4 Data structures in R

(AST230) R for Data Science

Md Rasel Biswas

Data in R

- Until now, you've created fairly simple data in R and stored it as a vector.
- However, most (if not all) of you will have much more complicated datasets from your various experiments and surveys that go well beyond what a vector can handle.
- In previous lectures we've gone through the main four data types (i.e vector types) in R, i.e. logical, integer, double, character
- Now let's have a look at some of main structures that we have for storing these data.

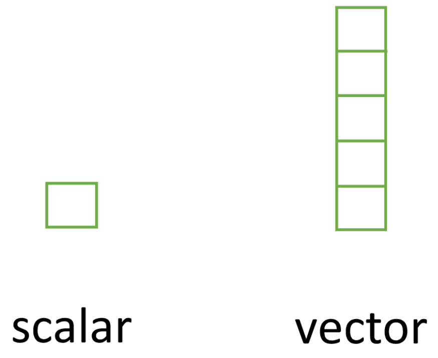
Data Structures

- R has many data structures, some of the important ones are:

1. Atomic vectors
2. Matrices
3. Arrays
4. Factors
5. Lists
6. Data frames
7. Tibbles

1 Atomic Vectors

- Perhaps the simplest type of data structure is the vector
- You've already been introduced to vectors
- Vectors that have a single value (length 1) are called scalars
- key thing to remember is that all the elements inside a vector must be of the same data type



2 Matrices

- When a rectangular data structure contains a single type of data in all its cells (i.e., in all its rows and columns), we have a matrix of data.
- In R, a matrix really is an atomic vector that is tweaked into another shape (i.e., a re-shaped vector).
- Internally, this is implemented by taking a vector and adding attributes that describe its shape and the names of its rows or columns

2 Matrices

- R function `matrix()` is used to create a matrix from a atomic vector.

```
# creating matrix using matrix()
A = matrix(
  c(1, 2, 3, 4, 5, 6, 7, 8, 9),
  nrow = 3,
  ncol = 3,
  byrow = TRUE
)
A
```

```
     [,1] [,2] [,3]
[1,]    1    2    3
[2,]    4    5    6
[3,]    7    8    9
```

2 Matrices

```r
matrix(1:6, nrow = 2) # default: byrow = FALSE
```

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

```r
# Creating matrix using rbind() or cbind()
rbind(1:3, 11:13, 33:35)
```

```
     [,1] [,2] [,3]
[1,]    1    2    3
[2,]   11   12   13
[3,]   33   34   35
```

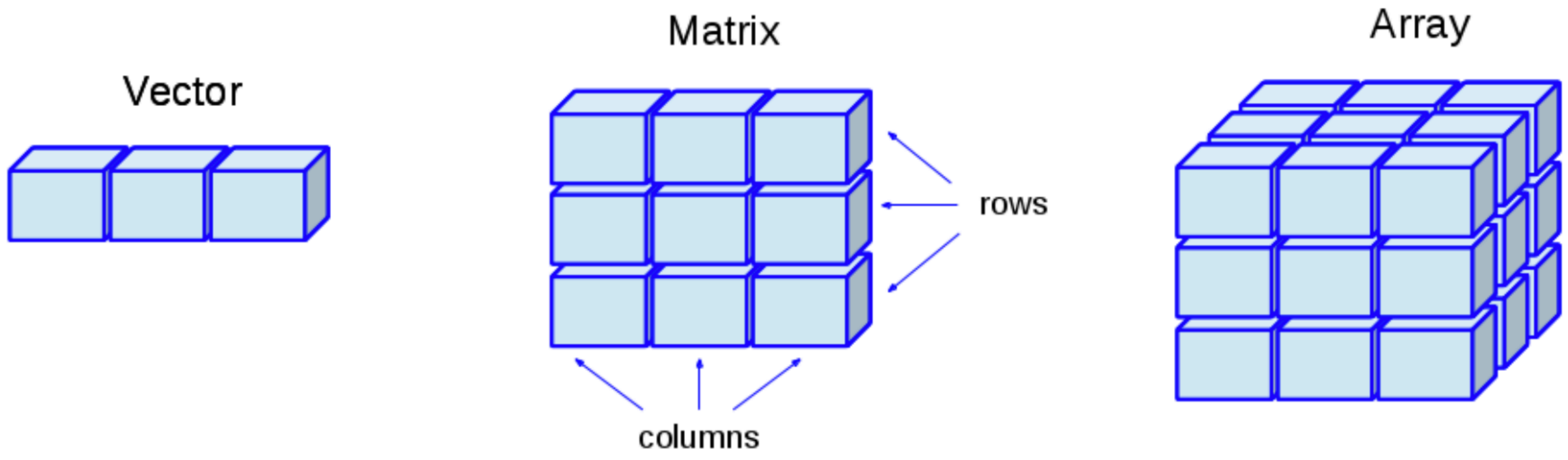
```r
cbind(letters[1:2], c("k", "m"), letters[18:19])
```

```
     [,1] [,2] [,3]
[1,] "a"  "k"  "r"
[2,] "b"  "m"  "s"
```

