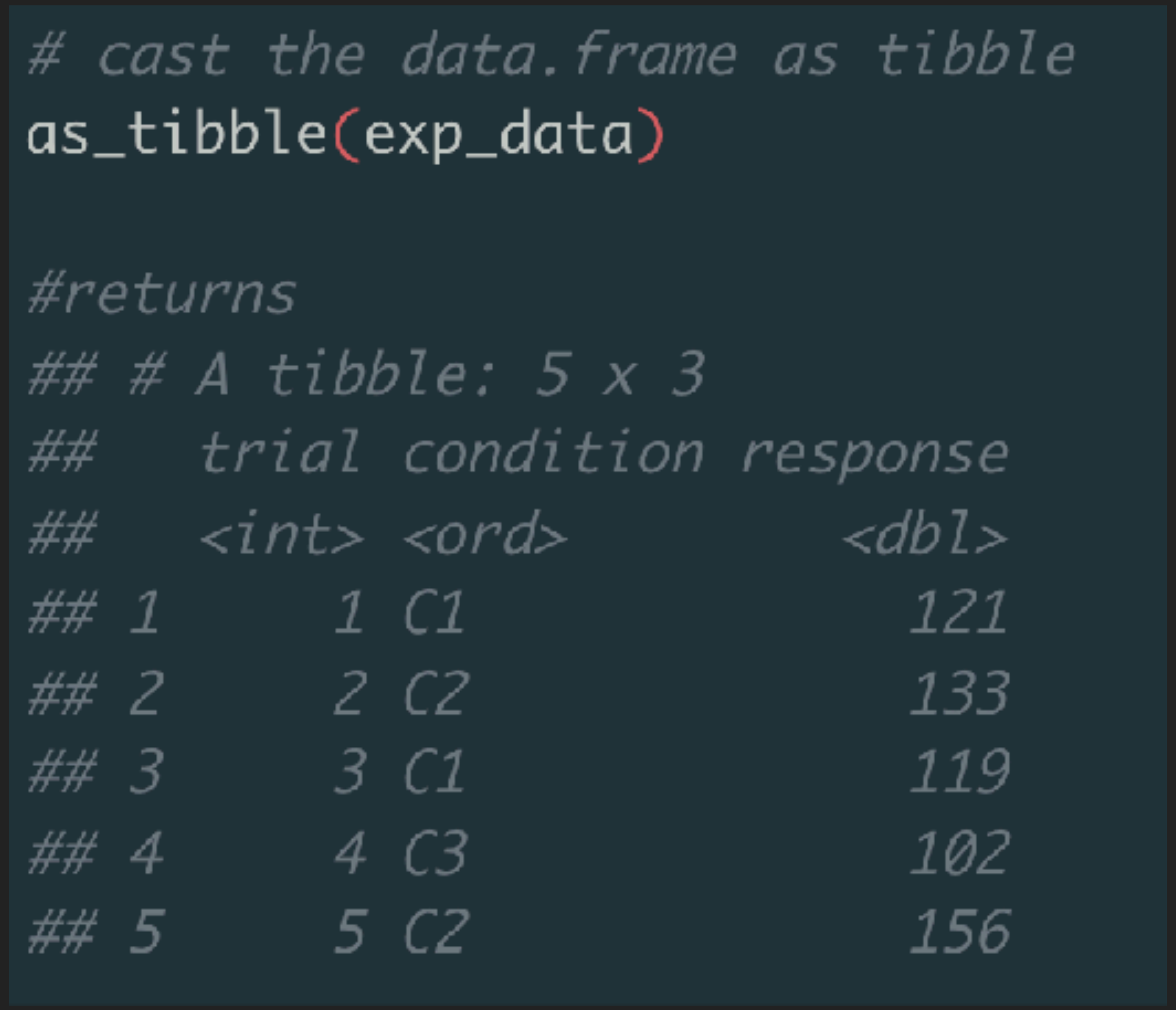
```
# returns
##   trial condition response
## 1     1        C1      121
## 2     2        C2      133
## 3     3        C1      119
## 4     4        C3      102
## 5     5        C2      156
```

DATA FRAMES & TIBBLES

- tibbles are data frames in the tidyverse
- some differences:
  - different output format
  - different encoding defaults
    - no “strings as factors” default
  - dynamic construction possible



```
my_tibble    = tibble(x = 1:10, y = x^2)      # dynamic construction possible
my_dataframe = data.frame(x = 1:10, y = x^2)  # ERROR :/
```

