Marine Data Science

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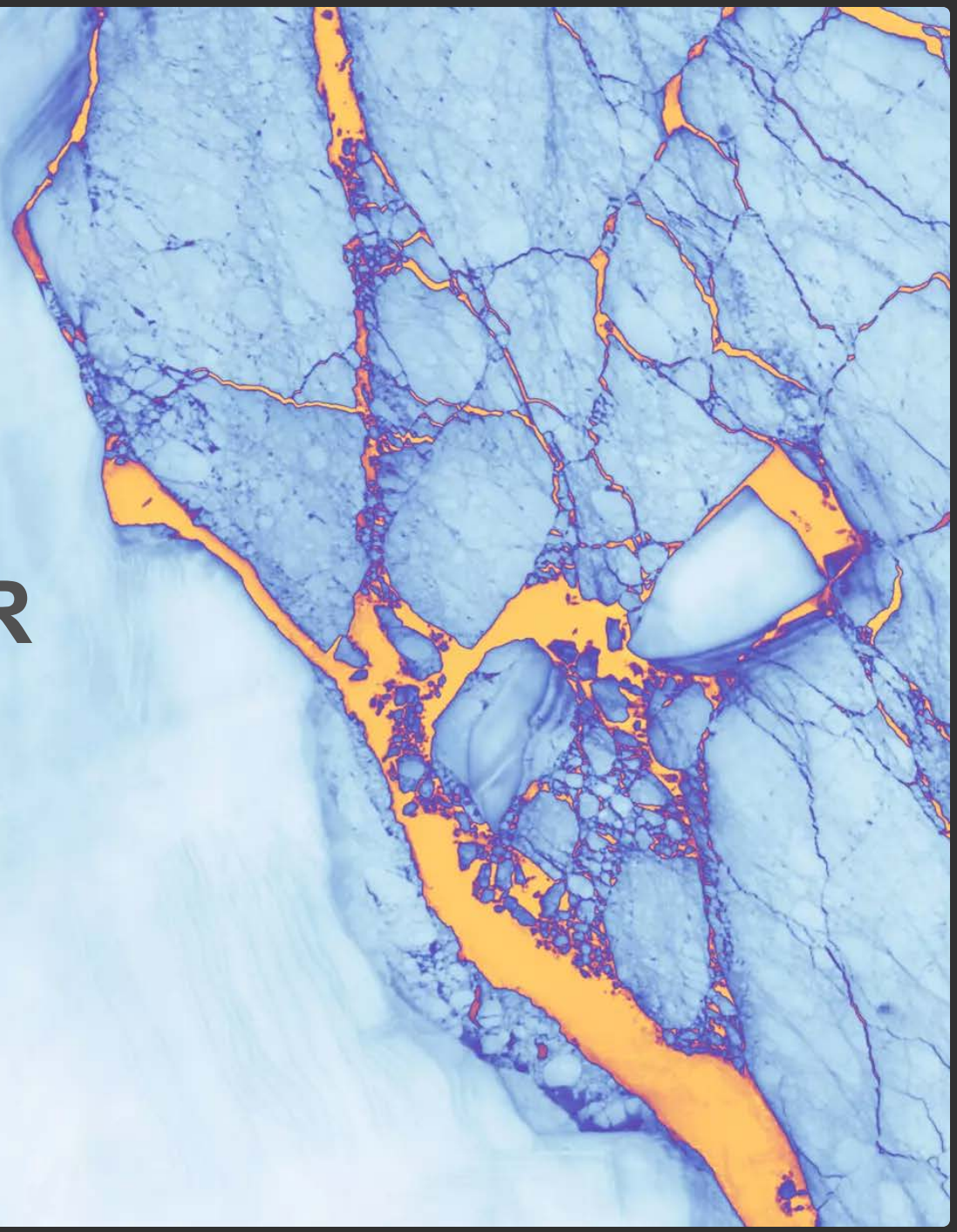

Data Analysis with R

3 - Data structures and basic calculations

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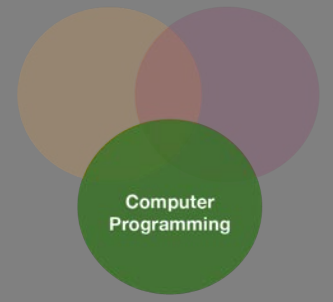


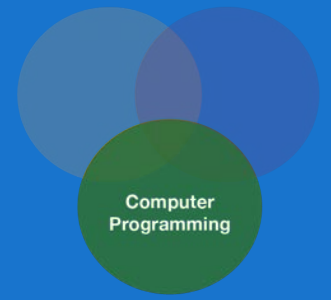
Some recap on data structures

Data structures

Five data types most often used in data analysis:

DIMENSIONS	HOMOGENEOUS	HETEROGENEOUS
1d	Atomic vector	List
2d	Matrix	Data frame
nd	Array	

Lists



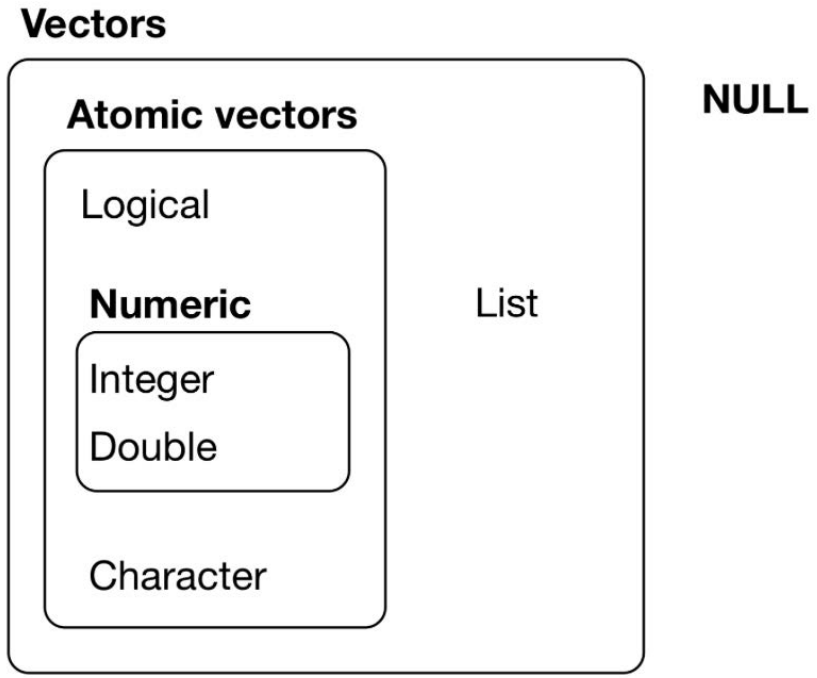
Lists

- are different from atomic vectors because their **elements** can be of **any type, including lists**
- you construct lists by using `list()` instead of `c()`:

```
x <- list(1:3, "a", c(TRUE, FALSE, TRUE), c(2.3, 5.9))
str(x)
```