2 Matrices

```r
# Creating matrix by adding dim attribute
z <- 1:6
dim(z) <- c(2, 3)
z
```

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



3 Arrays

- Arrays are just multidimensional matrices

```
# Creating array using array()
A = array(c(1, 2, 3, 4, 5, 6, 7, 8), dim = c(2, 2, 2))
A
```

```
, , 1

     [,1] [,2]
[1,]    1    3
[2,]    2    4

, , 2

     [,1] [,2]
[1,]    5    7
[2,]    6    8
```

3 Arrays

```r
# Creating array by adding dim attribute
z <- 1:18
dim(z) <- c(2, 3, 3)
z
```

```
, , 1

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

, , 2

     [,1] [,2] [,3]
[1,]    7    9   11
[2,]    8   10   12

, , 3

     [,1] [,2] [,3]
[1,]   13   15   17
[2,]   14   16   18
```

3 Arrays

Summary:

- Like vectors and matrices, arrays must contain elements all of the same data types.
- Data structures like matrices, or arrays are built on top of atomic vectors by adding attributes
- In other words, matrices and arrays are just atomic vectors with a `dim()` (dimension) attribute

Calculations on matrices

- Sometimes it's also useful to define row and column names for your matrix

```
my_mat <- matrix(1:16, nrow = 4, byrow = TRUE)
rownames(my_mat) <- c("A", "B", "C", "D")
colnames(my_mat) <- c("a", "b", "c", "d")
my_mat
```

```
   a  b  c  d
A  1  2  3  4
B  5  6  7  8
C  9 10 11 12
D 13 14 15 16
```

Calculations on matrices

- The usual matrix addition, multiplication etc can be performed. Note the use of the `%*%` operator to perform matrix multiplication.

```r
mat1 <- matrix(c(2, 0, 1, 1), nrow = 2)
mat1
```

```
     [,1] [,2]
[1,]    2    1
[2,]    0    1
```

```r
mat2 <- matrix(c(1, 1, 0, 2), nrow = 2)
mat2
```

```
     [,1] [,2]
[1,]    1    0
[2,]    1    2
```

```r
mat1 + mat2  # matrix addition
```

```
     [,1] [,2]
[1,]    3    1
[2,]    1    3
```

```r
# element by element products
mat1 * mat2
```

```
     [,1] [,2]
[1,]    2    0
[2,]    0    2
```

```r
# matrix multiplication
mat1 %*% mat2
```

```
     [,1] [,2]
[1,]    3    2
[2,]    1    2
```

Basic martrix functions

- R has numerous built in functions to perform matrix operations
- For example, to transpose a matrix we use the transposition function `t()`

```
my_mat_t <- t(my_mat)
my_mat_t
```

```
  A B  C  D
a 1 5  9 13
b 2 6 10 14
c 3 7 11 15
d 4 8 12 16
```