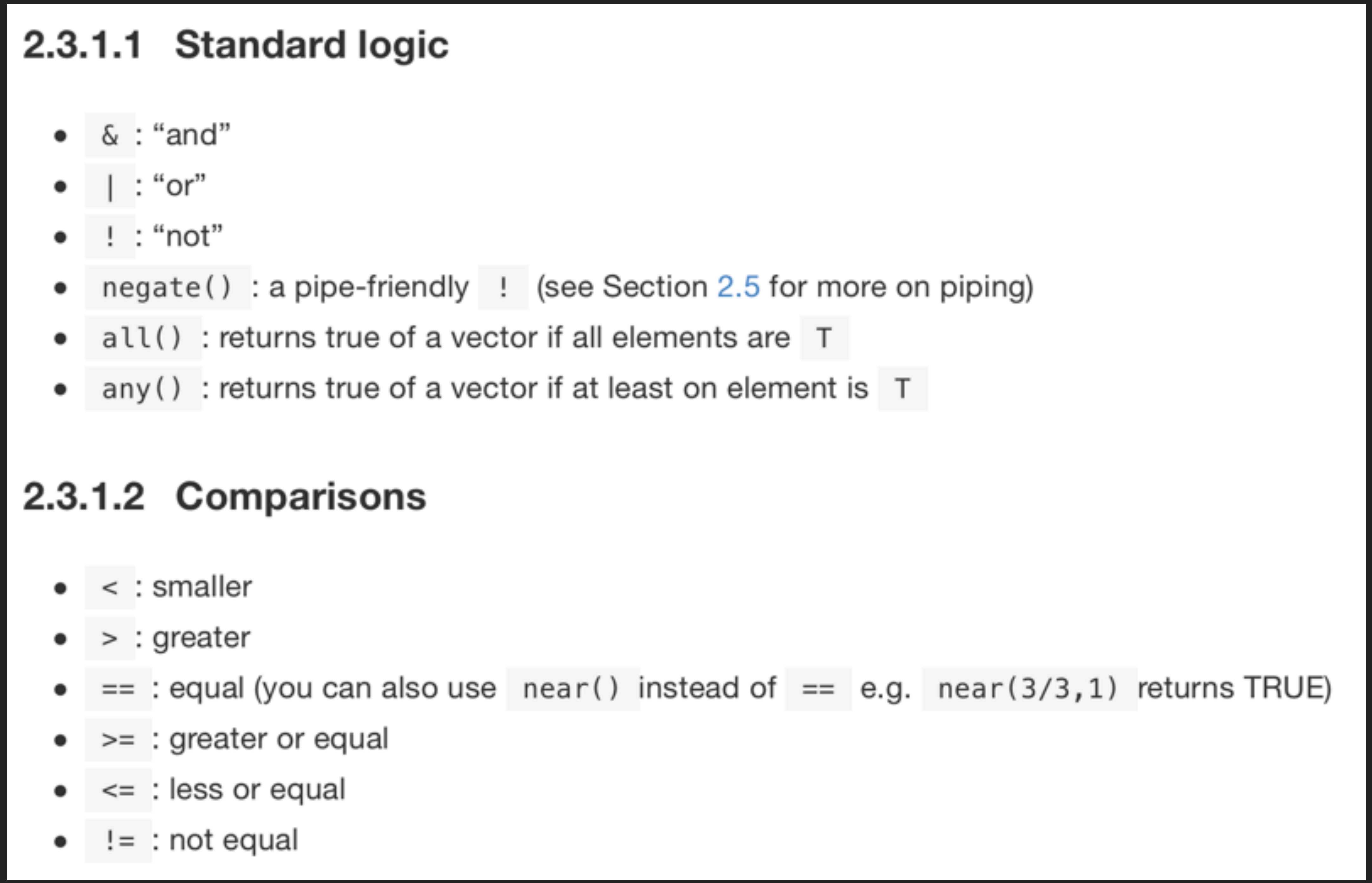


```
# cast the data.frame as tibble
as_tibble(exp_data)

#returns
## # A tibble: 5 x 3
##   trial condition response
##   <int> <ord>        <dbl>
## 1     1 C1             121
## 2     2 C2             133
## 3     3 C1             119
## 4     4 C3             102
## 5     5 C2             156
```

FUNCTIONS

- many useful predefined functions (obviously)
  - skim docs and cheat sheets for inspiration
  - continuously expand your inventory