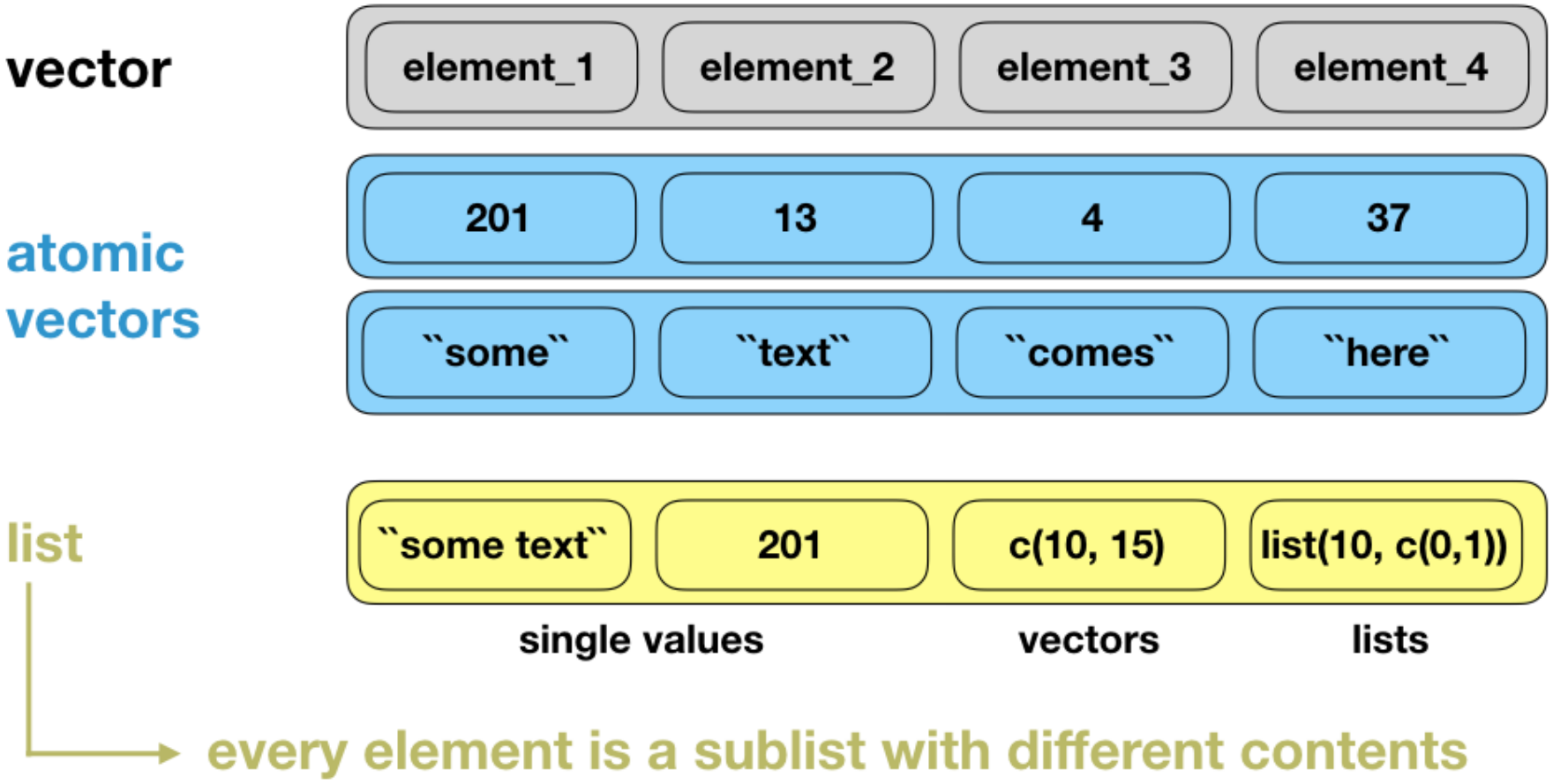
```
## List of 4
##  $ : int [1:3] 1 2 3
##  $ : chr "a"
##  $ : logi [1:3] TRUE FALSE TRUE
##  $ : num [1:2] 2.3 5.9
```

Lists are vectors



`NULL` is often used to represent the absence of a vector (as opposed to `NA` which is used to represent the absence of a value in a vector). `NULL` typically behaves like a vector of length 0.

Why is a list considered a vector?



Lists (cont)

