R data types: Data Frames

Alberto Garfagnini

Università di Padova

R lecture 4

R Data frames

- two important S3 vectors built on top of lists are `data frames` and `tibbles`
- a `data frame` is like a matrix, with a 2-dim rows-and-columns structure
- it's a named list of vectors, with attributes for columns and rows names, (`names`, `row.names`), belonging to the `data.frame` class

- technically, a `data frame` is a `list` with all equal length vectors

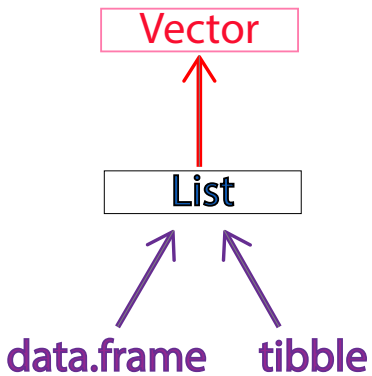
```
df1 <- data.frame(x = 1:3, y = letters[1:3])
typeof(df1)
%> [1] "list"

attributes(df1)
%> $names
%> [1] "x" "y"

%> $class
%> [1] "data.frame"

%> $row.names
%> [1] 1 2 3

str(df1)
%> 'data.frame':        3 obs. of  2 variables:
%>  $ x: int  1 2 3
%>  $ y: Factor w/ 3 levels "a","b","c": 1 2 3
```



R Data Frames : examples

- we have a table with the results of two exams for the stdent of an hipotetical course, and we want to import them in a `data.frame`

$Exam_1$	$Exam_2$	Gender
27	25	M
28	30	F
...		
27	27	M
25	28	F

```
exam1 <- c(27,28,24,24,30,26,23,23,24,28,27,25)
exam2 <- c(25,30,26,24,30,30,25,25,30,28,27,28)
gender <- c("M","F","M","M","M","M","M","M","F","F","M","F")

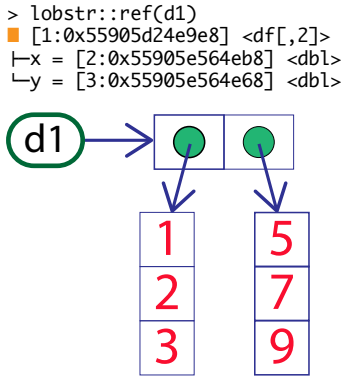
dc <- data.frame(exam1, exam2, gender)
head(dc, n=2) # extract the first two lines of the data frame
%>   exam1 exam2 gender
%> 1    27    25      M
%> 2    28    30      F


dc1 <- data.frame(exam1, exam2, gender,
                  stringsAsFactors = FALSE)
str(dc1)
'data.frame':   12 obs. of  3 variables:
 $ exam1 : num  27 28 24 24 30 26 23 23 24 28 ...
 $ exam2 : num  25 30 26 24 30 30 25 25 30 28 ...
 $ gender: chr  "M" "F" "M" "M" ...
```


R Data Frames objects creation

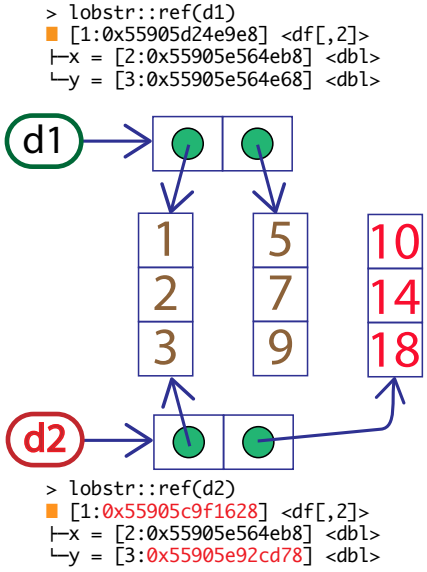
- Data frames are list of vectors, therefore copy-on-modify has important consequences

```
d1 <- data.frame(x = c(1, 2, 3),
                 y = c(5, 7, 9))
d1
%>   x y
%> 1 1 5
%> 2 2 7
%> 3 3 9
```



- if we modify a column ➜ only the reference to the new column will be updated

```
d2 <- d1
d2[, 2] <- d2[, 2] * 2
d2
%>   x  y
%> 1 1 10
%> 2 2 14
%> 3 3 18
```