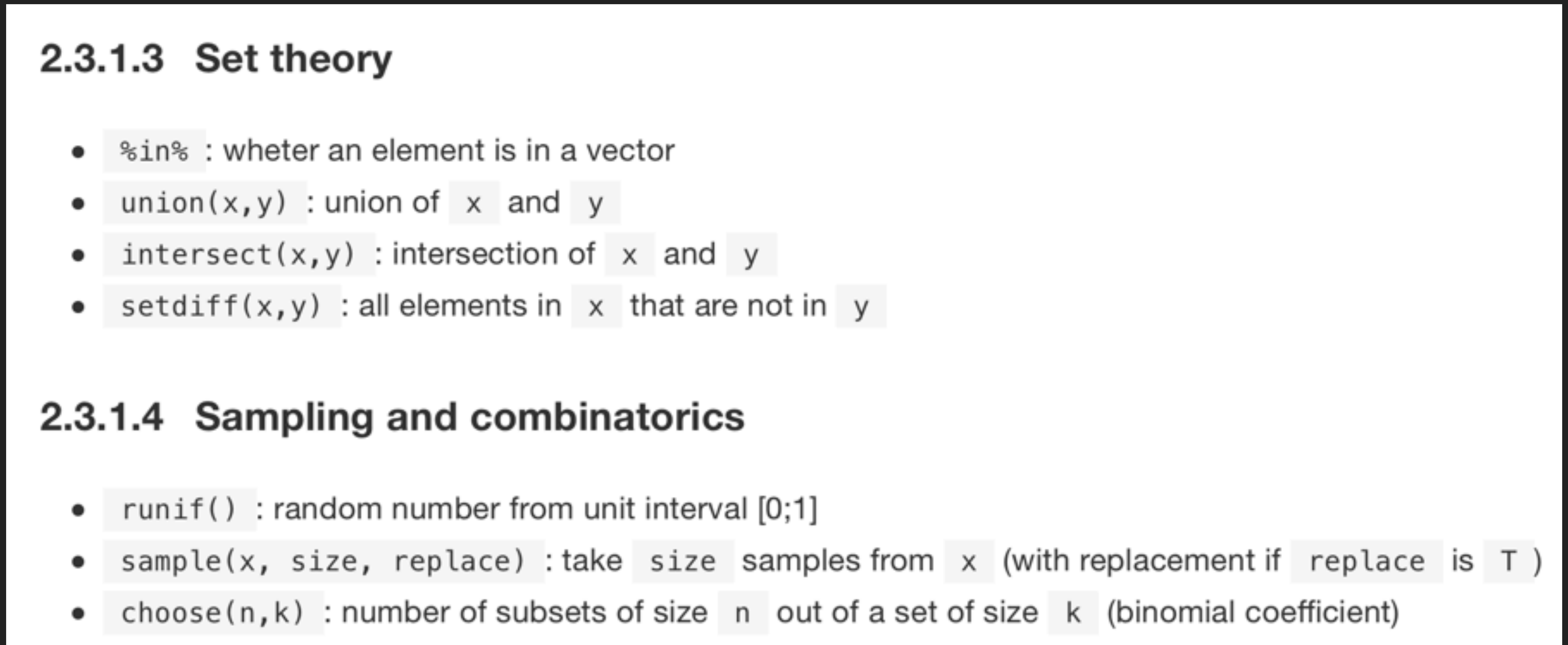


2.3.1.1 Standard logic

- `&` : “and”
- `|` : “or”
- `!` : “not”
- `negate()` : a pipe-friendly `!` (see Section 2.5 for more on piping)
- `all()` : returns true of a vector if all elements are `T`
- `any()` : returns true of a vector if at least on element is `T`

2.3.1.2 Comparisons

- `<` : smaller
- `>` : greater
- `==` : equal (you can also use `near()` instead of `==` e.g. `near(3/3,1)` returns TRUE)
- `>=` : greater or equal
- `<=` : less or equal
- `!=` : not equal



2.3.1.3 Set theory

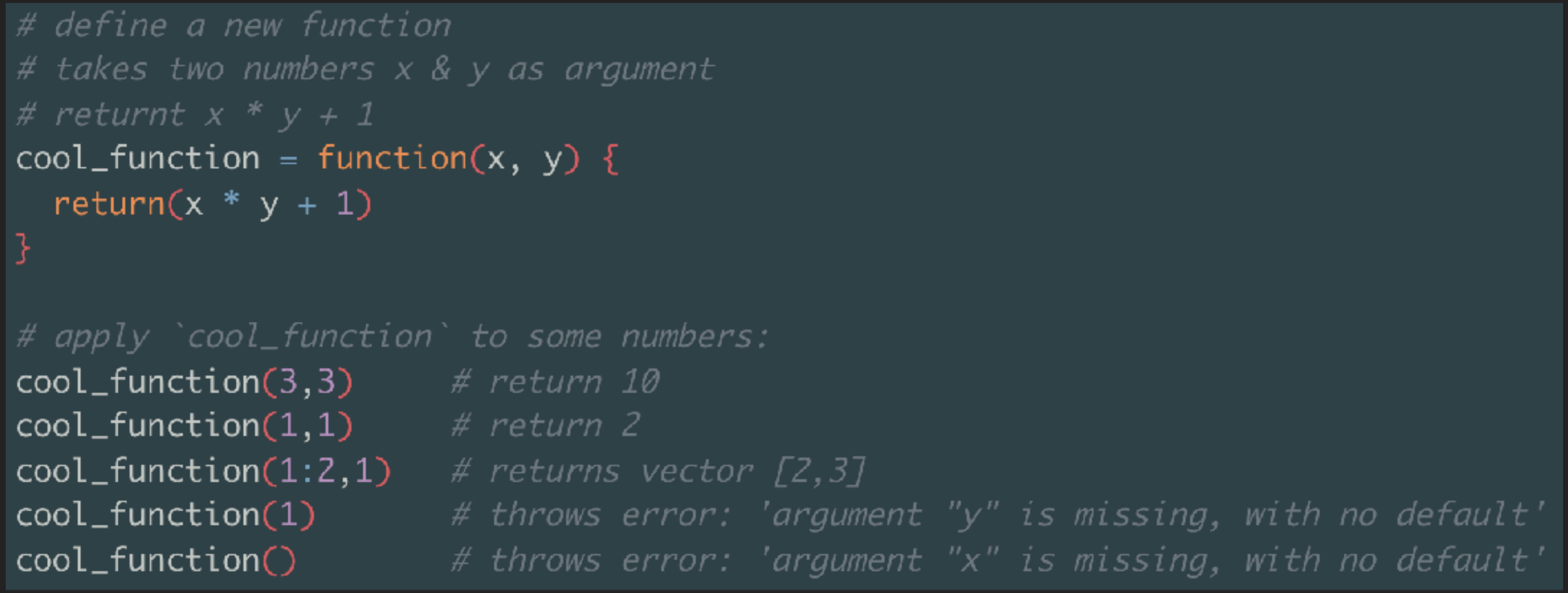
- `%in%` : wheter an element is in a vector
- `union(x,y)` : union of `x` and `y`
- `intersect(x,y)` : intersection of `x` and `y`
- `setdiff(x,y)` : all elements in `x` that are not in `y`