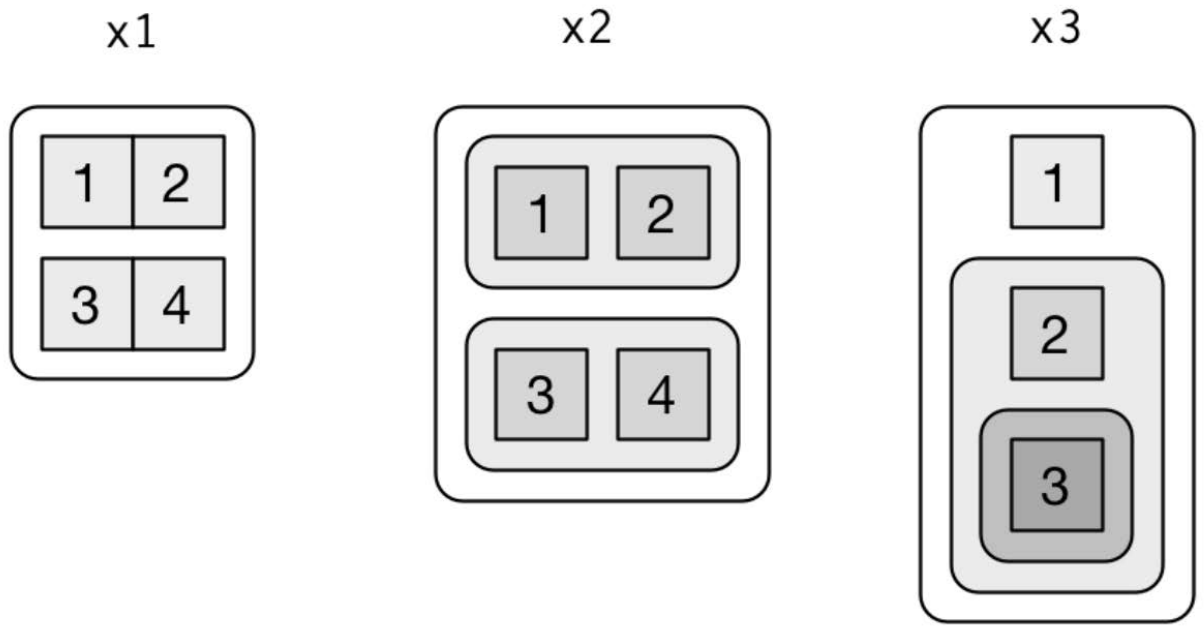
- are sometimes called **recursive vectors**, because a list can contain other lists.

```
x <- list(list(list(list())))
str(x)
```

```
## List of 1
##  $ :List of 1
##   ..$ :List of 1
##   .. ..$ : list()
```

Visualization of the following lists

```
x1 <- list(c(1, 2), c(3, 4))
x2 <- list(list(1, 2), list(3, 4))
x3 <- list(1, list(2, list(3)))
```



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Lists (cont)

- `typeof()` a list is a list
- you can **test** for a list with `is.list()` and
- **coerce** to a list with `as.list()`
- you can **turn** a list into an **atomic vector** with `unlist()`.
- if the elements of a list have different types, `unlist()` uses the **same coercion rules** as `c()`.
- lists are used to **build** up many of the more **complicated data structures** in R.

Structure of lists

A very useful tool for working with lists is `str()` because it focuses on the structure, not the content.

```
x <- list(1, 2, 3)
str(x)
```

```
## List of 3
##  $ : num 1
##  $ : num 2
##  $ : num 3
```

Structure of lists

A very useful tool for working with lists is `str()` because it focuses on the structure, not the content.

```
x <- list(1, 2, 3)
str(x)
```

```
## List of 3
##  $ : num 1
##  $ : num 2
##  $ : num 3
```

```
x_named <- list(a = 1, b = 2, c = 3)
str(x_named)
```

```
## List of 3
##  $ a: num 1
##  $ b: num 2
##  $ c: num 3
```

Subsetting

Three ways to subset a list:

1. `[` extracts a **sublist**.
2. `[[` extracts a **single componen**t from a list.
3. `$` is a shorthand for extracting **named elements** of a list.

Subsetting (cont)

I will demonstrate each way using the following list:

```
a <- list(a = 1:3, b = "a string", c = pi, list(-1, -5))
str(a)
```

```
## List of 4
##  $ a: int [1:3] 1 2 3
##  $ b: chr "a string"
##  $ c: num 3.14
##  $  :List of 2
##   ..$ : num -1
##   ..$ : num -5
```

Subsetting: '[ ]'

1. `[` extracts a sublist. The **result** will always be a **list** (it keeps the original list 'container' and removes all elements not selected). Like with vectors, you can subset with a **logical, integer, or character vector**.

```
str(a[1:2])
```

```
## List of 2
##  $ a: int [1:3] 1 2 3
##  $ b: chr "a string"
```

```
str(a[4])
```

```
## List of 1
##  $ :List of 2
##   ..$ : num -1
##   ..$ : num -5
```

Subsetting: '[ ]'

1. `[` extracts a sublist. The **result** will always be a **list** (it keeps the original list 'container' and removes all elements not selected). Like with vectors, you can subset with a **logical, integer, or character vector**.

```
str(a[1:2])
```

```
## List of 2
##  $ a: int [1:3] 1 2 3
##  $ b: chr "a string"
```

```
str(a[4])
```

```
## List of 1
##  $ :List of 2
##   ..$ : num -1
##   ..$ : num -5
```

```
a[4]
```

```
## [[1]]
## [[1]][[1]]
## [1] -1
##
## [[1]][[2]]
## [1] -5
```

Subsetting: '[[ ]]'

2. `[[` extracts a single component from a list. It **removes a level of hierarchy** from the list (= you remove **one** 'container').

```
str(a[[1]])
```

```
##  int [1:3] 1 2 3
```

```
str(a[[4]])
```

```
## List of 2
##  $ : num -1
##  $ : num -5
```

```
a[[4]]
```

```
## [[1]]
## [1] -1
##
## [[2]]
## [1] -5
```

Subsetting: '$'

3. `$` is a **shorthand for extracting named** elements of a list. It works similarly to `[[` except that you don't need to use quotes.

