Data Handling: Import, Cleaning and Visualisation

Lecture 4:

Data Storage and Data Structures

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Updates

Updates

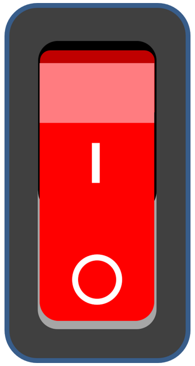
- Forum on Canvas to discuss the solutions to the R-exercises

Recap and warm-up

The binary system

Microprocessors can only represent two signs (states):

- ‘Off’ = `0`
- ‘On’ = `1`



The binary and the hexadecimal counting frames

Binary:

- Only two signs: `0`, `1`.
- Base 2.
- Columns: $2^0 = 1$, $2^1 = 2$, $2^2 = 4$, and so forth.

Hexadecimal:

- **16 symbols**:
- `0`-`9` (used like in the decimal system)…
- and `A`-`F` (for the numbers 10 to 15).

Decimal numbers in a computer

Number	128	64	32	16	8	4	2	1
0 =	0	0	0	0	0	0	0	0
1 =	0	0	0	0	0	0	0	1
2 =	0	0	0	0	0	0	1	0
3 =	0	0	0	0	0	0	1	1
…								
139 =	1	0	0	0	1	0	1	1

Decimal numbers in hexadecimal

Number	...	$16^2 = 256$	$16^1 = 16$	$16^0 = 1$
0 =	...	0	0	0
1 =	...	0	0	1
15 =	...	0	0	F
16 =	...	0	1	0
256 =	...	1	0	0
...	...			
139 =	0	0	8	B