- To extract the diagonal elements of a matrix and store them as a vector we can use the `diag()` function.

```
my_mat_diag <- diag(my_mat)
my_mat_diag
```

```
[1]  1  6 11 16
```

Basic martrix functions

Functions	Description
`chol(x)`	Choleski decomposition
`t(x)`	Transpose of a matrix x.
`diag(x)`	Extracts the diagonal elements of a matrix
`ncol(x)`	Returns the number of columns
`nrow(x)`	Returns the number of rows
`colSums(x)`	Returns the sum of columns
`rowSums(x)`	Returns the sum of rows
`solve(A,b)`	Solve the system $Ax = b$
`solve(x)`	Calculate the inverse

Exercise 4

1. Create a vector called `x` consisting of the first fifteen integers of the number line.
2. Use the function `dim()` to assign dimension to vector `x` with three rows and five columns. What is the class of `x` now?
3. Given the following matrices,

$$A = \begin{bmatrix} 2 & 9 & 0 & 0 \\ 0 & 4 & 1 & 4 \\ 7 & 5 & 5 & 1 \\ 7 & 8 & 7 & 4 \end{bmatrix} \qquad b = \begin{bmatrix} -1 \\ 6 \\ 0 \\ 9 \end{bmatrix}$$

i. Calculate $A^T b$.

ii. Find the inverse of matrix A.

iii. Solve the equation for x, where $Ax = b$.

Exercise 4

4.

i. Generate a vector `x0` of order 20 with all elements as 1

ii. Generate a vector `x1` of order 20 with elements randomly selected from 30:70, consider a seed 80

iii. Create a matrix `X` with the first column `x0` and the second column `x1`

iv. Generate a vector `Y` of order 20 using the equation $y_i = 1.2 + 1.8x1 + \epsilon_i$, where $\epsilon_i \sim N(0, 9)$

v. Obtain the value of $(X'X)^{-1}X'Y$, use the R function `solve()` to obtain an inverse of a square matrix.

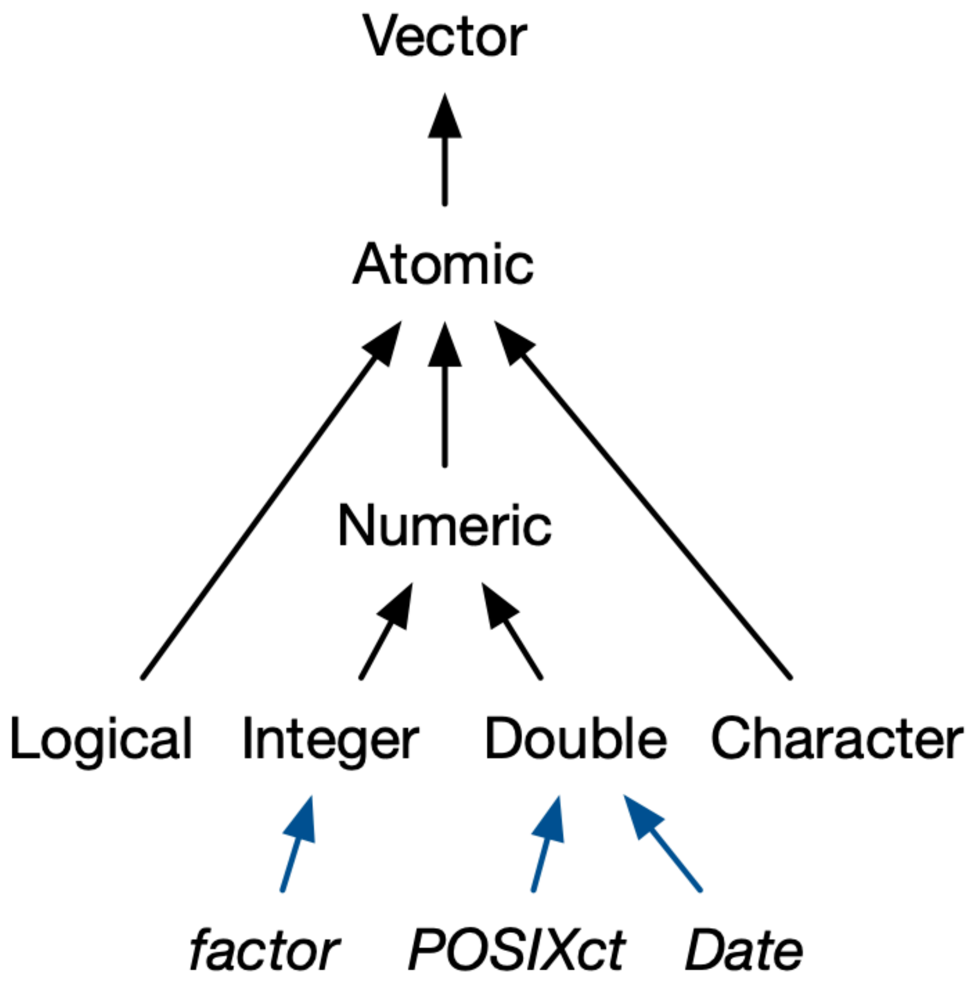
S3 Atomic Vectors:

