R Lists and Data Frames

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R internals: variables and objects creation

- We create a vector with three values and assign it to a reference variable, `x`

```
x <- c(1,2,3)
```

- we now copy `x` to another variable `y`:

```
y <- x
```

- and modify one element of `y`

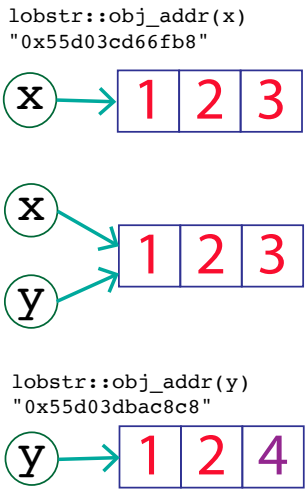
```
y[3] <- 4
```

- did we modify also `x`?

  No, they refer to two different objects:

```
str(x)
# num [1:3] 1 2 3
str(y)
# num [1:3] 1 2 4
```

- the behavior is called `copy-on-modify`
- all R objects are `immutable`



The `lobstr` package allows to visualize R data structures: it shows memory location and size of objects.
URL: `https://github.com/r-lib/lobstr`

R Lists

- List are important objects in R each element of the list can be of different type
- from the technical point of view: each element of a list is of the same type: it is a reference to another R object
- building a list:

```
l1 <- list( 1:3,
            "one list element",
            rep(c(T,F,T), 1:3),
            c(3.5, 4, 6.2, -1.75) )
# [[1]]
# [1] 1 2 3

# [[2]]
# [1] "one list element"

# [[3]]
# [1]  TRUE FALSE FALSE  TRUE  TRUE  TRUE

# [[4]]
# [1]  3.50  4.00  6.20 -1.75


str(l1)
# List of 4
#  $ : int [1:3] 1 2 3
#  $ : chr "one list element"
#  $ : logi [1:6] TRUE FALSE FALSE TRUE TRUE TRUE
#  $ : num [1:4] 3.5 4 6.2 -1.75
```


Indexing Lists

- subscripts on vectors, matrices, arrays, and dataframes have one set of square brackets
- subscripts on lists use double square brackets:

```
l1 <- list( 1:3, "list element",
            c(TRUE, FALSE, FALSE),
            c(3.5, 4, 6.2, -1.75)  )
```

- double square brackets [[]] return the element in the list with its type

```
l1[[4]]
[1]  3.50  4.00  6.20 -1.75

storage.mode(l1[[4]])
# [1] "double"

str( l1[[4]] )
# num [1:4] 3.5 4 6.2 -1.75

l1[[4]][3]
# [1] 6.2
```

➜ single square brackets [] always return a list

```
str( l1[4] )
# List of 1
#  $ : num [1:4] 3.5 4 6.2 -1.75
```

R named Lists

- list elements can be given a name at creation time:

```
l1 <- list(index =  1:3, text = "list element",
           test = c(TRUE, FALSE, FALSE),
           speed = c(3.5, 4, 6.2, -1.75)  )

str(l1)
# List of 4
#  $ index: int [1:3] 1 2 3
#  $ text : chr "list element"
#  $ test : logi [1:3] TRUE FALSE FALSE
#  $ speed: num [1:4] 3.5 4 6.2 -1.75
```

- and this allows to extract elements by name
- these are all equivalent:

```
l1$speed
# [1]  3.50  4.00  6.20 -1.75

l1[["speed"]]
# [1]  3.50  4.00  6.20 -1.75

l1[[4]]
# [1]  3.50  4.00  6.20 -1.75
```