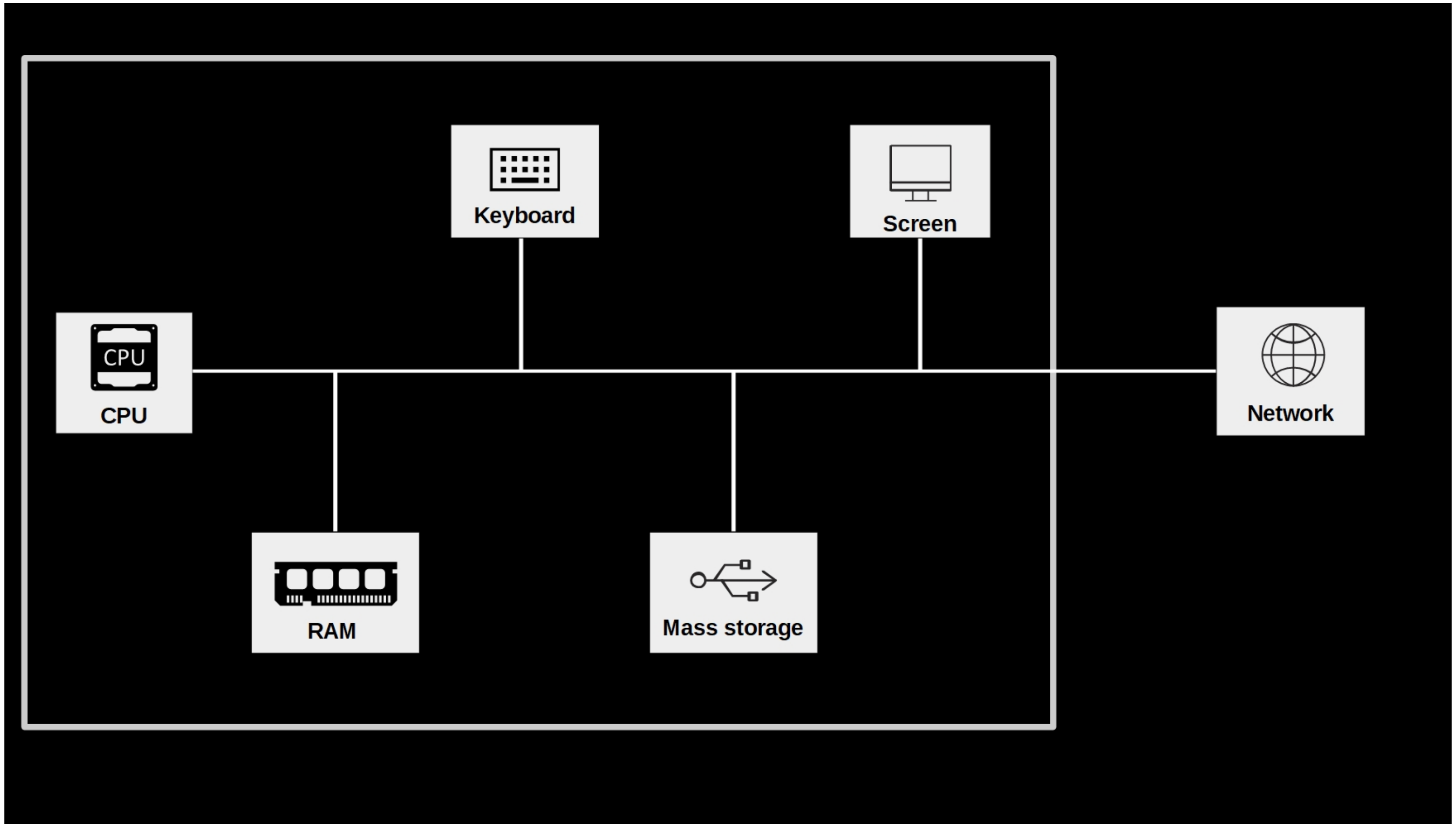
Computers and text

How can a computer understand text if it only understands `0`s and `1`s?

- **Standards** define how `0`s and `1`s correspond to specific letters/characters of different human languages.
- These standards are usually called **character encodings**.
- Coded character sets that map unique numbers (in the end in binary coded values) to each character in the set.
- For example, ASCII (American Standard Code for Information Interchange) or **utf-8**.

ASCII logo. (public domain).

Digital data processing



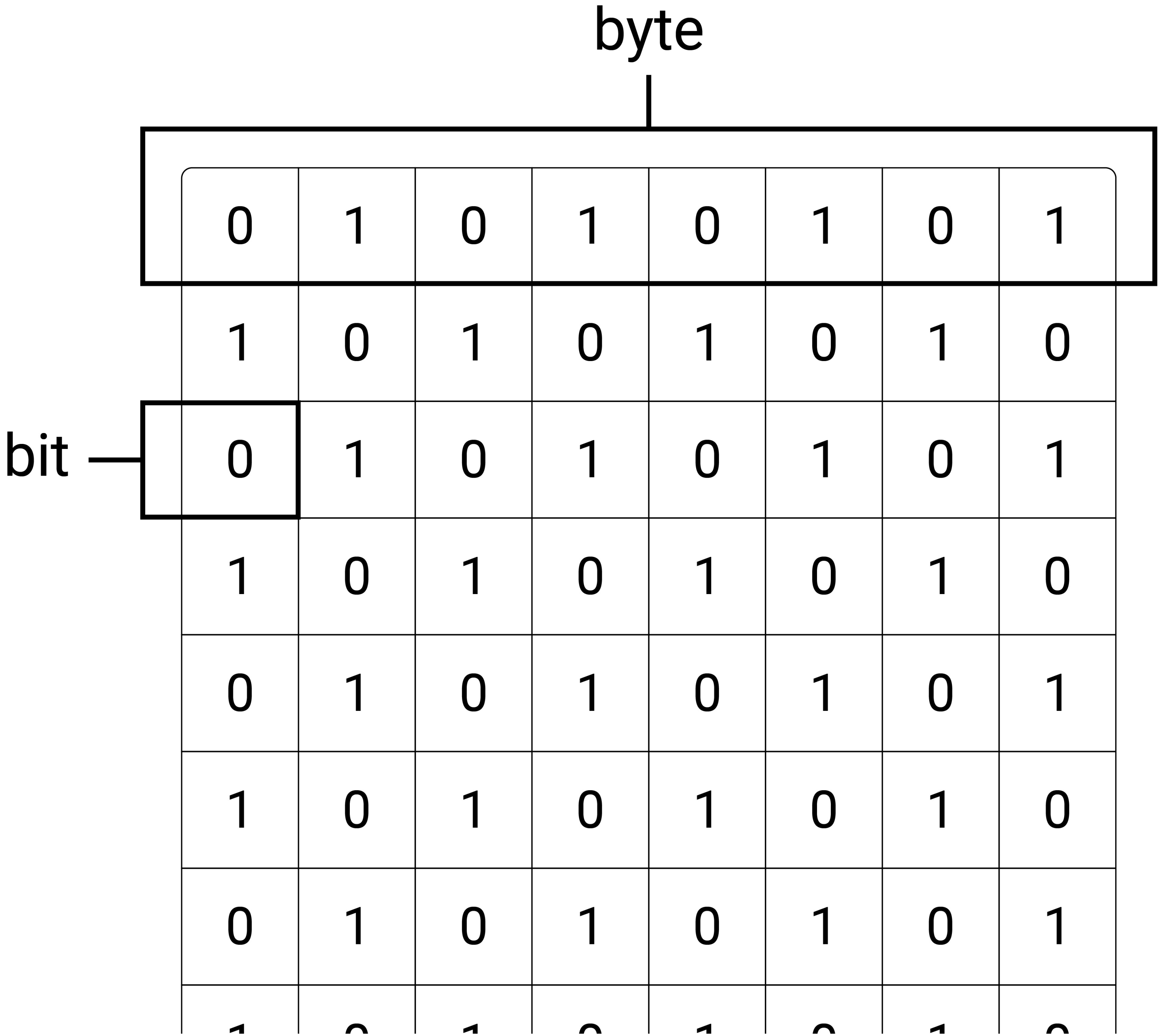
Digital data processing: a detour through bytes