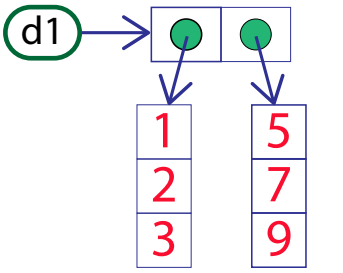


R Data Frames objects creation

- Data frames are list of vectors, therefore copy-on-modify has important consequences

```
d1 <- data.frame(x = c(1, 2, 3),
                 y = c(5, 7, 9))
d1
%>   x y
%> 1 1 5
%> 2 2 7
%> 3 3 9
```

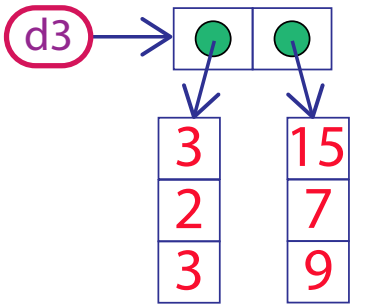
```
> lobstr::ref(d1)
■ [1:0x55905d24e9e8] <df[,2]>
├─x = [2:0x55905e564eb8] <dbl>
└─y = [3:0x55905e564e68] <dbl>
```



- but if any row is modified ➜ every column is modified because every column must be copied

```
d3 <- d1
d3[1, ] <- d3[1, ] * 3
d3
%>   x  y
%> 1 3 15
%> 2 2  7
%> 3 3  9
```

```
> lobstr::ref(d3)
■ [1:0x55905e6f1058] <df[,2]>
├─x = [2:0x55905ea0c238] <dbl>
└─y = [3:0x55905ea0c1e8] <dbl>
```

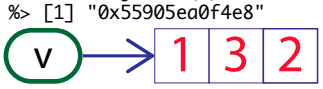


Modify-in-place

- Modifying an R object usually creats a copy
- but there are 2 exceptions:
  - objects with single binding get a special performance optimization
  - environments, a special type of object, are always modified in place

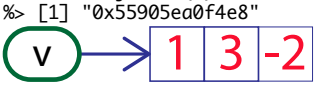
```
v <- c(1, 3, 2)
lobstr::obj_addr(v)
%> [1] "0x55905ea0f4e8"
```

```
lobstr::obj_addr(v)
%> [1] "0x55905ea0f4e8"
```




```
v[[3]] <- -2
lobstr::obj_addr(v)
%> [1] "0x55905ea0f4e8"
```

```
lobstr::obj_addr(v)
%> [1] "0x55905ea0f4e8"
```



- but it is very difficult to predicts when R applies this optimization
- concerning object binding, R only counts 0, 1 or MANY
- it means that if an object has 2 bindings (i.e. many), and one gets deleted, the reference does not go back to 1 (many - 1 = many)
- when a funtion is called, it makes a reference to the object ➜ it is very difficult to predict weather or not a copy will occur
- cfr: https://developer.r-project.org/Refcnt.html

Accessing `data frames` elements

- a `data frame` is a `list`, therefore we can access them via component index value `[[ j ]]` or via component names

```
str(dc)
%> 'data.frame':    12 obs. of  3 variables:
%>  $ exam1 : num  27 28 24 24 30 26 23 23 24 28 ...
%>  $ exam2 : num  25 30 26 24 30 30 25 25 30 28 ...
%>  $ gender: Factor w/ 2 levels "F","M": 2 1 2 2 2 2 2 2 1 1 ...

dc[[1]] # access by component index
%>  [1] 27 28 24 24 30 26 23 23 24 28 27 25

dc$exam1 # access by component name
%>  [1] 27 28 24 24 30 26 23 23 24 28 27 25
%> Levels: F M
```

- but a `data frame` can be treated in a matrix-like fashion, as well

```
dc[,1] # select column 1
%>  [1] 27 28 24 24 30 26 23 23 24 28 27 25

dc[1,1] # and access the single element, as well
%> [1] 27
```