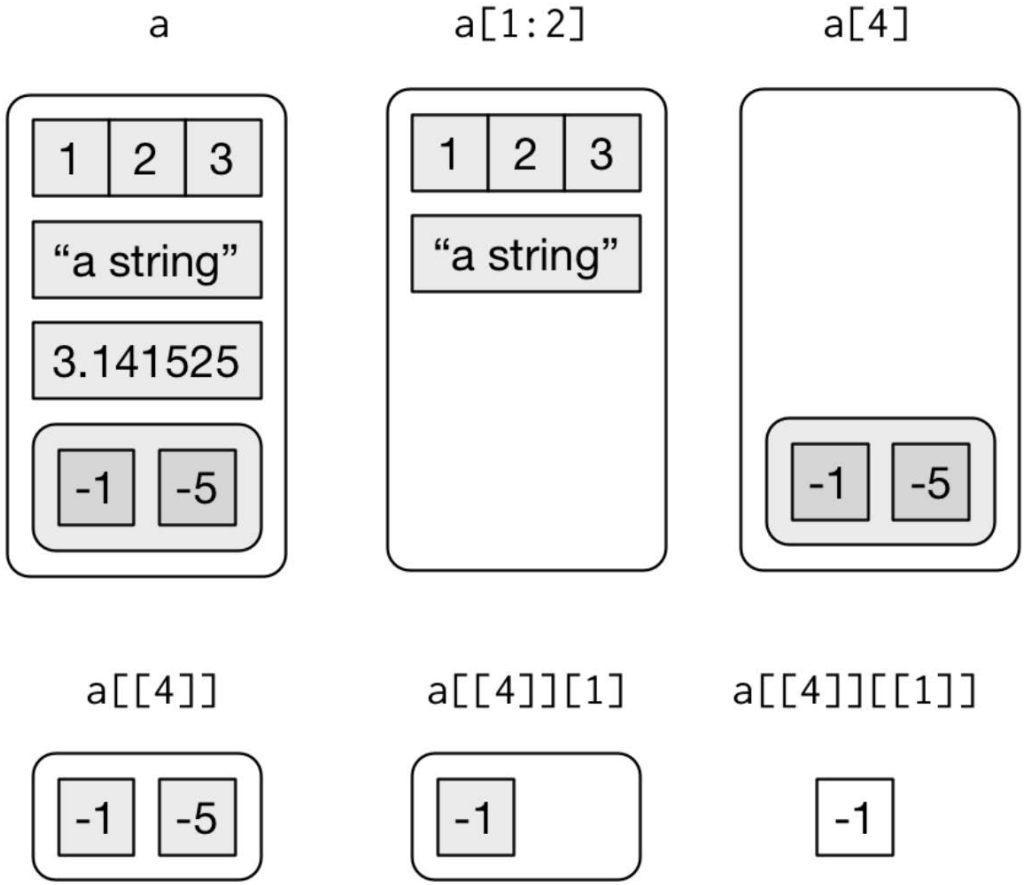
```
a$a
```

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

```
# same as
a[["a"]]
```

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

Some visualization of subsetting lists



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Your turn...

Visualize the following lists as nested sets

1. list(a, b, list(c, d), list(e, f))
2. list(list(list(list(list(list(a))))))

Quiz 1: Subsetting lists

The following list has been created:

```
list_example <- list(one = 1:10, two = letters,
  three = list(abc = c(132, 876, 42), xyz = c(T,F,F,T,F,T)), four = NULL)
```

What does the following return? `list_example[1:2]`

- a vector with the first 2 elements of each list
- a list of all sublists, each containing only the first 2 elements of the original sublists
- a list containing only sublist "one" and "two"
- NA

Submit | Show Hint | Show Answer | Clear

Quiz 2: Subsetting lists

The following list has been created:

```
list_example <- list(one = 1:10, two = letters,
  three = list(abc = c(132, 876, 42), xyz = c(T,F,F,T,F,T)), four = NULL)
```

What does the following return? `list_example["four"]`

- NULL
- error message
- a list containing NULL
- a vector with NULL elements

Submit | Show Hint | Show Answer | Clear

Quiz 3: Subsetting lists

The following list has been created:

```
list_example <- list(one = 1:10, two = letters,
  three = list(abc = c(132, 876, 42), xyz = c(T,F,F,T,F,T)), four = NULL)
```

What does the following return? `list_example[[1]][2]`

- a list containing "a"
- a list containing 1
- a vector containing "b"
- a vector containing 2

Submit | Show Hint | Show Answer | Clear

Quiz 4: Subsetting lists

The following list has been created:

```
list_example <- list(one = 1:10, two = letters,
  three = list(abc = c(132, 876, 42), xyz = c(T,F,F,T,F,T)), four = NULL)
```

What does the following return? `list_example[3][[2]]`

- NA
- a list containing FALSE
- the logical vector 'xyz'
- a vector containing "c"
- error message

Submit | Show Hint | Show Answer | Clear

Quiz 5: Subsetting lists

What is equivalent to the following code (multiple answers correct)? And which of the options below returns a suprising value?

```
list_example[["three"]][c("abc", "xyz")]
```

- [ ] list_example[[3]][1:2]
- [ ] list_example[[3]][[1:2]]
- [ ] list_example[[3]][c("abc", "xyz")]
- [ ] list_example$three[1:2]
- [ ] list_example$three[c("abc", "xyz")]

Submit | Show Hint | Show Answer | Clear

Quiz 6 - Challenge: Subsetting lists

Create a new vector that contains the 4th element of sublist "one" and element 1 and 3 from sublist "abc" within "three" in 'list_example'.

1. What is the sum of this vector?

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Quiz 7 - Challenge: Subsetting lists

Execute the following R command in your console

```
lm_list <- lm(Sepal.Length ~ Sepal.Width, data = iris)
```

and look at the structure of the list you created with

```
str(lm_list, max.level = 1) # max.level=1 shows only the first level
# of the hierarchy (and not all sub/sub/..lists))
```