R Lists storage

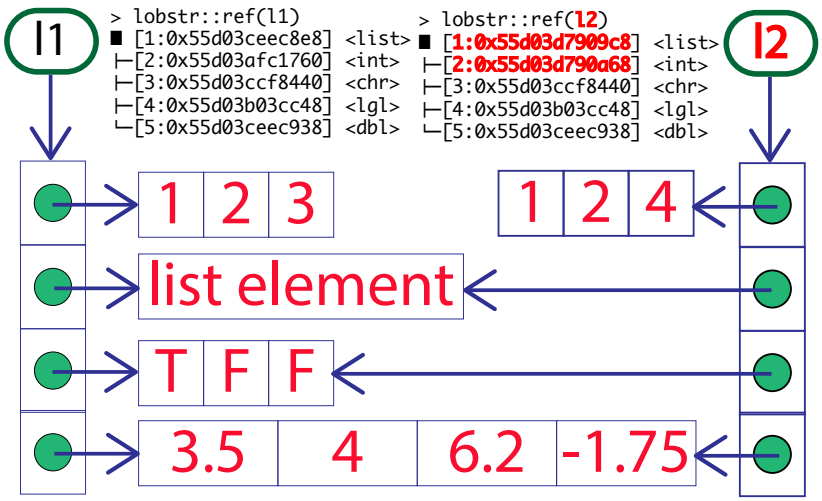
- Lists are an evolution of atomic vectors: each element can be of any type
- from the technical point of view: each element of a list is of the same type: it is a reference to another R object
- building a list:

```
l1 <- list( 1:3,
            "list element",
            c(TRUE, FALSE, FALSE),
            c(3.5, 4, 6.2, -1.75)
)
typeof(l1)
# [1] "list"
```

- we copy to a new list and modify one element

```
l2 <- l1

l2[[1]] <- c(1L,2L,4L)
```



R data.frames

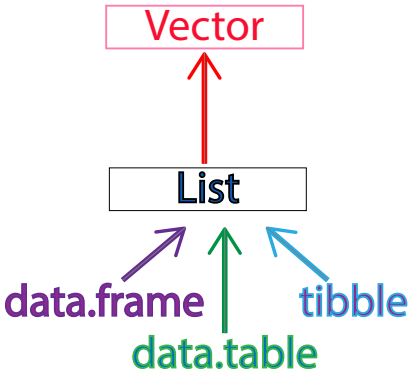
- two important S3 vectors built on top of lists are `data.frames`, `tibbles`, and `data.table`,
- a `data frame` is like a matrix, with a 2-dim rows-and-columns structure
- it's a named list of vectors, with attributes for columns and rows names, (`names`, `row.names`), belonging to the `data.frame` 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 student of an hipotetical course, and we want to import them in a `data.frame`

$Exam_1$	$Exam_2$	Channel
27	25	A-L
28	30	M-Z
...		
27	27	M-Z
25	28	A-L

```
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)
channel <- c("AL","MZ","MZ","MZ","MZ","MZ","MZ","MZ","AL","AL","MZ","AL"

dc <- data.frame(exam1, exam2, channel)
head(dc, n=2) # extract the first two lines of the data frame
#   exam1 exam2 channel
# 1    27    25      AL
# 2    28    30      MZ
```

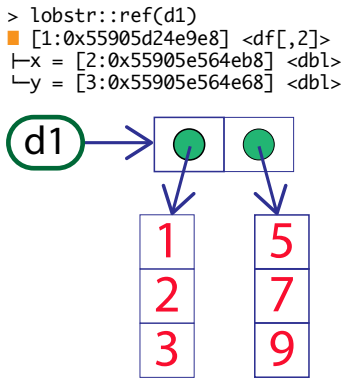
From R 4.0 stringsAsF actors = FALSE by default

```
dc1 <- data.frame(exam1, exam2, channel,
                  stringsAsFactors = TRUE)
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 ...
#  $ channel: Factor w/ 2 levels "AL","MZ": 1 2 2 2 2 2 2 2 1 1 ...
```

R `data.frames` objects creation (1)