Data frames row names

- data frames allow to label each row with a name, a character vector containing only unique names

```
df1 <- data.frame( age = c(35, 25, 18),
                   hair = c("blond", "brown", NA),
                   row.names = c("Bob", "Tom", "Sam"))
df1
%>      age  hair
%> Bob  35 blond
%> Tom  25 brown
%> Sam  18  <NA>

names(df1)
%> [1] "age"  "hair"

row.names(df1)
%> [1] "Bob" "Tom" "Sam"
```

- but row names are a bad practice:

(1) metadata is metadata : storing it in a different way to the rest of data is a bad idea

(2) row names are a poor abstraction for labeling rows : they only work when a row can be identified by a single string

(3) row names must be unique : any duplication of rows will create new row names ➜ complicated "string surgery" may be needed

Advanced data frames : data selection

```
dc[2:4,]  # Select only rows 2:4
%>   exam1 exam2 gender
%> 2    28    30      F
%> 3    24    26      M
%> 4    24    24      M

dc[-(2:10),] # drop rows 2:10
%>    exam1 exam2 gender
%> 1     27    25      M
%> 11    27    27      M
%> 12    25    28      F
```

- with the sample function , data can be selected at random

```
dc[sample(1:12,3),]  # select 3 rows at random
%>   exam1 exam2 gender
%> 8    23    25      M
%> 9    24    30      F
%> 6    26    30      M

dc[sample(1:12,3),]  # select 3 rows at random
%>    exam1 exam2 gender
%> 1     27    25      M
%> 10    28    28      F
%> 2     28    30      F
```


Advanced data frames : data selection

- suppose we want to extract all columns that contain numbers, rather than characters or logicals, from a data frame

```
dc[,sapply(dc,is.numeric)]
%>    exam1 exam2
%> 1     27    25
%> 2     28    30
%> 3     24    26
%> 4     24    24
%> 5     30    30
%> 6     26    30
%> 7     23    25
%> 8     23    25
%> 9     24    30
%> 10    28    28
%> 11    27    27
%> 12    25    28
```

```
dc <- data.frame(exam1, exam2, gender)
str(dc)
'data.frame':  12 obs. of  3 variables:
$ exam1 : num  27 28 ...
$ exam2 : num  25 30 ...
$ gender: Fact w/ 2 levels "F","M": 2 1
```

- and now we want to get only factors (and remove numerics)

```
dc[,sapply(dc,is.factor)]
%>  [1] M F M M M M M M F F M F
%> Levels: F M
```

Advanced data frames and NA elements

- sometimes our data frame can have missing values (NA) and we may need to omit those values
- we can create a shorter data frame using the na.omit() function

```
data
%>    slope   pH area
%> 1     11 4.1  3.6
%> 2     NA 5.2  5.1
%> 3      3 4.9  2.8
%> 4      5  NA  3.7
```

```
na.omit(data)
%>    slope   pH area
%> 1     11 4.1  3.6
%> 3      3 4.9  2.8
```

```
clean_data <- na.exclude(data)
clean_data
%>    slope   pH area
%> 1     11 4.1  3.6
%> 3      3 4.9  2.8
```

```
lapply(clean_data, mean)
%> $slope
%> [1] 7
%> $pH
%> [1] 4.5
%> $area
%> [1] 3.2
```

```
# Let's count the missing values
apply(apply(data,2,is.na),2,sum)
%> slope    pH  area
%>     1     1     0
```