1. What is the last value of the 'residuals'?

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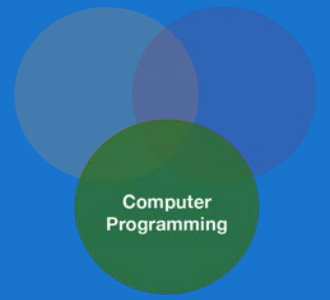
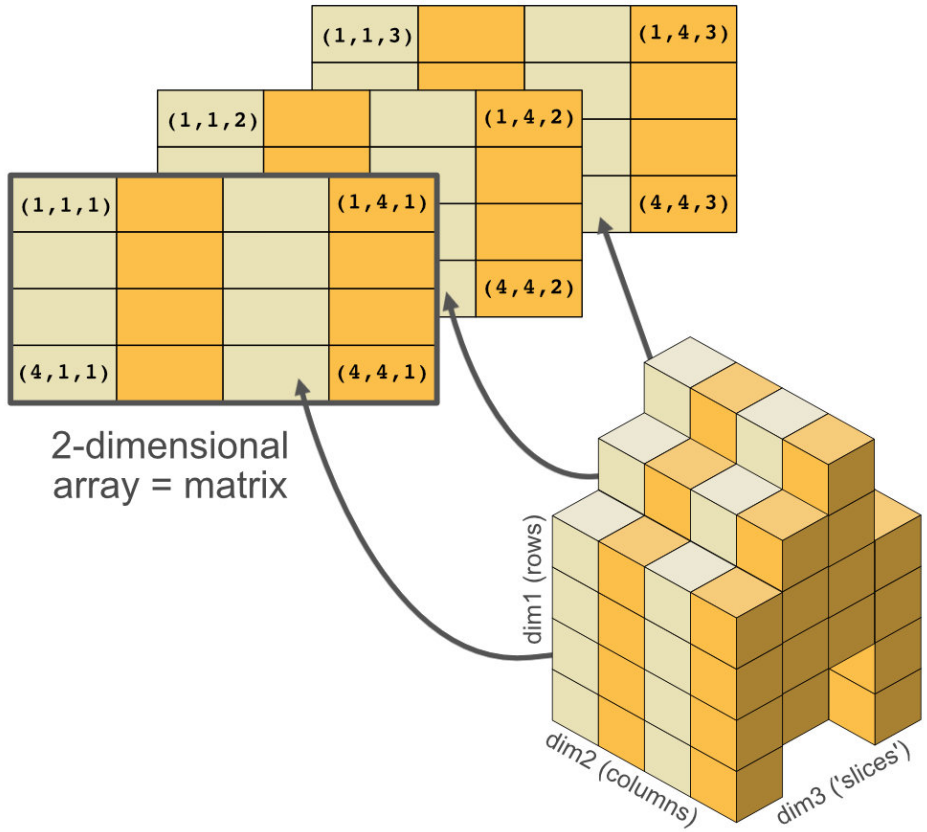


Other homogeneous data structures: matrices and arrays

Matrices and arrays

- Adding a `dim` attribute to an atomic vector allows it to behave like a **multi**-dimensional **array**.
- A special case of the array is the **matrix**, which has **two** dimensions.
- **Matrices** are used commonly as part of the **mathematical machinery** of statistics.
- Arrays are much **rarer**, but worth being aware of.



Creating matrices

Matrices are **created** with

- `matrix()`
- or by **combining vectors** (of **equal length**) to a matrix using `cbind()` (stands for column-binding).

Creating matrices

Matrices are **created** with

- `matrix()`
- or by **combining vectors** (of **equal length**) to a matrix using `cbind()` (stands for column-binding).

```
a <- matrix(1:6, ncol = 3, nrow = 2)
a
```

```
##      [,1] [,2] [,3]
## [1,]    1    3    5
## [2,]    2    4    6
```

```
v1 <- 1:3
v2 <- 4:6
a <- cbind(v1, v2)
a
```

```
##      v1 v2
## [1,]  1  4
## [2,]  2  5
## [3,]  3  6
```

Attributes length and names

`length()` and `names()` have **high-dimensional generalisations**:

Attribute length

`length()` generalises to

- `nrow()` and `ncol()` for **matrices**, and
- `dim()` for arrays.

```
length(a)
```

```
## [1] 6
```

```
nrow(a)
```

```
## [1] 3
```

```
ncol(a)
```

```
## [1] 2
```

Attribute names

`names()` generalises to

- `rownames()` and `colnames()` for **matrices**, and
- `dimnames()`, a list of character vectors, for arrays.

```
colnames(a) <- c("A","B")
rownames(a) <- c("a","b","c")
a
```

```
##   A B
## a 1 4
## b 2 5
## c 3 6
```

Subsetting matrices and arrays

Most common way of subsetting matrices (2d) and arrays (>2d) is a simple **generalisation of 1d subsetting**:

- You supply a **1d index** for each dimension, separated by a comma (*integer, logical, or character* indices allowed).
- **Blank subsetting** is now useful because it lets you keep all rows or all columns.

Subsetting matrices and arrays

Most common way of subsetting matrices (2d) and arrays (>2d) is a simple **generalisation of 1d subsetting**:

- You supply a **1d index** for each dimension, separated by a comma (*integer, logical, or character* indices allowed).
- **Blank subsetting** is now useful because it lets you keep all rows or all columns.

```
a <- matrix(1:9, nrow = 3)
colnames(a) <- c("A", "B", "C")
a
```

```
##      A B C
## [1,] 1 4 7
## [2,] 2 5 8
## [3,] 3 6 9
```

```
a[1:2, 2]
a[, c("A", "C") ]
```

Guess which values you get!

Subsetting matrices and arrays

Most common way of subsetting matrices (2d) and arrays (>2d) is a simple **generalisation of 1d subsetting**:

- You supply a **1d index** for each dimension, separated by a comma (*integer, logical, or character* indices allowed).
- **Blank subsetting** is now useful because it lets you keep all rows or all columns.

```
a <- matrix(1:9, nrow = 3)
colnames(a) <- c("A", "B", "C")
a
```

```
##      A B C
## [1,] 1 4 7
## [2,] 2 5 8
## [3,] 3 6 9
```

```
a[1:2, 2]
```

```
## [1] 4 5
```

```
a[, c("A", "C") ]
```

```
##      A C
## [1,] 1 7
## [2,] 2 8
## [3,] 3 9
```

Your turn...

Quiz 8: Subsetting matrices

Subset the following matrix...

```
(mat <- matrix(c(0,NA,4,18,35,97,7,9,20), nrow = 3))
```

```
##      [,1] [,2] [,3]
## [1,]    0   18    7
## [2,]   NA   35    9
## [3,]    4   97   20
```

to get all values in row 1

Type your answer

Submit and Compare | Clear

Quiz 9: Subsetting matrices

Subset the following matrix...

```
(mat <- matrix(c(0,NA,4,18,35,97,7,9,20), nrow = 3))
```

```
##      [,1] [,2] [,3]
## [1,]    0   18    7
## [2,]   NA   35    9
## [3,]    4   97   20
```

to get all values in row 1 and 3

Type your answer

Submit and Compare Clear

Quiz 10: Subsetting matrices

Subset the following matrix...

```
(mat <- matrix(c(0,NA,4,18,35,97,7,9,20), nrow = 3))
```

```
##      [,1] [,2] [,3]
## [1,]    0   18    7
## [2,]   NA   35    9
## [3,]    4   97   20
```

to get all values in column 2

Type your answer

Submit and Compare | Clear

Quiz 11: Subsetting matrices

Subset the following matrix...