- Remember: matrices, arrays are just atomic vectors that are reshaped
- In addition to these regular atomic vectors, there are some S3 atomic vectors
- One of the most important vector attributes is `class`, which underlies the S3 object system
- A class attribute turns an object into an S3 object, which means it will behave differently from a regular vector when passed to a generic function
- Every S3 object is built on top of a base type, and often stores additional information in other attributes

S3 Atomic Vectors:

- Some important S3 vectors used in base R are
  - Categorical data recorded in `factor` vector
  - Dates are stored in `Date` vector
  - Date-times are stored in `POSIXct` and `POSIXlt` vectors
- Among these, we will discuss only the `factor` vector.

S3 Atomic Vectors:



4 Factors

- Factors are used to store categorical information in R, a categorical variable has only pre-defined levels, e.g., gender has two levels `male` and `female`
- Factors are similar to `character` data except it can take only predefined values
- Factors are built on top of an integer vector with two attributes:
- a class, “factor”, which makes it behave differently from regular integer vectors, and
- levels, which defines the set of allowed value

Factors look like strings, but behave like integers

4 Factors

- The function `factor()` is used to create factor vector from an atomic vector and it has the following arguments
- `x` → data vector
- `levels` → values of `x` that will be used as the level of the factor
- `labels` → a vector of labels for the levels

```
# Creating factor using factor()
fac = factor(x = c(1, 2, 1, 1, 2, 1, 2),
               levels = c(1, 2),
               labels = c("Male", "Female"))
fac
```

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

```
as.character(fac)
```

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

4 Factors

```r
# not providing levels
fac1 = factor(c("Male", "Female", "Male",
                "Male", "Female", "Male", "Female"))
fac1
```

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

```r
# providing levels
fac2 = factor(c("Male", "Female", "Male",
                "Male", "Female", "Male", "Female"),
              levels = c("Male", "Female"))
fac2
```

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

```r
typeof(fac1)
```

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

```r
attributes(fac1)
```

```
$levels
[1] "Female" "Male"

$class
[1] "factor"
```

5 Lists

- List is a vector with heterogeneous elements, i.e., each element of a list can be any type
- The function `list()` is used to create a list

```
list1 <- list(1:3,
              "a",
              c(TRUE, FALSE, FALSE),
              c(2.5, 5.1, 9))
list1
```

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

[[2]]
[1] "a"

