Lecture 4: Data Structures I: Vectors and Factors

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BSDS 100 - Intro to Data Science with R

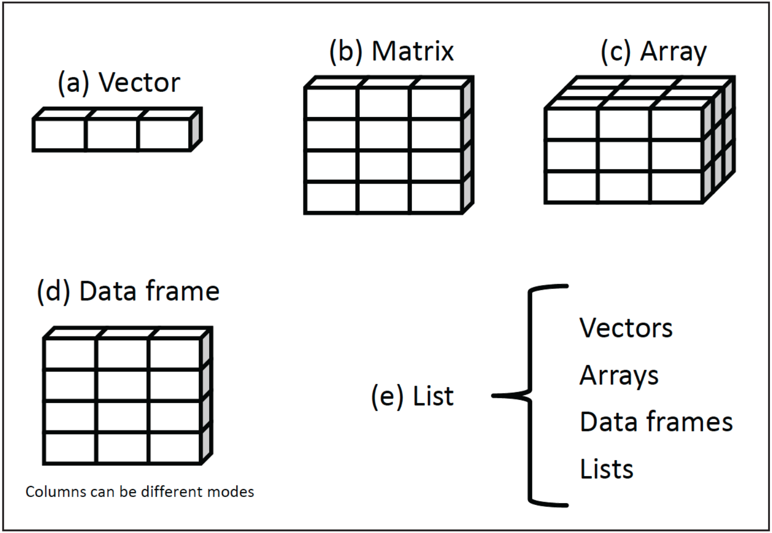
Outline

- Vectors
- Factors

Data Structures

- A **data structure** is a format or organization of data in software that enables efficient use.
- Every programming language has its own types of data structures
- In `R`, you can create your own type of data structure; however, there are some that are automatically recognized by the software.
- **Examples**: list, array, data.frame, vector, matrix, string

Data Structures



Data Structures & Dimensionality

Dimension	Homogeneous	Heterogeneous
1	Atomic Vector	List
2	Matrix	Data Frame
n	Array	

Homogeneous: All contents must be of the same type

Heterogeneous: Contents can be of different types

Note: There are no 0-dimensional (scalar) types in R, only vectors of length one

Part I: Vectors

Vectors

- The basic data structure in `R` is the vector
- There two types of vectors: atomic vectors and lists

Properties of Vectors

- Type (`typeof()`)
- Length (`length()`)
- Attributes (`attributes()`)

Use `is.atomic()` or `is.list()` to determine if an object is a vector, **not** `is.vector()`

Atomic Vectors

Four Common Types of Vectors

- Logical
- Integer
- Double (numeric)
- Character

```
> doubleAtomicVector <- c(1, 3.14, 99.999)

# use L prefix to get integers instead of doubles
> integerAtomicVector <- c(1L, 3L, 19L)

> logicalAtomicVector <- c(TRUE, FALSE, T, F)

> characterAtomicVector <- c("this", "is a", "string")
```

Example: Try This

1. Create the vector `myFavNum` of you favorite fractional number
2. Create the vector `myNums` of your seven favorite numbers
3. Create the vector `firstNames` of the first names of two people next to you
4. Create the vector `myVec` of the last name and age of someone you know

Example: Answer these

1. Guess and then check what types your vectors are.
2. Check the length of each vector.
3. Did you write the code in the console window or the editor?
4. How do you execute a line of code in the editor?
5. How do you execute multiple lines of code simultaneously in the editor?
6. Did you leverage the `TAB` button for auto-completion?