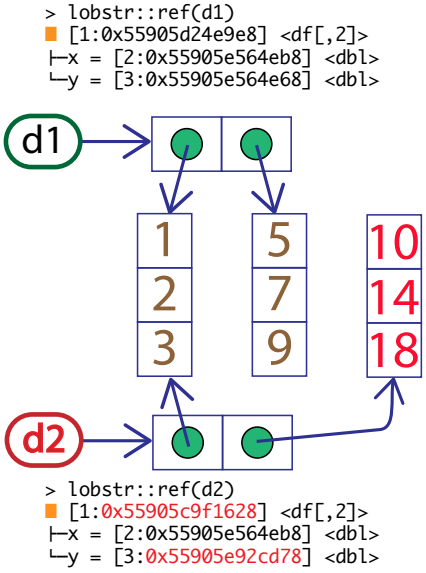
- Data frames are list of vectors, therefore copy-on-modify has important consequences

```
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

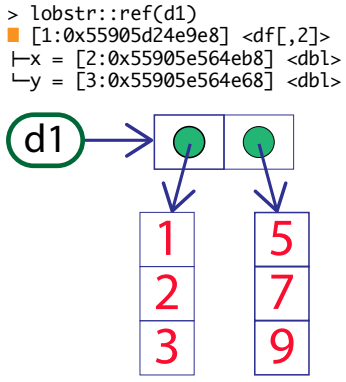
```
d2 <- d1
d2[, 2] <- d2[, 2] * 2
d2
#   x  y
# 1 1 10
# 2 2 14
# 3 3 18
```



R `data.frames` objects creation (2)

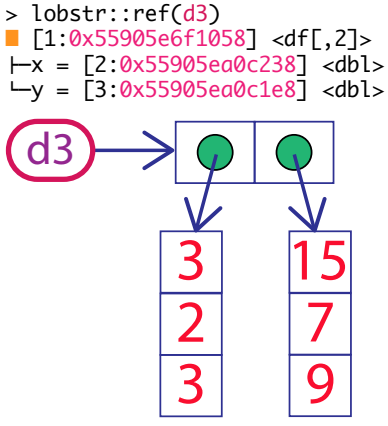
- Data frames are list of vectors, therefore copy-on-modify has important consequences

```
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
```



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

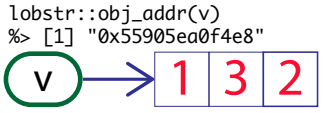
```
d3 <- d1
d3[1, ] <- d3[1, ] * 3
d3
#   x  y
# 1 3 15
# 2 2  7
# 3 3  9
```



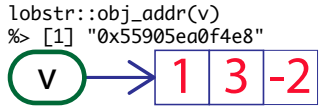
Modify-in-place

- 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"
```




```
v[3] <- -2
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(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 ...
 $ channel: Factor w/ 2 levels "AL","MZ": 1 2 2 2 2 2 2 2 1 1 ...

dc1[[1]] # access by component index
#  [1] 27 28 24 24 30 26 23 23 24 28 27 25

dc1$exam1 # access by component name
#  [1] 27 28 24 24 30 26 23 23 24 28 27 25
```

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

```
dc1[,1] # select column 1
#  [1] 27 28 24 24 30 26 23 23 24 28 27 25

dc1[1,1] # and access the single element, as well
# [1] 27
```

Advanced data frames : data selection (1)

- ```
  dc1[2:4,]  # Select only rows 2:4
  # exam1 exam2 channel
  # 2    28    30       MZ
  # 3    24    26       MZ
  # 4    24    24       MZ

  dc1[-(2:10),] # drop rows 2:10
  #    exam1 exam2 channel
  # 1     27    25       AL
  # 11    27    27       MZ
  # 12    25    28       AL
  ```

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

  ```
  dc1[sample(1:12,3),]  # select 3 rows at random
  #     exam1 exam2 channel
  # 10    28    28       AL
  # 5     30    30       MZ
  # 1     27    25       AL

  dc1[sample(1:12,3),]  # select 3 rows at random
  #   exam1 exam2 channel
  # 2    28    30       MZ
  # 4    24    24       MZ
  # 7    23    25       MZ
  ```


Advanced data frames : data selection (2)

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

  ```
  dc[,sapply(dc1,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, channel )
  str(dc)
  'data.frame':  12 obs. of  3 variables:
  $ exam1 : num  27 28 ...
  $ exam2 : num  25 30 ...
  $ channel: Fact w/ 2 lvl "AL","MZ": 1 2 ...
  ```

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

  ```
  dc[,sapply(dc,is.factor)]
  # [1] AL MZ MZ MZ MZ MZ MZ MZ AL AL MZ AL
  # Levels: AL MZ
  ```
  ```

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

Subsetting atomic vectors (1)

```
x  <- c(2.1, 4, 6.7, 1.75)
```

- positive integers return elements at a specified position