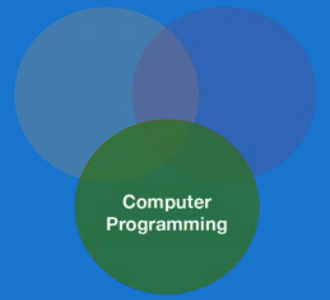
```
(mat <- matrix(c(0,NA,4,18,35,97,7,9,20), nrow = 3))
```

```
##      [,1] [,2] [,3]
## [1,]    0   18    7
## [2,]   NA   35    9
## [3,]    4   97   20
```

to get all values in row 2 and 3 and column 1 and 2

Type your answer

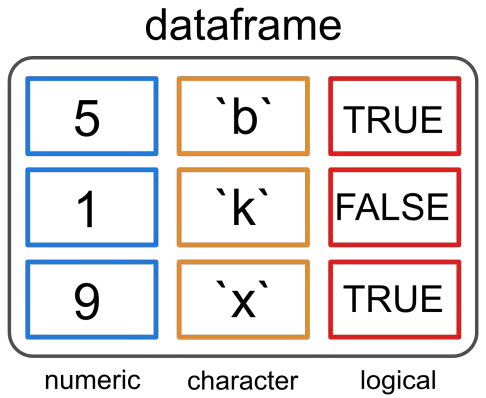
Submit and Compare Clear



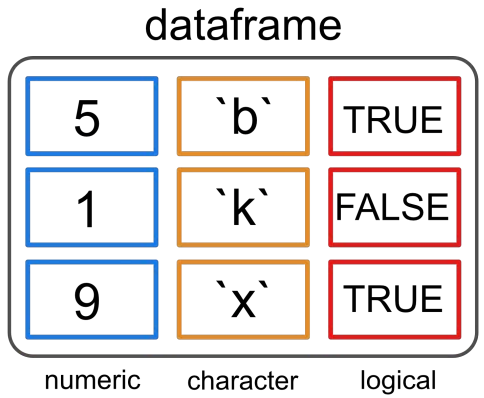
Other heterogeneous data structures: data frames

Data frames

- **Most common way** of storing data in R.
- Represents a **list of equal-length vectors**
  - → makes it 2-dimensional structure
- Shares properties of both the matrix and the list:



Data frames



- **Most common way** of storing data in R.
- Represents a **list of equal-length vectors**
  - → makes it 2-dimensional structure
- Shares properties of both the matrix and the list:
  - **names**: has `names()`, `colnames()`, and `rownames()`, although `names()` and `colnames()` are the same thing.
  - **length**: `length()` is the length of the underlying list and so is the same as `ncol()`; `nrow()` gives the number of rows.

Generating data frames

You create a data frame using `data.frame()` (note the **point** inbetween both words!), which takes **named vectors** as input:

```
df <- data.frame(x = 1:3, y = c("a", "b", "c"))
str(df)
```

```
## 'data.frame':    3 obs. of  2 variables:
##  $ x: int  1 2 3
##  $ y: Factor w/ 3 levels "a","b","c": 1 2 3
```

Generating data frames

You create a data frame using `data.frame()` (note the **point** inbetween both words!), which takes **named vectors** as input:

```
df <- data.frame(x = 1:3, y = c("a", "b", "c"))
str(df)
```

```
## 'data.frame':    3 obs. of  2 variables:
##  $ x: int  1 2 3
##  $ y: Factor w/ 3 levels "a","b","c": 1 2 3
```

- Beware of `data.frame()`s default behaviour, which turns **strings into factors**. Use `stringsAsFactors = FALSE` to suppress this behaviour:

```
df <- data.frame(x = 1:3, y = c("a", "b", "c"), stringsAsFactors = FALSE)
str(df)
```

```
## 'data.frame':    3 obs. of  2 variables:
##  $ x: int  1 2 3
##  $ y: chr  "a" "b" "c"
```

Subsetting data frames

Either like a **matrix** (useful if several columns and rows are selected)

```
df[1:2, 1] # row 1-2, column 1
```

```
## [1] 1 2
```

Subsetting data frames

Either like a **matrix** (useful if several columns and rows are selected)

```
df[1:2, 1] # row 1-2, column 1
```

```
## [1] 1 2
```

Or like a **list**

```
df$x  # shows all elements of column 'x'
```

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

```
df$y[2]  # 2nd element of column 'y'
```

```
## [1] "b"
```

```
df[[2]][2]  # same
```

```
## [1] "b"
```

Your turn...

Generate a data frame yourself...

that contains

- **4 variables** with differet data types (logical, character, double, and/or integer),
- all of **length 20** and
- give each variable a **name**.

Quiz 12: `iris` dataset - data structure

Explore the following dataset

```
head(iris, 1)
```

```
##   Sepal.Length Sepal.Width Petal.Length Petal.Width Species
## 1          5.1         3.5          1.4         0.2  setosa
```

What type of data structure is `iris`?

- list
- matrix
- array
- data frame

Submit | Show Hint | Show Answer | Clear

Quiz 13: `iris` dataset - dimensions

What are the dimensions of the dataset `iris`?

- ○ 5 rows, 150 columns
- ○ 150 rows, 5 columns

Submit | Show Hint | Show Answer | Clear

Quiz 14: `iris` dataset - data type

Which basic data types does the dataset `iris` contain?