Accessing Elements of a Vector

- To access the individual elements of a vector

```
> (myAtomicVector <- c(1, 2, 3, 4, -99, 5, NA, 4, 22.223))
[1]   1.000   2.000   3.000   4.000 -99.000   5.000      NA
[8]   4.000  22.223

#look at fifth element of the vector
> myAtomicVector[5]
[1] -99

> myAtomicVector[c(1, 2, 5, 9)]
[1]   1.000   2.000 -99.000  22.223

> myAtomicVector[10]
[1] NA

#look at the third through eigth elements of the vector
> myAtomicVector[3:8]
[1]   3   4 -99   5  NA   4
```

Accessing Elements of a Vector

- To look at the first and last 6 elements of a vector

```
> (myAtomicVector <- c(1, 2, 3, 4, -99, 5, NA, 4, 22.223))
[1]   1.000   2.000   3.000   4.000 -99.000   5.000      NA
[8]   4.000  22.223

#look at the first and last six elements of the vector
> head(myAtomicVector)
[1] 1.000   2.000   3.000   4.000 -99.000   5.000

> tail(myAtomicVector)
[1] 4.000 -99.000   5.000     NA   4.000  22.223
```

Example, continued

1. Add `myFavNum` to the seventh entry of `myNums` and store the result in a variable named `myFirstAddition`
2. Add `myFavNum` to each of the seven entries of `myNums` and store the result in a variable named `mySecondAddition`
3. Add `myFavNum` to **all** of the values in `myNums` and store the result in a variable named `myFirstSum`
4. Add `myFavNum` to the smallest number in `myNums` and store the result in a variable named `thisIsGettingMoreComplex`
5. Add the second entry of `myNums` to the age of the person you select for `myVec` and store the result in a variable named `whatTypeOfVectorIsThis`
   - Does what we did make sense? Did it work? Why?

Solution

```
# preamble
myFavNum <- 3.1415
myNums <- c(1, 3, 55, 33, 86, -sqrt(2), -110)
# also works myNums <- 1:7
firstNames <- c("Jeff", "Terence", "David")
myVec <- c("Parr", 99)
```

1. `myFirstAddition <- myFavNum + myNums[7]`
2. `mySecondAddition <- myFavNum + myNums`
3. `myFirstSum <- myFavNum + sum(myNums)`
4. `thisIsGettingMoreComplex <- myFavNum + min(myNums)`
5. `whatTypeOfVectorIsThis <- sum(c(myNums[2], myVec[2]))`

   ```
   Error in sum(c(myNums[2], myVec[2])) :
     invalid 'type' (character) of argument
   ```

Missing Values

Missing values are specified with `NA`, a logical vector of length one.

- `NA` will always be coerced to the correct type if used inside `c()`

```
> c(1, 2, 3, NA)
[1]  1  2  3 NA

> x <- c(1, 2, 3, NA)

> typeof(x)
[1] "double"
```

```
> x[1]
[1] 1

> x[4]
[1] NA

> typeof(x[4])
[1] "double"
```

Argument `na.rm = TRUE`

- Certain functions will fail when applied to vectors with an `NA`

```
> myAtomicVector_01 <- c(99.1, 98.2, 97.3, 96.4, NA)
[1] 99.1 98.2 97.3 96.4   NA

> sum(myAtomicVector_01)
[1] NA

> mean(myAtomicVector_01)
[1] NA
```

Argument `na.rm = TRUE`

- You can avoid this by providing the argument `na.rm = TRUE`

```
> sum(myAtomicVector_01, na.rm = TRUE)
[1] 391

> mean(myAtomicVector_01, na.rm = TRUE)
[1] 97.75
```

Types & Tests

To check the type of a vector, use `typeof()`, or more specifically

- `is.character()`
- `is.double()`
- `is.integer()`
- `is.logical()`
- `is.na()`

Coercion

Coercion is a great feature in `R` which can make coding easy, but may also have unintended consequences.