```
x[c(1,3)]
# [1] 2.1 6.7

% Duplicate indices will duplicate values
x[c(1,1,3,3)]
# [1] 2.1 2.1 6.7 6.7

% Real numbers are truncated to integers
x[sort(x)]
# [1] 2.10 4.00 1.75   NA
```

- negative integers exclude elements

```
x[-c(1,3)]
# [1] 4.00 1.75

% NB negative and positive ints cannot be mixed
x[c(-1,3)]
# Error in x[c(-1, 3)]:only 0's may be mixed with negative subscripts
```

Subsetting atomic vectors (2)

```
x  <- c(2.1, 4, 6.7, 1.75)
```

- logical vectors select elements where the logical value is `TRUE`

```
x[c(T, T, F, T)]
# [1] 2.10 4.00 1.75

x[x>2]
# [1] 2.1 4.0 6.7
```

- if in `x[sel]`, `length(sel) != length(x)` the recycling rules are used: the shorter vector is recycled to the length of the longer

```
x[c(TRUE, FALSE)]
# [1] 2.1 6.7

%# is equivalent to:
x[c(TRUE, FALSE, TRUE, FALSE)]
# [1] 2.1 6.7
```

- nothing returns the original vector

```
x[]
# [1] 2.10 4.00 6.70 1.75
```


Subsetting atomic vectors (3)

```
x  <- c(2.1, 4, 6.7, 1.75)
```

- zero returns a zero-length vector (it can be helpful to generate test data)

```
x[0]
# numeric(0)
```

- named vectors can be accessed with character vectors

```
y <- setNames(x, LETTERS[1:length(x)])
y
#    A    B    C    D
# 2.10 4.00 6.70 1.75
y["A"]
#   A
# 2.1

y[c('A', 'A', 'D')]
#   A    A    D
# 2.10 2.10 1.75
```

- WARNING: subsetting with factors will use the underlying integer vector, not the character levels. ➜ Avoid subsetting with factors

```
y[factor("B")]
#   A
# 2.1
```

Subsetting matrices (1)

- subsetting a matrix or a list works in a similar way as subsetting atomic vectors

```
S  <- matrix(1:9, nrow = 3)
# [1,]   1   4   7
# [2,]   2   5   8
# [3,]   3   6   9
```

- using `[]` always returns a list
- `[[]]` and `$` allows to pull out elements from the list
- the common rule to subset a matrix (2D) and an array (nD, $n > 2$) is to supply a 1D vector for each dimension, separated by a comma
- blank subsetting allows to keep all data for the corresponding dimension

```
%# Get rows 1 and 3 and all columns
S[c(1,3), ]
#      [,1] [,2] [,3]
# [1,]    1    4    7
# [2,]    3    6    9

colnames(S) <- c("S1", "S2", "S3")
S[c(T, F, T), c("S1", "S3")]
#      S1 S3
# [1,]  1  7
# [2,]  3  9
```


Subsetting matrices (2)

- matrices and arrays are just vectors with special attributes, therefore they can be subset with a single vector, as if they were a 1D vector

```
v <- outer(1:5,1:5, FUN="paste", sep=",")
v
#      [,1]  [,2]  [,3]  [,4]  [,5]
# [1,] "1,1" "1,2" "1,3" "1,4" "1,5"
# [2,] "2,1" "2,2" "2,3" "2,4" "2,5"
# [3,] "3,1" "3,2" "3,3" "3,4" "3,5"
# [4,] "4,1" "4,2" "4,3" "4,4" "4,5"
# [5,] "5,1" "5,2" "5,3" "5,4" "5,5"

v[seq(3, 23, 5)]
# [1] "3,1" "3,2" "3,3" "3,4" "3,5"
```

- to preserve the original matrix dimension, use `drop = FALSE`

```
(S <- matrix(1:6, nrow = 2))
#      [,1] [,2] [,3]
# [1,]    1    3    5
# [2,]    2    4    6