2.3.1.4 Sampling and combinatorics

- `runif()` : random number from unit interval [0;1]
- `sample(x, size, replace)` : take `size` samples from `x` (with replacement if `replace` is `T`)
- `choose(n,k)` : number of subsets of size `n` out of a set of size `k` (binomial coefficient)

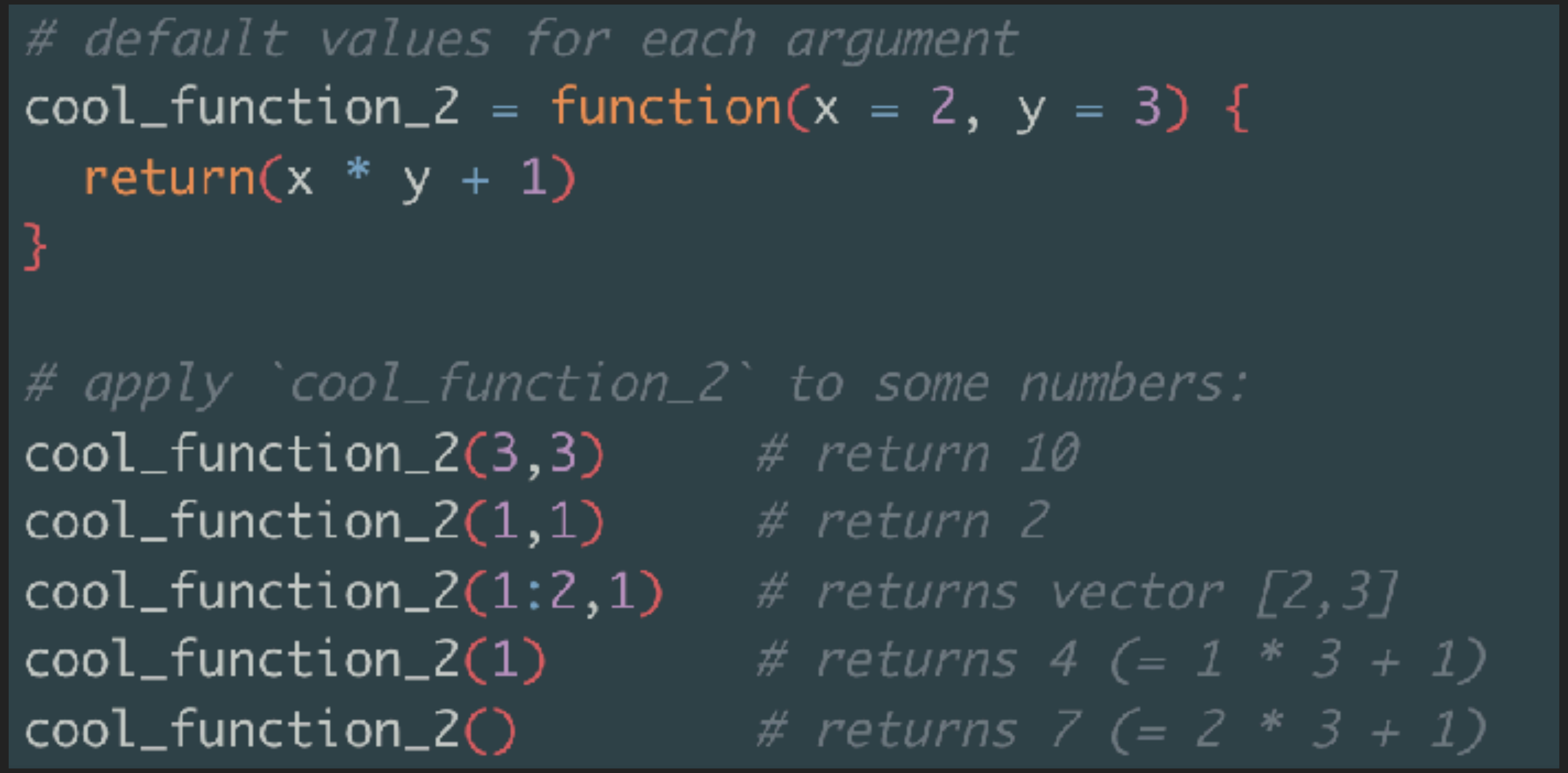
DEFINING CUSTOM FUNCTIONS

- named functions with/without default values



```r
# define a new function
# takes two numbers x & y as argument
# returnt x * y + 1
cool_function = function(x, y) {
  return(x * y + 1)
}

# apply `cool_function` to some numbers:
cool_function(3,3)     # return 10
cool_function(1,1)     # return 2
cool_function(1:2,1)   # returns vector [2,3]
cool_function(1)       # throws error: 'argument "y" is missing, with no default'
cool_function()        # throws error: 'argument "x" is missing, with no default'
```