We saw last week in our example that the size in RAM of our “economist” html object was **`468048 bytes`**.

```
economistText <- content(economist, as = "text")
print(economistText)

object.size(economist)
pryr::object_size(economist)
```

Digital data processing: a detour through bytes


byte
bit

Bigger units for storage capacity

- $1 \text{ kilobyte (KB)} = 1000^1 \text{ bytes}$
- $1 \text{ megabyte (MB)} = 1000^2 \text{ bytes}$
- $1 \text{ gigabyte (GB)} = 1000^3 \text{ bytes}$

Warm-up: Quiz on Canvas

Computer Code and Data Storage

Computer code

- Instructions to a computer, in a language it understands… (R)
- Code is written to **text files**
- Text is ‘translated’ into 0s and 1s which the CPU can process.

Data storage

- Data usually stored in **text files**
  - Read data from text files: data import.
  - Write data to text files: data export.

Unstructured data in text files

- Store `Hello World!` in `helloworld.txt`.
  - Allocation of a block of computer memory containing `Hello World!`.
  - Simply a sequence of `0`s and `1`s…
  - `.txt` indicates to the operating system which program to use when opening this file.
- Encoding and format tell the computer how to interpret the `0`s and `1`s.

Inspect a text file

Interpreting `0`s and `1`s as text...

```
cat helloworld.txt; echo
```

```
## Hello World!
```

Or, from the R-console:

```
system("cat helloworld.txt")
```

Inspect a text file

Directly looking at the `0`s and `1`s…

```
xxd -b helloworld.txt
```

```
00000000: 01001000 01100101 01101100 01101100 01101111 00100000  Hello
00000006: 01010111 01101111 01110010 01101100 01100100 00100001  World!
```

Inspect a text file

Similarly we can display the content in hexadecimal values:

```
xxd  data/helloworld.txt
```

```
00000000: 4865 6c6c 6f20 576f 726c 6421            Hello World!
```

Encoding issues

```
cat hastamanana.txt; echo
```

```
## Hasta Ma?ana!
```

- What is the problem?

Encoding issues

Inspect the encoding

```
file -b hastamanana.txt
```

```
## ISO-8859 text, with CRLF line terminators
```

Use the correct encoding

Read the file again, this time with the correct encoding

```
iconv -f iso-8859-1 -t utf-8 hastamanana.txt | cat
```

```
## Hasta Mañana!
```

UTF encodings

- ‘Universal’ standards.
- Contain broad variety of symbols (various languages).
- Less problems with newer data sources…

Take-away message

- **Recognize an encoding issue when it occurs!**
- Problem occurs right at the beginning of the **data pipeline**!
  - Rest of pipeline affected…
  - … cleaning of data fails …
  - … analysis suffers.