Advanced data frames : sorting elements

```
dc[order(exam1),]
%>    exam1 exam2 gender
%> 7     23    25      M
%> 8     23    25      M
...
```

```
dc[order(exam1, decreasing=TRUE),]
%>    exam1 exam2 gender
%> 5     30    30      M
%> 2     28    30      F
```

- ```
  dc[order(gender, exam1, exam2, decreasing=TRUE),]
  %>    exam1 exam2 gender
  %> 5     30    30      M
  %> 11    27    27      M
  %> 1     27    25      M
  %> 6     26    30      M
  %> 3     24    26      M
  %> 4     24    24      M
  %> 7     23    25      M
  %> 8     23    25      M
  %> 2     28    30      F
  %> 10    28    28      F
  %> 12    25    28      F
  %> 9     24    30      F
  ```
  ```

Summary of data selection in `data frames`

- given a `data frame` called `data`, we assume `n` is a row number, and `m` is one of the column.
- the syntax `[n,]` selects all the columns given row `n`, while `[,m]` selects all the rows with column `m`

command	meaning
`data[n,]`	select all of the columns from row n of the data frame
`data[-n,]`	drop the whole of row n from the data frame
`data[1:n,]`	select all of the columns from rows 1 to n of the data frame
`data[-(1:n),]`	drop all of the columns from rows 1 to n of the data frame
`data[c(i,j,k),]`	select all of the columns from rows i, j, and k of the data frame
`data[x > y,]`	use a logical test ($x > y$) to select all columns from certain rows
`data[,m]`	select all of the rows from column m of the data frame
`data[,-m]`	drop the whole of column m from the data frame
`data[,1:m]`	select all of the rows from columns 1 to m of the data frame
`data[,-(1:m)]`	drop all of the rows from columns 1 to m of the data frame
`data[,c(i,j,k)]`	select all of the rows from columns i, j, and k of the data frame
`data[,x > y]`	use a logical test ($x > y$) to select all rows from certain columns
`data[,c(1:m,i,j,k)]`	add duplicate copies of columns i, j, and k to the data frame
`data[x > y,a != b]`	extract certain rows ($x > y$) and certain columns ($a! = b$)
`data[c(1:n,i,j,k),]`	add duplicate copies of rows i, j, and k to the data frame

The `tibble` data structure

- it is a modern reimagining of the `data frame`
- it is provided by the `tibble` package which is part of the `tidyverse` core library

```
library(tidyverse)
%>  Attaching packages --------  tidyverse 1.3.0
%>  ggplot2 3.3.0      purrr   0.3.3
%>  tibble  2.1.3      dplyr   0.8.5
%>  tidyr   1.0.2      stringr 1.4.0
%>  readr   1.3.1      forcats 0.5.0
%>  Conflicts ------------ tidyverse_conflicts()
%>  dplyr::filter() masks stats::filter()
%>  dplyr::lag()    masks stats::lag()
```

- a `data frame` can be converted to a `tibble`

```
dct <- tibble(dc)
dct
%> # A tibble: 12 x 1
%>    dc$exam1 $exam2 $gender
%>       <dbl>  <dbl> <fct>
%>  1       27     25 M
 ...
%> 12       25     28 F
```

https://tibble.tidyverse.org/

- or created from vectors (as for the `data frame`)

```
dct <- data.frame(exam1 = c(27,28,24,24,30,26,23,23,24,28,27,25),
                  exam2 = exam2, gender)
```

Tibbles vs. data.frame : printing

- two main differences in the usage of a tibble versus a data.frame:
- printing and subsetting
- Tibbles have a refined print method that shows only the first 10 rows:

```
atb <- tibble( a = lubridate::now() + runif(1e3) * 86400,
               b = 1:1e3,
               c = runif(1e3),
               d = sample(letters, 1e3, replace = TRUE) )
atb
%> # A tibble: 1,000 x 4
%>    a                     b      c d
%>    <dttm>              <int>  <dbl> <chr>
%>  1 2020-03-24 08:56:26     1 1.00   q
%>  2 2020-03-24 10:57:29     2 0.996  z
%>  3 2020-03-24 00:32:33     3 0.620  r
%>  4 2020-03-24 01:16:23     4 0.804  d
%>  5 2020-03-24 03:32:17     5 0.311  e
%>  6 2020-03-24 00:22:27     6 0.206  u
%>  7 2020-03-23 12:58:48     7 0.0390 e
%>  8 2020-03-23 20:36:03     8 0.449  d
%>  9 2020-03-24 01:29:00     9 0.271  r
%> 10 2020-03-24 10:52:01    10 0.460  v
%> # with 990 more rows
```


Tibbles vs. data.frame : subsetting

- tibbles can extract by name or position

```
tb1 <- tibble( x = runif(5),
               y = rnorm(5) )

# Extract by name
tb1$x
#> [1] 0.7330 0.2344 0.6604 0.0329 0.4605
tb1[["x"]]
#> [1] 0.7330 0.2344 0.6604 0.0329 0.4605

# Extract by position
tb1[[1]]
#> [1] 0.7330 0.2344 0.6604 0.0329 0.4605
```

- `tibbles` are more strict than `data.frame`: they never do partial matching, and they will generate a warning if the column you are trying to access does not exist