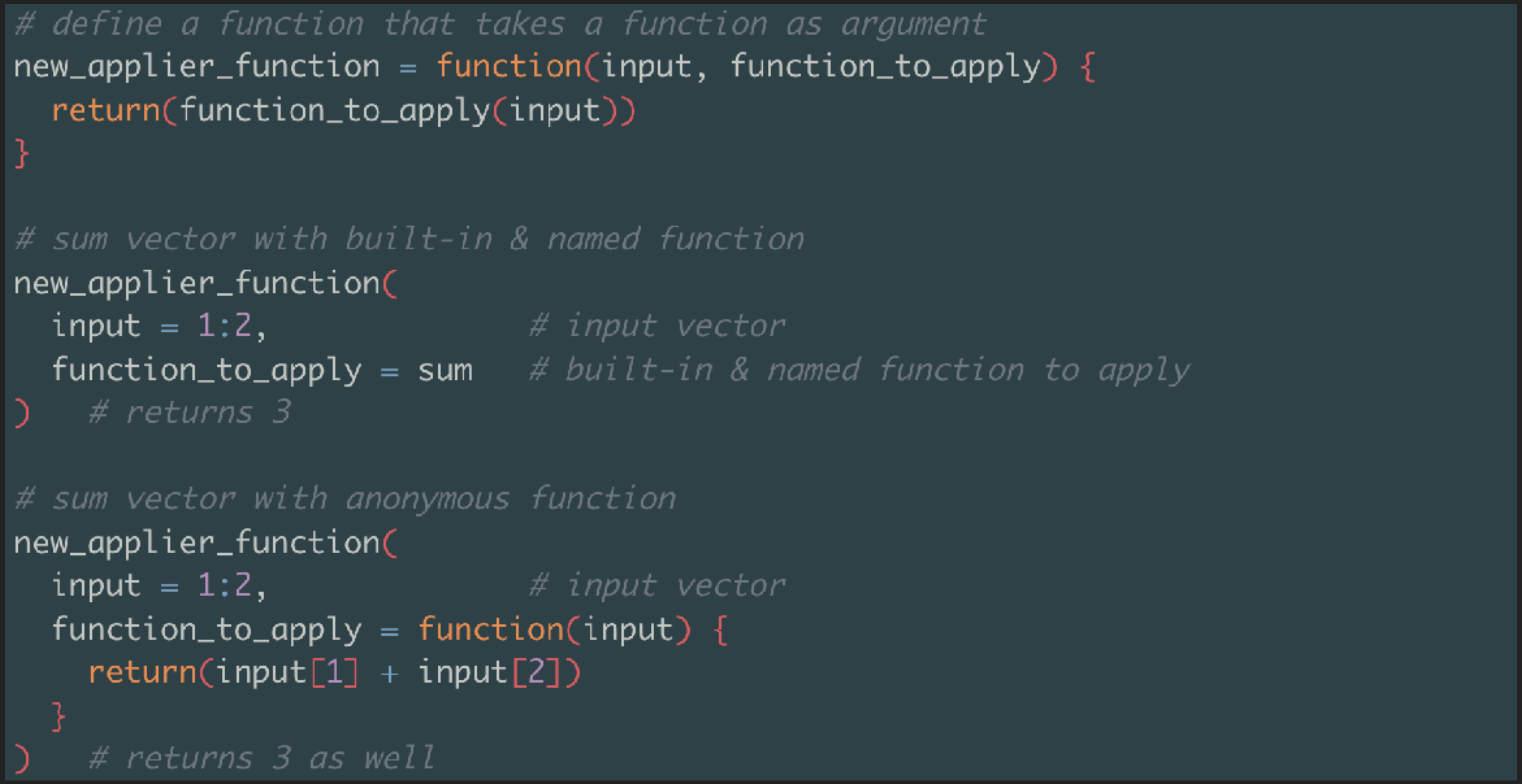


```r
# default values for each argument
cool_function_2 = function(x = 2, y = 3) {
  return(x * y + 1)
}

# apply `cool_function_2` to some numbers:
cool_function_2(3,3)     # return 10
cool_function_2(1,1)     # return 2
cool_function_2(1:2,1)   # returns vector [2,3]
cool_function_2(1)       # returns 4 (= 1 * 3 + 1)
cool_function_2()        # returns 7 (= 2 * 3 + 1)
```

DEFINING CUSTOM FUNCTIONS

- anonymous functions (for local use)