From text to data structure

Structured Data Formats

- We are used to not thinking about the formats of our data… and let the computer choose what to do with data when we click on a file.
- All data are text files, but with standardized **structure**.
- **Special characters** define the structure.
- More complex **syntax**, more complex structures can be represented…

Table-like formats

Example `ch_gdp.csv`.

```
year,gdp_chfb
1980,184
1985,244
1990,331
1995,374
2000,422
2005,464
```

What is the structure?

Table-like formats

- What is the reocurring pattern?
  - Special character ,
  - New lines
  - Table is visible from structure in raw text file…

How can we instruct a computer to read this text as a 6-by-2 table?

A simple **parser** algorithm

CSVs and fixed-width format

- ‘Comma-Separated Values’ (therefore `.csv`)
    - commas separate values
    - other delimiters (`;`, tabs, etc.) possible
    - new lines separate rows/observations
- Instructions of how to read a `.csv`-file: CSV parser.

How does the computer know that the end of a line is reached?

```
00000000: efbb bf79 6561 722c 6764 705f 6368 6662  ...year,gdp_chfb
00000010: 0d31 3938 302c 3138 340d 3139 3835 2c32  .1980,184.1985,2
00000020: 3434 0d31 3939 302c 3333 310d 3139 3935  44.1990,331.1995
00000030: 2c33 3734 0d32 3030 302c 3432 320d 3230  ,374.2000,422.20
00000040: 3035 2c34 3634                           05,464
```

CSVs and fixed-width format

- Common format to store and transfer data.
- Very common in a data analysis context.
- Natural format/structure when the dataset can be thought of as a table.

More complex formats

- N-dimensional data
- Nested data
- **XML**, **JSON**, **YAML**, etc.
  - Often encountered online!
  - (Next lecture!)

Data Structures and Data Types in R

Structures to work with…

- Data structures for storage on hard drive (e.g., csv).
- Representation of data in RAM (e.g. as an R-object)
  - What is the representation of the ‘structure’ once the data is parsed (read into RAM)?

Structures to work with (in R)

We distinguish two basic characteristics:

1. Data types:
    - **integers**;
    - **real numbers** (‘numeric values’, ‘doubles’, floating point numbers);
    - **characters** (‘string’, ‘character values’);
    - (**booleans**)

Structures to work with (in R)

We distinguish two basic characteristics:

1. Data types.
2. Basic data structures in RAM:
   - **Vectors**
   - **Factors**
   - **Arrays/Matrices**
   - **Lists**
   - **Data frames** (very **R**-specific)

Describe data

The `type` and the `class` of an object can be used to describe an object.

- **type**: technical and low-level description of the actual storage mode or physical representation of an object.
  - It tells **how the object is stored in memory**.
- **class**: attribute about the nature of an `R` object.
  - It tells you **how to treat the object in a broad sense**.

Data types: numeric and integers

R interprets these bytes of data as type **`double`** (‘numeric’) or type **`integer`**:

```
a <- 1.5
b <- 3
c <- 3L

# Use math operators
a + b
```

```
## [1] 4.5
```

Data types: numeric and integers

```r
a <- 1.5
typeof(a); class(a)
```

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

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

```r
c <- 3L
typeof(c); class(c)
```

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

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

Data types: character

```
a <- "1.5"
b <- "3"
```

```
typeof(a)
```

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

```
class(a)
```

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

Now the same line of code as above will result in an error:

```
a + b
```

```
## Error in a + b: nicht-numerisches Argument für binären Operator
```

Data types: special values

- `NA`: “Not available”, i.e. missing value for any type
- `NaN`: “Not a number”: special case of NA for numeric
- `Inf`: specific to numeric
- `NULL`: absence of value

Data structures: vectors

- Collections of value of same type

```
persons <- c("Andy", "Brian", "Andy")
persons
```

```
## [1] "Andy"  "Brian" "Andy"
```

```
ages <- c(24, 50, 30)
ages
```

```
## [1] 24 50 30
```

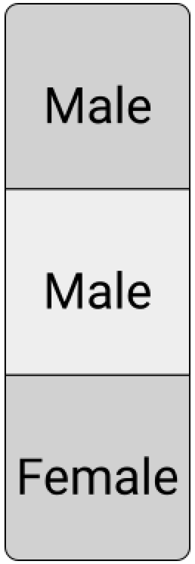
Data structures: vectors

What happens when you create a vector out of `persons` and `ages`?

```
c(persons, ages)
```

Data structures: factors

- Factors are sets of categories.
- The values come from a fixed set of possible values.