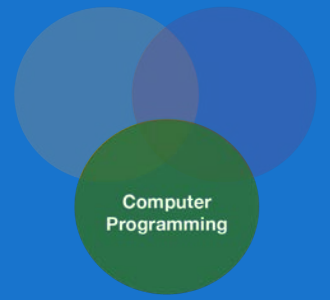
- [ ] logical
- [ ] integer
- [ ] double
- [ ] character
- [ ] factor
- [ ] date

Submit | Show Hint | Show Answer | Clear

Quiz 15: `iris` dataset - subsetting

1. Calculate the sum of all observations in the dataset using the function `sum()`

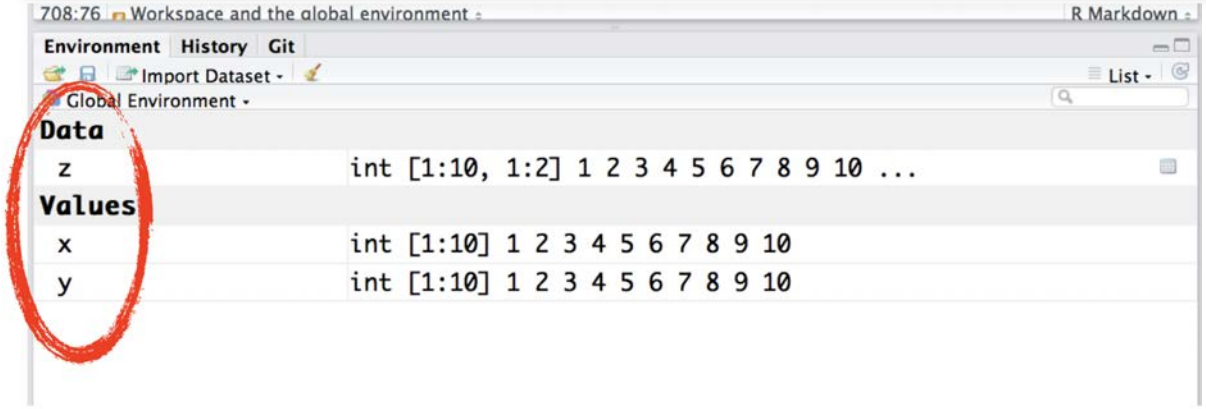
Submit | Show Hint | Show Answer | Clear



The workspace or the global environment

When you create R objects, you'll see them appear in your environment pane under **Global Environment**:

```
x <- 1:10
y <- 1:10
z <- cbind(x,y)  # matrix
```



The global environment, more often known as the **user's workspace**, is the first item on the search path. When a user starts a new session in R, the R system creates a new environment **for objects created during that session**.

You can list all objects in the workspace using the function `ls()`:

```
x <- 1:10
y <- 1:10
z <- cbind(x,y)  # matrix
ls()
```

```
## [1] "x" "y" "z"
```

Remove objects from workspace

You can remove an object with `rm()`:

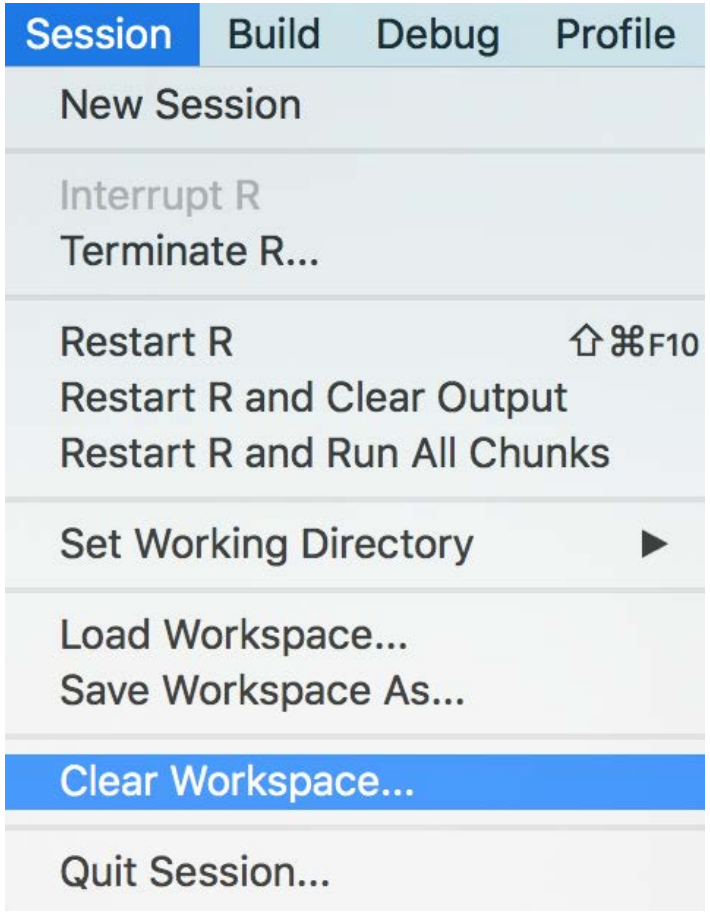
```
x <- 4
x
rm(x)
```

Remove objects from workspace

You can remove an object with `rm()`:

```
x <- 4
x
rm(x)
```

Or remove all objects in one go:

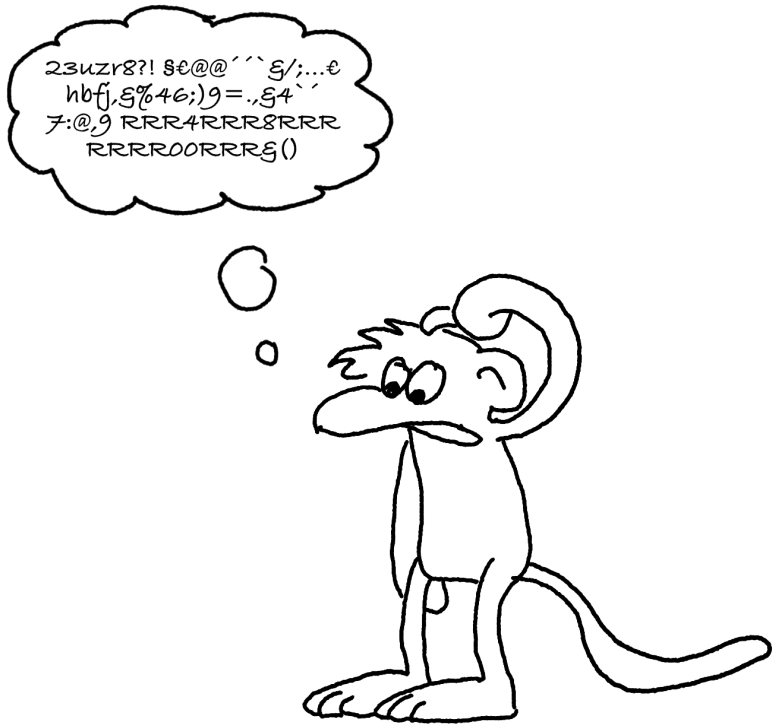


```
str(), [, [[, $,

matrix(), cbind(), nrow(), ncol(), dim, rownames(), colnames(),
dimnames(),

data.frame(), data.frame(stringsAsFactors = FALSE)
```

Overview of functions you learned today

How do you feel now.....?