S[1, ]
# [1] 1 3 5

S[1, , drop = FALSE]
#      [,1] [,2] [,3]
# [1,]    1    3    5
```

Selecting `lists` (1)

- there are two other subsetting operators:
- `[[]]` is used to extract single items
- `$` is used as a shorthand: `x$y` stands for `x[["y"]]`

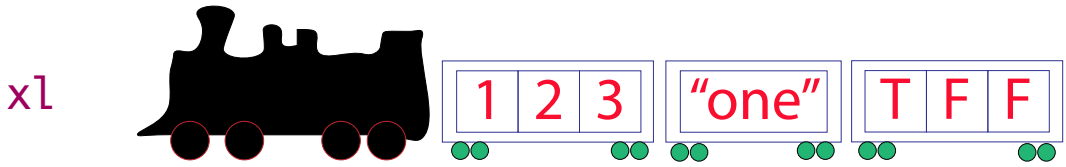
- `[[]]` is most important while working with lists: subsetting a list with single `[]` always returns a smaller list

If list `xl` is a train carrying objects, then `xl[[5]]` is the object in car 5; `xl[4:6]` is a train of cars 4-6

https://twitter.com/RLangTip/status/268375867468681216

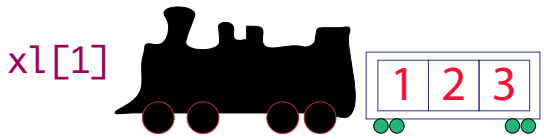
- with this metaphor let's build a list

```
xl <- list(1:3, "one", c(T,F,F))
```

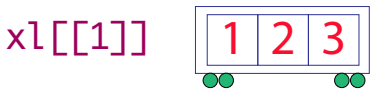


Selecting Lists a single elements

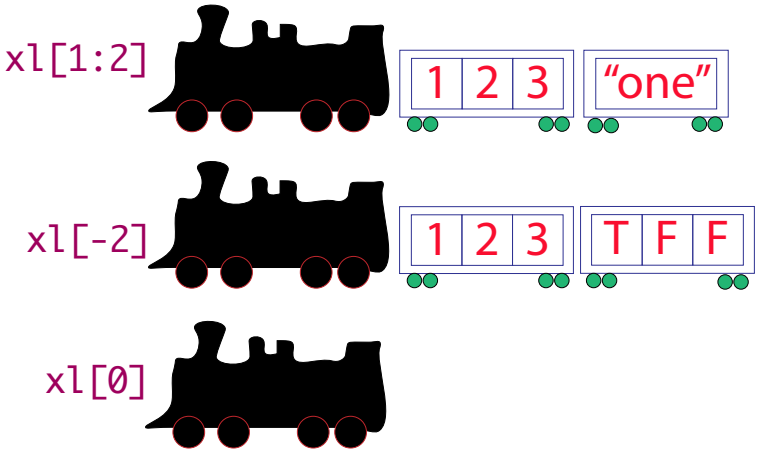
- two options are available when extracting a single element:
- create a smaller train, with fewer cars (using `[]`)



- or extract the content of a particular car (with `[[]]`)



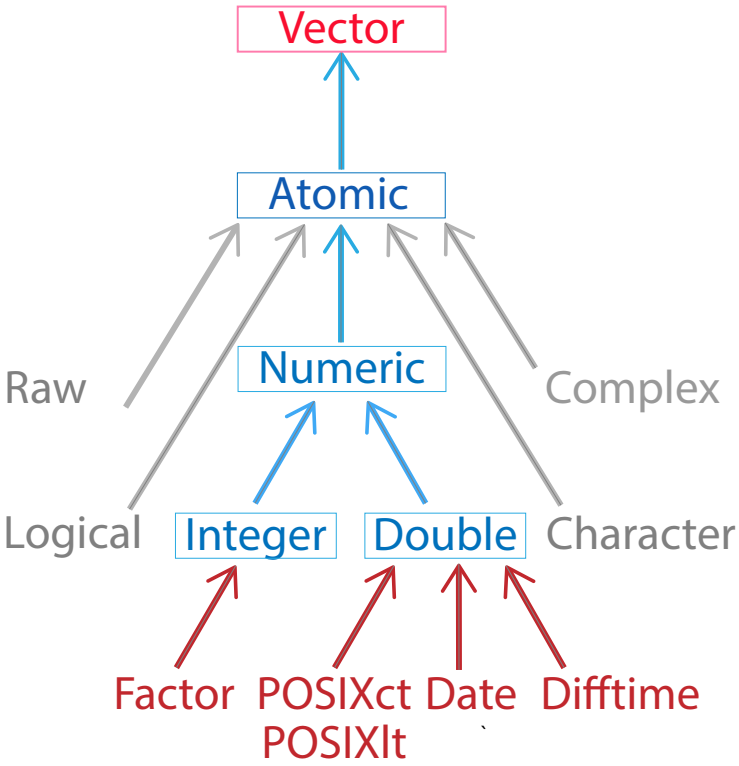
- extracting multiple (or zero) elements, we have to build a smaller train



S3 Atomic Vectors

S3 atomic vectors

- S3 is the basic object system in R.
- an object is turned into an S3 object with a `class` attribute
- some important S3 vectors used in R are
  - `factor vectors` : used to store categorical data, as a fixed set of levels
  - `Date vectors`, for time object with day resolution
  - `POSIXct/POSIXlt vectors`, for time object with second (or sub-second) resolution
  - `difftime vectors`, for storing time durations

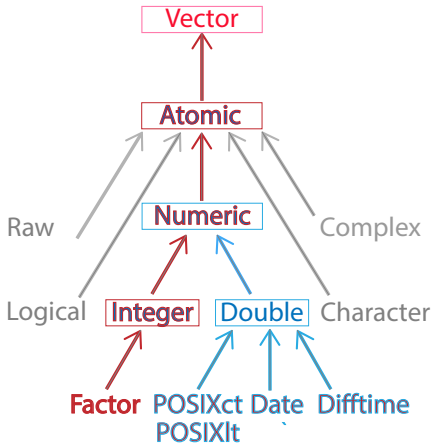


S3 atomic vectors : factors

- a `factor` is a vector that contains only predefined values
- it is used to store categorical data