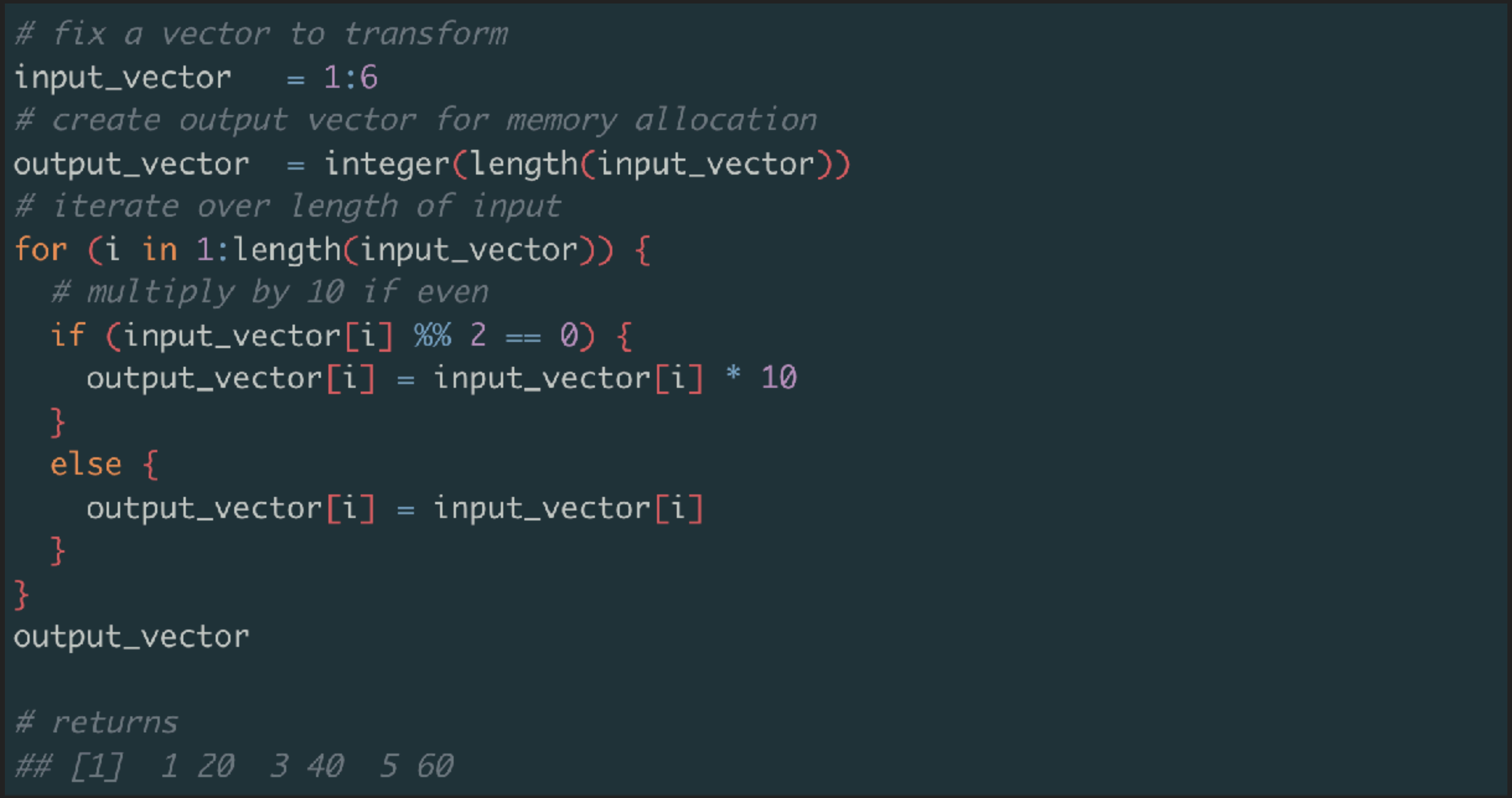
```r
# define a function that takes a function as argument
new_applier_function = function(input, function_to_apply) {
  return(function_to_apply(input))
}

# sum vector with built-in & named function
new_applier_function(
  input = 1:2,              # input vector
  function_to_apply = sum   # built-in & named function to apply
)   # returns 3

# sum vector with anonymous function
new_applier_function(
  input = 1:2,              # input vector
  function_to_apply = function(input) {
    return(input[1] + input[2])
  }
)   # returns 3 as well
```