Data structures: factors

Example:

```
gender <- factor(c("Male", "Male", "Female"))
gender
```

```
## [1] Male   Male   Female
## Levels: Female Male
```

Factors are “disguised” integers…

```
typeof(gender)
```

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

Data structures: factors

Two components:

- the integer (or “levels”);
- the labels.

```
levels(gender)
```

```
## [1] "Female" "Male"
```

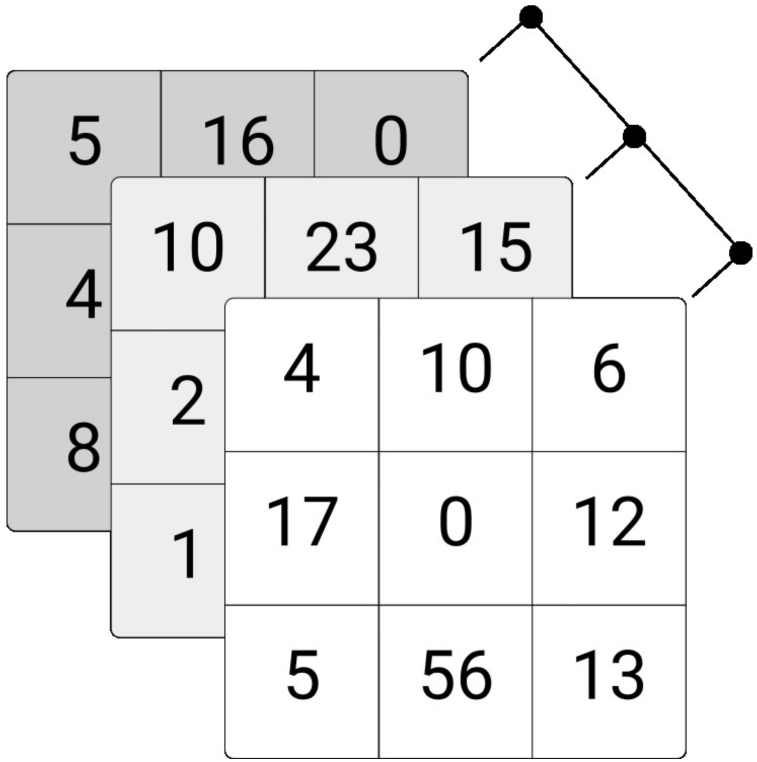
Data structures: matrices

Matrices are two-dimensional collections of values of the same type

1	4	7
2	5	8
3	6	9

Data structures: arrays

Arrays are higherdimensional collections of values of the same type



Data structures: matrices/arrays

Example:

```
my_matrix <- matrix(c(1,2,3,4,5,6), nrow = 3)
my_matrix
```

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

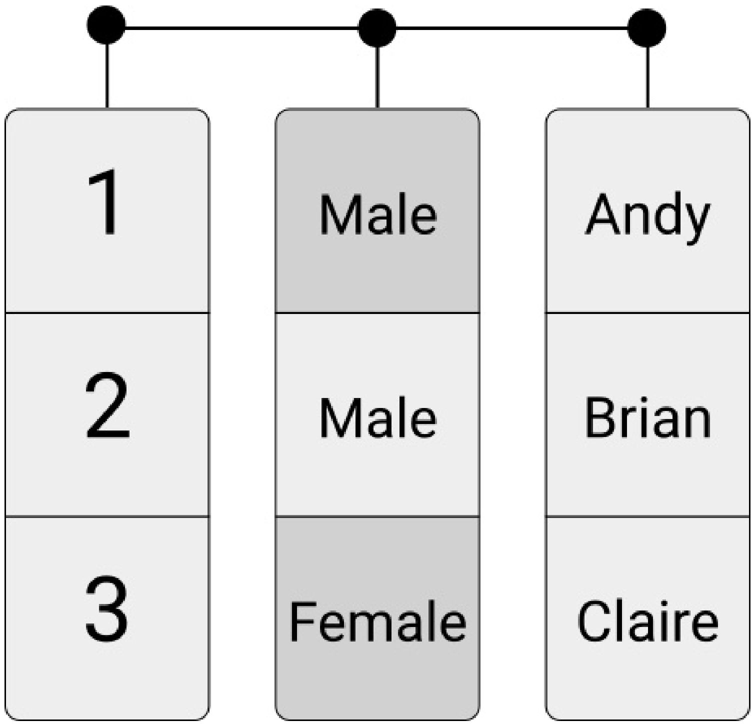
Data structures: matrices/arrays

```
my_array <- array(c(1,2,3,4,5,6,7,8), dim = c(2,3,4))
my_array
```

```
## , , 1
##
##      [,1] [,2] [,3]
## [1,]    1    3    5
## [2,]    2    4    6
##
## , , 2
##
##      [,1] [,2] [,3]
## [1,]    7    1    3
## [2,]    8    2    4
##
## , , 3
##
##      [,1] [,2] [,3]
## [1,]    5    7    1
## [2,]    6    8    2
##
## , , 4
##
##      [,1] [,2] [,3]
## [1,]    3    5    7
## [2,]    4    6    8
```