[[3]]
[1]  TRUE FALSE FALSE

[[4]]
[1] 2.5 5.1 9.0
```

5 Lists

```r
typeof(list1)
```

```
[1] "list"
```

```r
is.list(list1)
```

```
[1] TRUE
```

```r
length(list1)
```

```
[1] 4
```

```r
str(list1)
```

```
List of 4
 $ : int [1:3] 1 2 3
 $ : chr "a"
 $ : logi [1:3] TRUE FALSE FALSE
 $ : num [1:3] 2.5 5.1 9
```

5 Lists

- Lists are sometimes called **recursive** vectors because a list can contain other lists. This makes them fundamentally different from atomic vectors

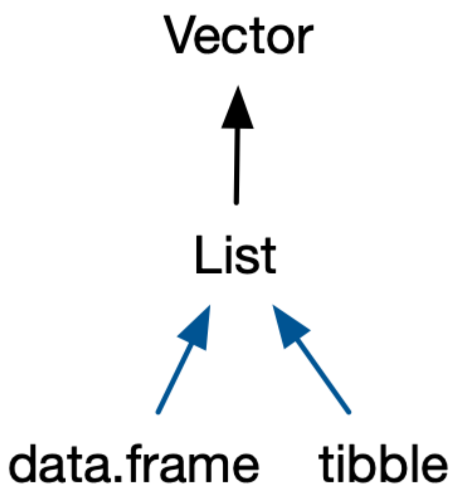
```
l3 <- list(list(list("First list")))
str(l3)
```

```
List of 1
 $ :List of 1
  ..$ :List of 1
  .. ..$ : chr "First list"
```

- List

S3 Lists:

- **Recall:** Data structures like matrices, arrays, or factors are built on top of atomic vectors by adding attributes.
- Similarly, in addition to the regular lists, there are two important S3 vectors built on top of lists
  - They are are data frames and tibbles.



6 Data Frames

- A data frame is a named list of vectors with attributes for (column) `names`, `row.names`, and its `class`, "data.frame"
- In contrast to a regular list, a data frame has an additional constraint:
  - **the length of each of its vectors must be the same**
- This gives data frames their rectangular structure
- Columns are variables, and rows are observations
- Data frame is R's equivalent to spreadsheet
- If you do data analysis in R, you're going to be using data frames

6 Data Frames

- R function `data.frame()` is used to create a new data frame, where atomic vectors can be used as inputs

```
# Creating a data frame
name = c("Fahim", "Abir", "Aman")
language = c("R", "Python", "Java")
age = c(22, 25, 45)
df = data.frame(name, language, age)
df
```

```
   name language age
1 Fahim        R  22
2  Abir   Python  25
3  Aman     Java  45
```

```
typeof(df)
```

```
[1] "list"
```

```
attributes(df)
```

```
$names
[1] "name"     "language" "age"

$class
[1] "data.frame"
```

6 Data Frames

- While the attributes of data frame and matrix are different, a matrix can be transformed into a data frame using the function `as.data.frame()`