FOR-LOOPS

- create container -> each loop fills content

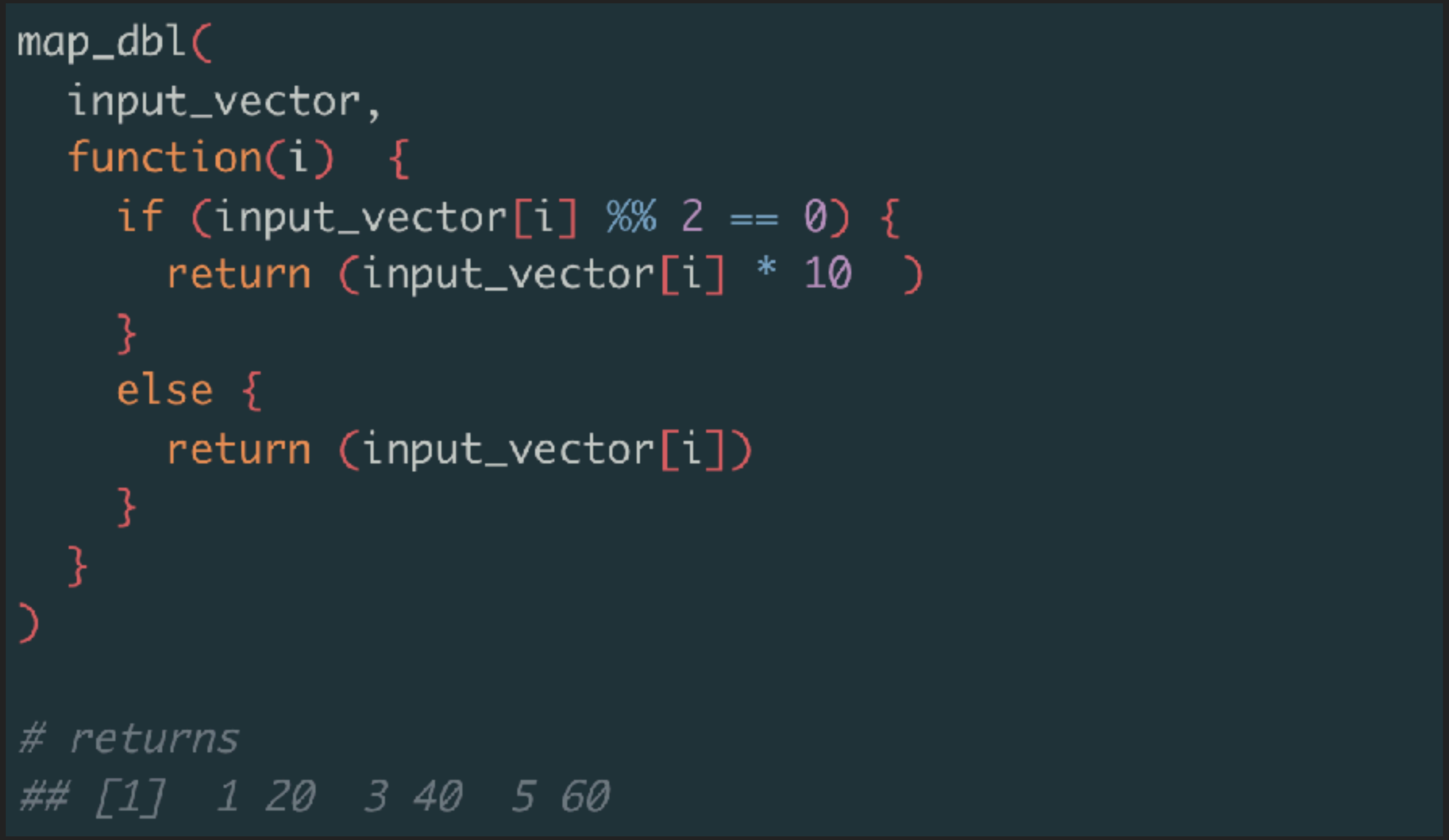


```
# fix a vector to transform
input_vector    = 1:6
# create output vector for memory allocation
output_vector  = integer(length(input_vector))
# iterate over length of input
for (i in 1:length(input_vector)) {
  # multiply by 10 if even
  if (input_vector[i] %% 2 == 0) {
    output_vector[i] = input_vector[i] * 10
  }
  else {
    output_vector[i] = input_vector[i]
  }
}
output_vector

# returns
## [1]  1 20  3 40  5 60
```

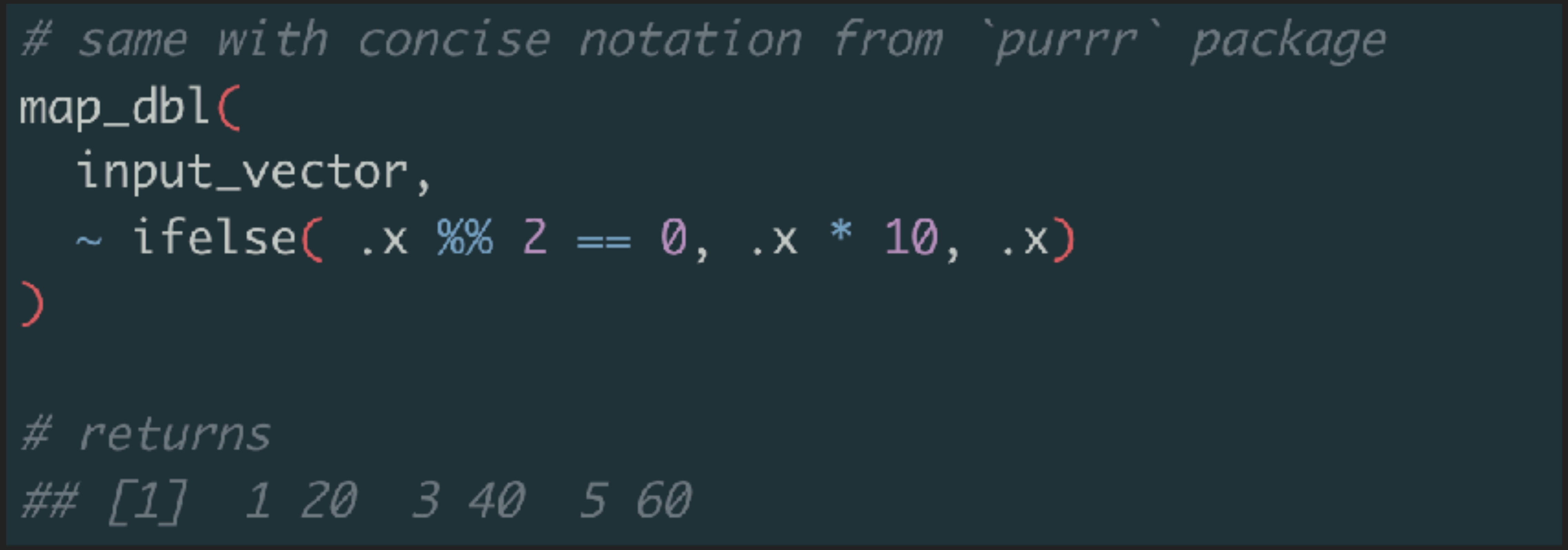
MAPPING

- `map_` functions are tidyverse dialect for base R's `apply`



```
map_dbl(
  input_vector,
  function(i)  {
    if (input_vector[i] %% 2 == 0) {
      return (input_vector[i] * 10  )
    }
    else {
      return (input_vector[i])
    }
  }
)

# returns
## [1]  1 20  3 40  5 60
```