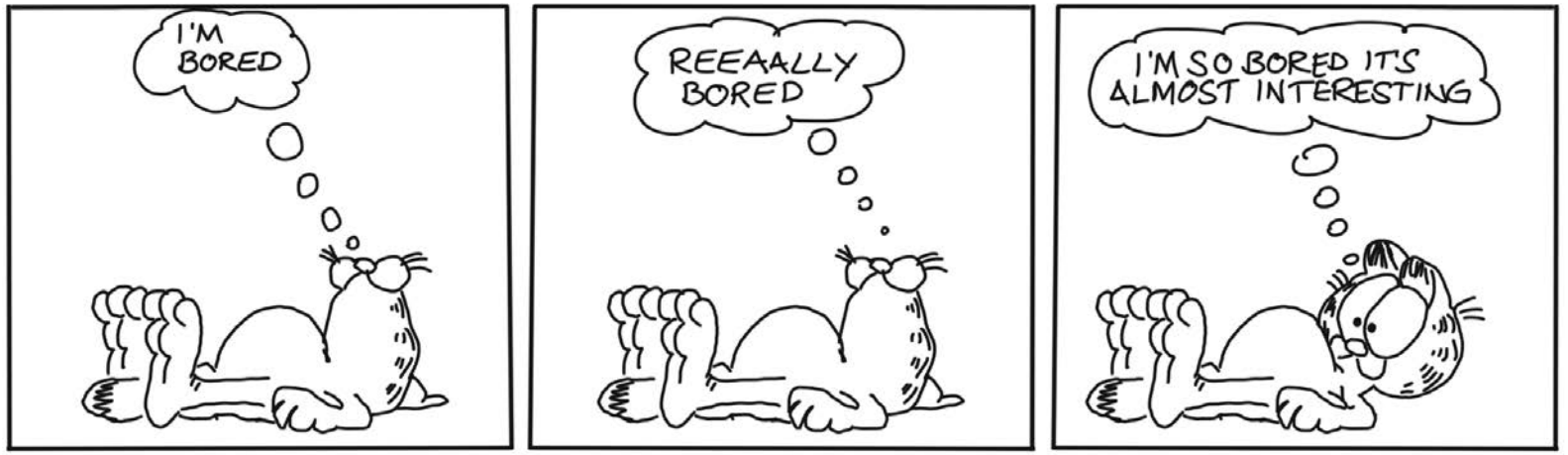
Totally confused?



Again, try out the online tutorial at Data Camp.

And go over this lecture again and do the quizzes.

Totally bored?

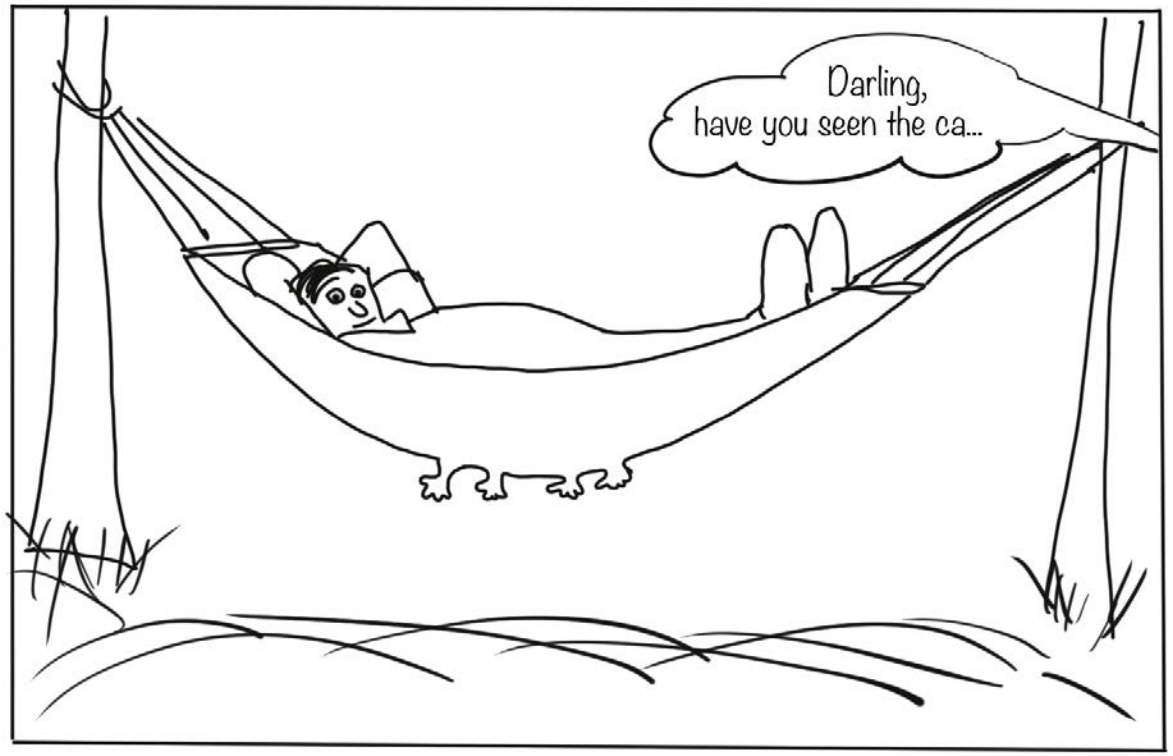


Then try out the following: Calculate for the `iris` data set

- the mean sepal and petal length per species, and
- the minimum petal width for the species "setose".
- Which species has the longest sepal width?

Totally content?

Then go grab a coffee, lean back and enjoy the rest of the day...!



Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Thank You

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http://www.github.com/saskiaotto

Image on title and end slide: Section of an infrared satallite image showing the Larsen C ice shelf on the Antarctic Peninsula - USGS/NASA Landsat: A Crack of Light in the Polar Dark, Landsat 8 - TIRS, June 17, 2017
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