```
x <- factor(c("a", "b", "b", "c"))
str(x)
# Factor w/ 3 levels "a","b","c": 1 2 2 3

typeof(x)
# [1] "integer"
attributes(x)
# $levels
# [1] "a" "b" "c"
#
# $class
# [1] "factor"
```



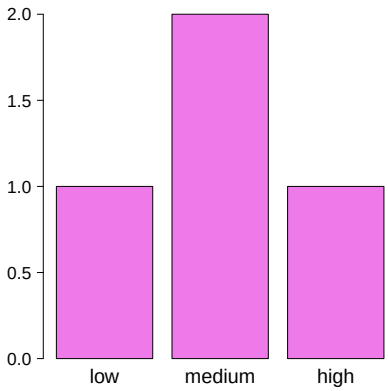

```
coord <- factor(c("Est", "West", "Est", "North"),
                levels = c("North", "Est", "South", "West")) ; coord
# [1] Est   West  Est   North
# Levels: North Est South West

table(coord)
# coord
# North   Est South  West
#     1     2     0     1
```


S3 atomic vectors : ordered factors

- they behave like factors, but the order of the levels is meaningful

```
grade <- ordered(c("high", "low", "medium",
                   "medium"),
           levels = c("low","medium","high"))
str(grade)
# Ord.factor w/ 3 levels
#                "low"<"medium"<..: 3 1 2 2
summary(grade)
#    low medium   high
#      1      2      1
barplot(table(grade), color="orchid2")
```



Note

- in base R factors are encountered very frequently:
- many base R functions (`read.csv()`, `data.frame()`) automatically convert character vectors to factors
- to suppress this behavior use `stringsAsFactors = FALSE`
- factors are built on top of integers, be careful when treating them like strings

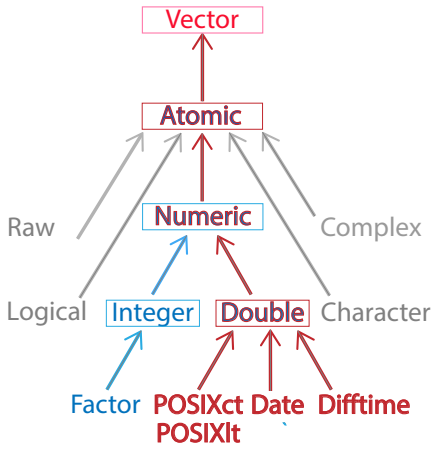
S3 atomic vectors : Dates

Date vectors are built on top of double vectors