```
mat1 <- matrix(1:12, nrow = 3)
attributes(mat1)
```

```
$dim
[1] 3 4
```

```
mat2 <- as.data.frame(mat1)
```

```
attributes(mat2)
```

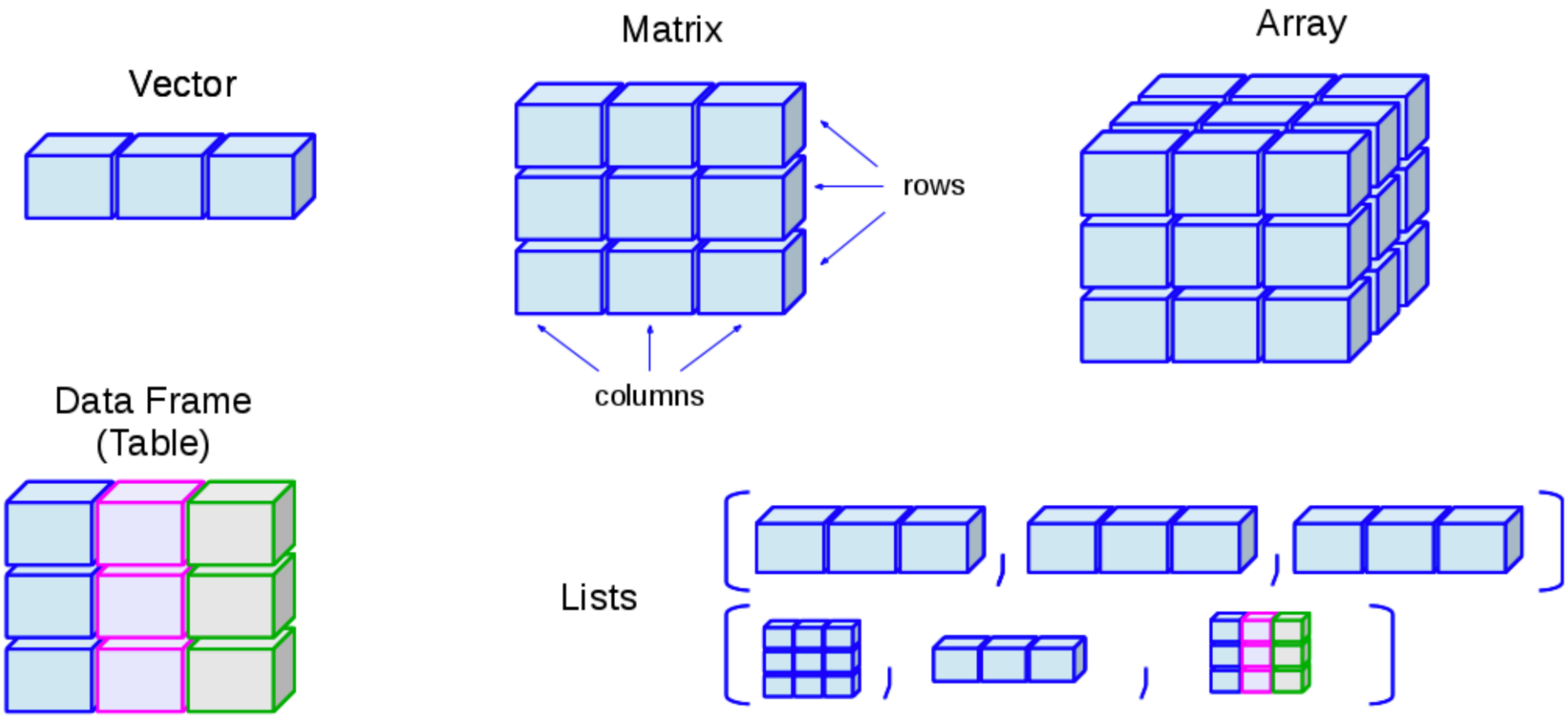
```
$names
[1] "V1" "V2" "V3" "V4"

$class
[1] "data.frame"

$row.names
[1] 1 2 3
```

6 Data Frames

There are various ways to inspect a data frame, such as:

- `str()` gives a very brief description of the data
- `names()` gives the name of each variable in the data
- `summary()` gives some very basic summary statistics for each variable
- `head()` shows the first few rows
- `tail()` shows the last few rows

6 Data Frames



7 Tibbles

- Data frame is one of the most important ideas in R and it is one of the things that make R different from other programming languages
- Data frames are created more than 20 years ago and over the years, the way people use R have changed
- Some of the design decisions of data frame do not go well with current way of using R
- Tibbles are similar to data frames and it overcome some of limitations of data frames

7 Tibbles

- Tibbles are not the part of the base R, it is in the R package `tibble`
- To use tibble, one need to load the package `tibble` to the current R environment

```
# Load the tibble package
library(tibble)
# Create a tibble with three columns: name, age, and city
my_data <- tibble(
  name = c("Samir", "Amir", "Aman"),
  age = c(25, 30, 35),
  city = c("Dhaka", "Khulna", "Jashore")
)
my_data
```

```
# A tibble: 3 × 3
  name    age city
  <chr> <dbl> <chr>
1 Samir    25 Dhaka
2 Amir     30 Khulna
3 Aman     35 Jashore
```

Data frame vs. Tibble

Data frame