Data frames, tibbles, and data tables

- Each column contains a vector of a given data type (or factor), but all columns need to be of identical length.
- `data.frame`, `tibble`, `data.table`



Data frames, tibbles, and data tables

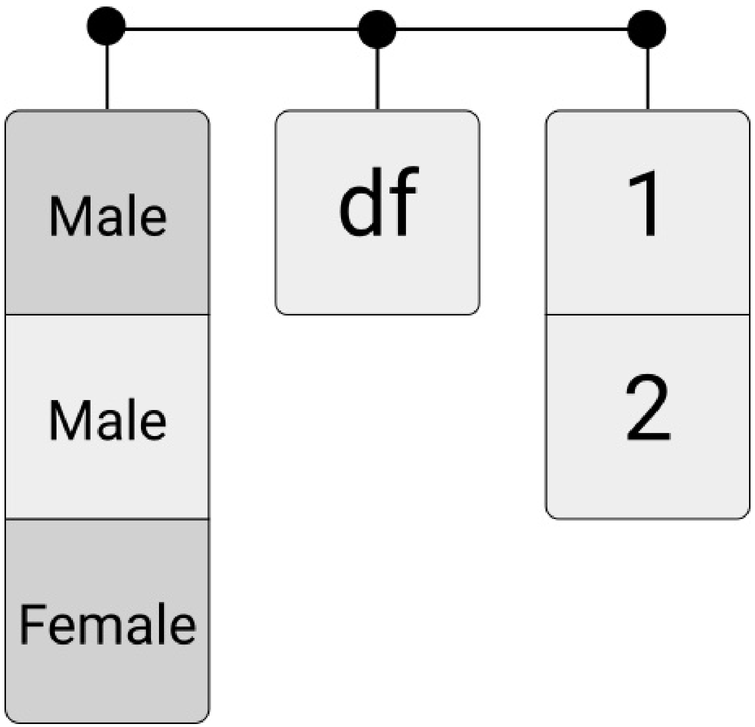
Example:

```
df <- data.frame(person = persons, age = ages, gender = gender)
df
```

```
##   person age gender
## 1   Andy  24   Male
## 2  Brian  50   Male
## 3   Andy  30 Female
```

Data structures: lists

Lists can contain different data types in each element, or even different data structures of different dimensions.



Data structures: lists

Example:

```
my_list <- list(my_array, my_matrix, df)
my_list
```

```
## [[1]]
## , , 1
##
##      [,1] [,2] [,3]
## [1,]    1    3    5
## [2,]    2    4    6
##
## , , 2
##
##      [,1] [,2] [,3]
## [1,]    7    1    3
## [2,]    8    2    4
##
## , , 3
##
##      [,1] [,2] [,3]
## [1,]    5    7    1
## [2,]    6    8    2
##
## , , 4
```

Data structures: most common attributes

- Names and dimnames
- dim
- class
- levels
- length

Data structure: most common attributes

```
x <- c(a=1, b=2, c=3)
names(x)
```

```
## [1] "a" "b" "c"
```

```
m <- matrix(1:6, nrow=2)
dim(m)
```

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

```
dimnames(m) <- list(c("row1", "row2"), c("col1", "col2", "col3"))
m
```

```
##      col1 col2 col3
## row1    1    3    5
## row2    2    4    6
```

Q&A

References