```
today <- Sys.Date()  ;  today
# [1] "2020-03-15"
typeof(today)
# [1] "double"
class(today)
# [1] "Date"

yesterday <- as.Date("2020-03-14")
yesterday
# [1] "2020-03-14"

delta <- today - yesterday  ;  delta
# Time difference of 1 days
class(delta)
# [1] "difftime"
```



they are represented as number of days since 1970/01/01

```
days_since_1970_01_01 <- unclass(today)
days_since_1970_01_01
# [1] 18336
class(days_since_1970_01_01)
# numeric
```


S3 atomic vectors : Date-times

- baseR provides two ways of storing date-time information:

- POSIXct

  ct = calendar time (the time_t type in C)

- POSIXlt

  lt = local time (the struct tm type in C)

* POSIXct vectors are built on top of double vectors, and time is represented as seconds since 1970/01/01

```
now_ct <- as.POSIXct(Sys.time(), tzone="CET")
now_ct
# [1] "2022-03-15 14:22:41 UTC"

r20bday_ct <- as.POSIXct("2022-02-29 12:00", tzone= "CET")
now_ct - r20bday_ct
# Time difference of 15.14075 days
```

* the tzone attribute controls only how date-time is formatted, not how it is represented

```
structure(now_ct, tzone="Europe/Rome")
# [1] "2022-03-15 15:30:53 CET"
structure(now_ct, tzone="Europe/Moscow")
# [1] "2022-03-15 17:30:53 MSK"
structure(now_ct, tzone="Asia/Chongqing")
# [1] "2022-03-15 22:30:53 CST"
```

Time duration

- durations represent the time difference between two pair of dates or date-times
- they are stored in `difftimes`
- this S3 class has a `unit` attribute that determines how the difference should be interpreted

```
one_week <- as.difftime(1, units="weeks")
attributes(one_week)
# $class
# [1] "difftime"
#
# $units
# [1] "weeks"

today <- Sys.time()
next_sunday <- today + one_week

structure(next_sunday, tzone="Europe/Rome")
# [1] "2022-03-22 16:04:58 CET"

fourty_min <- as.difftime(40, units="mins")
later <- today + fourty_min
later
# [1] "2022-03-15 15:44:58 UTC"
```


`unique` and `duplicated` for vectors

- with the function `table()` we can inspect how many times each name appears
- the function `unique()` extracts the unique values in a vector, in the order in which the values are encountered in the vector

```
names <- c("John", "John", "Jim", "Anna", "Beatrix", "Anna")
table(names)
# names
#    Anna Beatrix     Jim    John
#       2       1       1       2

unique(names)
# [1] "John"    "Jim"     "Anna"    "Beatrix"
```

- the function `duplicated` creates a vector of logical values which is TRUE if that name has already appeared in the vector

```
duplicated(names)
# [1] FALSE  TRUE FALSE FALSE FALSE  TRUE

names[!duplicated(names)]
# [1] "John"    "Jim"     "Anna"    "Beatrix"
```

Operating on sets: union, intersect and setdiff

- given two sets, the union() function gives a set with all elements, but counting only once those common to both sets

```
setA <- c ("a", "b", "c", "d", "e")
setB <- c ("d", "e", "f", "g")

union(setA,setB)
# [1] "a" "b" "c" "d" "e" "f" "g"
```

- intersection() gives ony the elements they have in common

```
intersect(setA, setB)
# [1] "d" "e"
```

- the difference between the two sets is order-dependent

```
setdiff(setA, setB)
# [1] "a" "b" "c"
setdiff(setB, setA)
# [1] "f" "g"

setequal(setA, setA) # compare if the sets are equal
# [1] TRUE
setequal(setA, setB)
# [1] FALSE

setA %in% setB
# [1] FALSE FALSE FALSE  TRUE  TRUE
setA[setA %in% setB]   # equal to intersect(setA, setB)
# [1] "d" "e"
```