```r
df2 <- data.frame(
  x = 1:3,
  y = LETTERS[1:3],
  z = c(2, 4, 6)
)
df2
```

```
  x y z
1 1 A 2
2 2 B 4
3 3 C 6
```

```r
typeof(df2)
```

```
[1] "list"
```

Tibble

```r
tb2 <- tibble(
  x = 1:3,
  y = LETTERS[1:3],
  z = x * 2
)
tb2
```

```
# A tibble: 3 × 3
      x y         z
  <int> <chr> <dbl>
1     1 A         2
2     2 B         4
3     3 C         6
```

```r
typeof(tb2)
```

```
[1] "list"
```

Data frame vs. Tibble

Data frame

```r
attributes(df2)
```

```
$names
[1] "x" "y" "z"

$class
[1] "data.frame"

$row.names
[1] 1 2 3
```

```r
str(df2)
```

```
'data.frame':	3 obs. of  3 variables:
 $ x: int  1 2 3
 $ y: chr  "A" "B" "C"
 $ z: num  2 4 6
```

Tibble

```r
attributes(tb2)
```

```
$class
[1] "tbl_df"     "tbl"        "data.frame"

$row.names
[1] 1 2 3

$names
[1] "x" "y" "z"
```

```r
str(tb2)
```

```
tibble [3 × 3] (S3: tbl_df/tbl/data.frame)
 $ x: int [1:3] 1 2 3
 $ y: chr [1:3] "A" "B" "C"
 $ z: num [1:3] 2 4 6
```

Data frame vs. Tibble

- While data frames automatically recycle columns that are an integer multiple of the longest column, tibbles will only recycle vectors of length one

Data frame

```r
data.frame(x = 1:4, y = 1:2)
```

```
  x y
1 1 1
2 2 2
3 3 1
4 4 2
```

```r
data.frame(x = 1:4, y = 1:3)
```

```
Error in data.frame(x = 1:4, y = 1:3): arguments
imply differing number of rows: 4, 3
```

Tibble

```r
tibble(x = 1:4, y = 1:2)
```

```
Error in `tibble()`:
! Tibble columns must have compatible sizes.
• Size 4: Existing data.
• Size 2: Column `y`.
ℹ Only values of size one are recycled.
```

```r
tibble(x = 1:4, y = 1)
```

```
# A tibble: 4 × 2
      x     y
  <int> <dbl>
1     1     1
2     2     1
3     3     1
4     4     1
```

Data frame vs. Tibble

- A data frame `mtcars` is available in base R

```r
head(mtcars, 2)
```

```
              mpg cyl disp  hp drat    wt  qsec vs am gear carb
Mazda RX4      21   6  160 110  3.9 2.620 16.46  0  1    4    4
Mazda RX4 Wag  21   6  160 110  3.9 2.875 17.02  0  1    4    4
```

```r
mtcars_t <- as_tibble(mtcars)
mtcars_t
```

```
# A tibble: 32 × 11
     mpg   cyl  disp    hp  drat    wt  qsec    vs    am  gear  carb
   <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
 1  21       6  160    110  3.9   2.62  16.5     0     1     4     4
 2  21       6  160    110  3.9   2.88  17.0     0     1     4     4
 3  22.8     4  108     93  3.85  2.32  18.6     1     1     4     1
 4  21.4     6  258    110  3.08  3.22  19.4     1     0     3     1
 5  18.7     8  360    175  3.15  3.44  17.0     0     0     3     2
 6  18.1     6  225    105  2.76  3.46  20.2     1     0     3     1
 7  14.3     8  360    245  3.21  3.57  15.8     0     0     3     4
 8  24.4     4  147.    62  3.69  3.19  20       1     0     4     2
 9  22.8     4  141.    95  3.92  3.15  22.9     1     0     4     2
10  19.2     6  168.   123  3.92  3.44  18.3     1     0     4     4
# ℹ 22 more rows
```