```
tdc <- as_tibble(dc)
```

```
dc$gender
#>  [1] M F M ... F M F
#> Levels: F M

dc$gen
#>  [1] M F M ... F M F
#> Levels: F M

.
```

```
tdc$gender
#>  [1] M F M ... F M F
#> Levels: F M

tdc$gen
#> NULL
#> Warning message:
#> Unknown or uninitialised column:
  'gen'.
```

Data Input

Data Input

- numbers can be `input`ed through the keyboard, from the Clipboard, from an external file on disk, or from an external file on the Web
- use the concatenate function for up to 10 numbers
- and `scan()` for typing or pasting data into a vector

```
y <- c (6,7,3,4,8,5,6,2)

tu <- scan()
%> 1: 6
%> 2: 3
%> 3: 4
%> 4: 2
%> 5:
%> Read 4 items
tu
%> [1] 6 3 4 2
```

- but the easiest way is to read data from a file (or from the Web), already shaped in a data frame format

Data Input using read.table()

- the read.table() function reads data from a local file and creates a data frame

```
data <- read.table("yield.txt",header=T)

data
%>    year wheat barley oats rye corn
%> 1  1980   5.9    4.4  4.1 3.8  4.4
%> 2  1981   5.8    4.4  4.3 3.7  4.1
%> 3  1982   6.2    4.9  4.4 4.1  4.0
...
%> 27 2006   8.0    5.9  6.0 6.1  4.5
%> 28 2007   7.2    5.7  5.5 5.7  3.9
%> 29 2008   8.3    6.0  5.8 6.1  4.4
```

- the parameter header = T tells R to use the first row as column names

```
names(data)
%> [1] "year"   "wheat"  "barley" "oats"   "rye"    "corn"

str(data)
%> 'data.frame':        29 obs. of  6 variables:
%>  $ year  : int  1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 ...
%>  $ wheat : num  5.9 5.8 6.2 6.4 7.7 6.3 7 6 6.2 6.7 ...
%>  $ barley: num  4.4 4.4 4.9 4.7 5.6 5 5.2 5 4.7 4.9 ...
%>  $ oats  : num  4.1 4.3 4.4 4.3 4.9 4.6 5.2 4.6 4.6 4.5 ...
%>  $ rye   : num  3.8 3.7 4.1 3.7 4.7 4.6 4.7 4.8 4.6 4.8 ...
%>  $ corn  : num  4.4 4.1 4 4.1 4.7 4.3 4.3 4.5 4.2 3.8 ...
```


Data Input using read.table()

- if the separator between variable names and data fields are not blanks or tabs, (\t), a different separator can be specified with the sep="," option

```
datav <- read.table("bowens.csv",sep=",", header=T)

str(datav)
%> 'data.frame':        733 obs. of  3 variables:
%>  $ place: Factor w/ 727 levels "Abingdon","Admoor␣Copse",..: 1 2 3 ..
%>  $ east : int  50 60 48 70 59 60 60 59 61 60 ...
%>  $ north: int  97 70 87 73 65 65 63 66 63 67 ...
```

read.table() : separators and decimal points

- the default field separator character in read.table() is sep=" ": which identifies with one or more spaces, one or more tabs (\t), and one or more newlines (\n)
- for comma-separated fields use read.csv()
- for semicolon-separated fields use read.csv2()
- for tab-delimited fields with decimal points as a commas, use read.delim2()

```
File: bowens.csv
--------------------
|place,east,north  |
|Abingdon,50,97    |
|Admoor Copse,60,70|
|...               |
|Youlbury,48,3     |
--------------------
```

```
str(bw)
%> 'data.frame':   733 obs. of  3 variables:
%>  $ place: Factor w/ 727 levels "AERE␣Harwell",..: 2 3 1 4 5 ...
%>  $ east : int  50 60 48 70 59 60 60 59 61 60 ...
%>  $ north: int  97 70 87 73 65 65 63 66 63 67 ...
```


read.csv() and read.delim()

- additional functions to read a file in table format exist