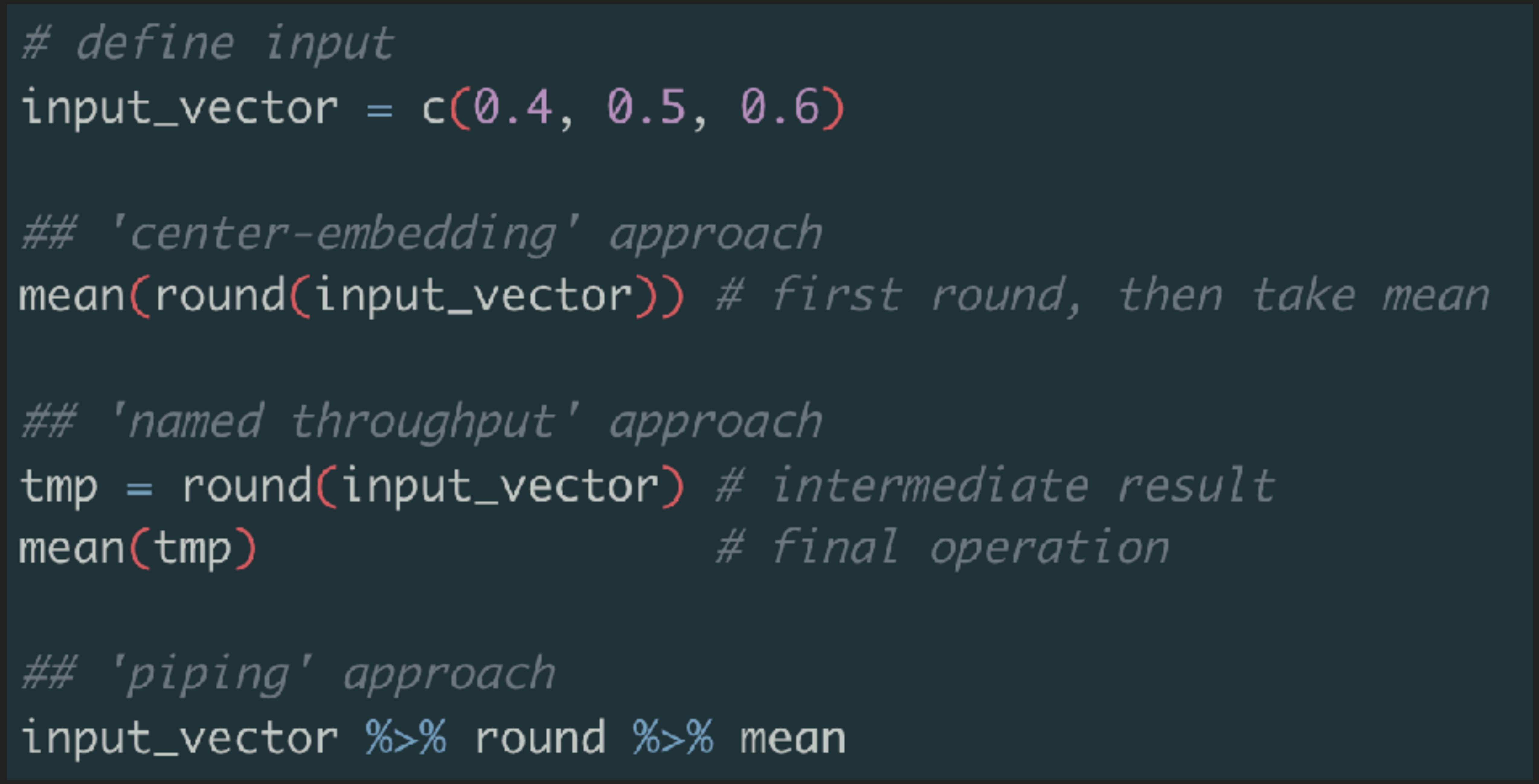


```
# same with concise notation from `purrr` package
map_dbl(
  input_vector,
  ~ ifelse( .x %% 2 == 0, .x * 10, .x)
)

# returns
## [1]  1 20  3 40  5 60
```

SEQUENCING OPERATIONS

- pipe operator `%>%` from the `magrittr` package



```
# define input
input_vector = c(0.4, 0.5, 0.6)

## 'center-embedding' approach
mean(round(input_vector)) # first round, then take mean

## 'named throughput' approach
tmp = round(input_vector) # intermediate result
mean(tmp)                 # final operation

## 'piping' approach
input_vector %>% round %>% mean
```

HOMEWORK FOR NEXT CLASS

- reread Chapter 2 of course notes
- glance at some Rmarkdown tutorial
- skim Chapter 3 (to the extent that it exists)
- [voluntary] do this experiment before Friday 12:15 (takes ca. 5 minutes)
    - clickable link to experiment