```
> ?read.table
...
read.delim(file, header = TRUE, sep = "\t", quote = "\"",
␣␣␣␣␣␣␣␣␣␣dec␣=␣".",␣fill␣=␣TRUE,␣comment.char␣=␣"",␣...)
...
read.csv(file,␣header␣=␣TRUE,␣sep␣=␣",",␣quote␣=␣"\"",
         dec = ".", fill = TRUE, comment.char = "", ...)
...
read.csv2(file, header = TRUE, sep = ";", quote = "\"",
␣␣␣␣␣␣␣␣␣␣dec␣=␣",",␣fill␣=␣TRUE,␣comment.char␣=␣"",␣...)
...
read.delim2(file,␣header␣=␣TRUE,␣sep␣=␣"\t",␣quote␣=␣"\"",
            dec = ",", fill = TRUE, comment.char = "", ...)
```

- further detailed instructions in the 'R Data Import/Export' manual:
  https://cran.r-project.org/doc/manuals/r-release/R-data.html

Data Input from the Web and from DB

- R can read data form the network using HTTP by specifying the file URL

```
wc <- read.table("https://tinyurl.com/murders-txt", header=T)

str(wc)
%> 'data.frame':    50 obs. of  4 variables:
%>  $ state      : Factor w/ 50 levels "Alabama","Alaska",..: 1 2 ...
%>  $ population: int  3615 365 2212 2110 21198 2541 3100 ...
%>  $ murder     : num  15.1 11.3 7.8 10.1 10.3 6.8 3.1 6.2 ...
%>  $ region     : Factor w/ 4 levels "North.Central",..: 3 4 4 ...
```

- several packages available on CRAN to help R communicate with DBMSs:

  combining a unified 'front-end' package with a 'back-end' module, several common relational databases can be accessed (RMySQL, ROracle, RPostgreSQL and RSQLite)

- finally, R can read binary data files: NASA's HDF5 (Hierarchical Data Format, https://www.hdfgroup.org/HDF5/) and UCAR's netCDF data files (network Common Data Form, http://www.unidata.ucar.edu/software/netcdf/)

- and image files

Example: data Input from the Web

- let's retrieve the latest data on the COVID-19 Virus infection from the European Centers for Disease Control https://www.ecdc.europa.eu/en

- R can read data form the network using HTTP by specifying the file URL

Example: data Input from the Web

- we download an EXCEL file
- we use the following packages: `lubridate`, `curl` and `readxl`

```
url <-  "https://www.ecdc.europa.eu/sites/default/files/documents/"
fname <- "COVID-19-geographic-disbtribution-worldwide-"
date <- lubridate::today() - 1
ext = ".xlsx"
target <- paste(url, fname, date, ext, sep="")
message("target: ", target)

tmp_file <- tempfile("data", "/tmp", fileext=ext)
tmp <- curl::curl_download(target, destfile=tmp_file)
```

- data are imported in a `tibble` data structure

```
(data <- readxl::read_xlsx(tmp_file))
%> A tibble: 6,012 x 8
%>   DateRep             Day Month  Year Cases Deaths Countries. GeoId
%>   <dttm>            <dbl> <dbl> <dbl> <dbl>  <dbl> <chr>      <chr>
%> 1 2020-03-21 00:00:00  21     3  2020     2      0 Afghanistan   AF
%> 2 2020-03-20 00:00:00  20     3  2020     0      0 Afghanistan   AF
%> 3 2020-03-19 00:00:00  19     3  2020     0      0 Afghanistan   AF
%> 4 2020-03-18 00:00:00  18     3  2020     1      0 Afghanistan   AF
%> 5 2020-03-17 00:00:00  17     3  2020     5      0 Afghanistan   AF
%> 6 2020-03-16 00:00:00  16     3  2020     6      0 Afghanistan   AF
%> 7 2020-03-15 00:00:00  15     3  2020     3      0 Afghanistan   AF
%> 8 2020-03-11 00:00:00  11     3  2020     3      0 Afghanistan   AF
%> 9 2020-03-08 00:00:00   8     3  2020     3      0 Afghanistan   AF
%>10 2020-03-02 00:00:00   2     3  2020     0      0 Afghanistan   AF
% ... with 6,002 more rows
```


Homework

- learn how to extract and manipulate data from the imported `tibble`
- in the next lecture we will see how to represent data with histograms and plots