- All elements in an atomic vector must be the same type
- If you attempt to combine different types in an atomic vector they will be coerced to the most flexible type
- **Most to least flexible types** $\downarrow$
  - character
  - double
  - integer
  - logical

- When a logical vector is coerced to numeric (double or integer), TRUE = 1 and FALSE = 0

```
> x <- c("abc", 123)

> typeof(x)
[1] "character"
```

You can explicitly coerce using `as.character()`, `as.double()`, `as.integer()`, and `as.logical()`

A Brief Digression: `str()`

- A quick way to figure out what data structure an object is composed of is to use `str()`, which is short for structure
- `str()` provides a concise description for any `R` data structure

Conditionally Subsetting Atomic Vectors

- The syntax is awkward and takes some time to get used to
- Once you understand the sequence of events in conditional subsetting, it will feel more natural
- Try to figure out what is happening in the following example:

```
> (myAtomicVector_01 <- c(99.1, 98.2, 97.3, 96.4))
[1] 99.1 98.2 97.3 96.4

> myAtomicVector_01[myAtomicVector_01 > 98]
[1] 99.1 98.2
```

What is actually happening in the last slide:

1. The `myAtomicVector_01 > 98` part of the statement tests each element of the vector to see whether it is > 98 and returns a `LOGICAL` value for each test which, in this case, returns the logical vector (`T T F F`)

2. The vector (`T T F F`) is passed to `myAtomicVector_01`, which returns the first two elements and omits the final two
   - An equivalent statement would be `myAtomicVector_01[c(T, T, F, F)]`

Handy vector functions

Function	Action
`seq(from, to, by)`	Creates a vector of numbers from from to to in increments of by
`rep(x, times)`	Creates a vector that repeats the values in x exactly times number of times
`x +(-, /, *) y`	For x and y of the *same length*, calculates a vector of the same length where each entry is the **entry-wise** summation (subtraction, division, or product) of x and y

Handy tricks

- If you would like to create a vector that is a sequence of numbers from x to y that increase by exactly one, then you can simply write

```
x:y
```

- rep() can be applied to a seq(), providing a flexible means to create sequences with repeating patterns.

  Example:

```
> rep(seq(1, 1.3, .1), 2)
[1] 1.0 1.1 1.2 1.3 1.0 1.1 1.2 1.3
```

Example

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

> y <- seq(from = .5, to = 3, by = .5)

> x
[1] 1 2 1 2 1 2

> y
[1] 0.5 1.0 1.5 2.0 2.5 3.0

> x+y
[1] 1.5 3.0 2.5 4.0 3.5 5.0

> x/y
[1] 2.0000000 2.0000000 0.6666667 1.0000000 0.4000000 0.6666667
```

A List of Logical Operators

Operator	Description
`<`	Less than
`<=`	Less than or equal to
`>`	Greater than
`>=`	Greater than or equal to
`==`	Exactly equal to
`!=`	Not equal to
`!`x	Not x
$x \mid y$	x or y
x `&` y	x and y
`isTRUE(`x`)`	Test if x is `TRUE`

Part II: Factors

Names

- A name is a vector attribute

```
> x <- c(1, 2, 3)
> names(x)
NULL

> x <- c(1, 2, 3); names(x) <- c("a", "b", "c")
> names(x)
[1] "a" "b" "c"

> x <- c(a = 1, b = 2, c = 3)
> names(x)
[1] "a" "b" "c"

> x <- c(a = 1, b = 2, 3)
> names(x)
[1] "a" "b" ""
```

Factors

- A factor is a vector of elements from a discrete set, and is used to store categorical (ordinal or nominal) data
- Factors are built on top of integer vectors using two attributes:
    1. The `class()` ‘factor’: makes them behave differently from regular integer vectors
    2. The `levels()`: define the discrete set of permissible values

Factors

```
> x <- factor(c("M","F","F","M"))

> x
[1] M F F M
Levels: F M

> class(x)
[1] "factor"

> typeof(x)
[1] "integer"
```

Nominal Factors

- Although we (intelligent humans) have an inherent ability to understand the ordering of the ordinal categories below, `R` does not, and unless told, will treat them as nominal categorical variables
- Nominal (unordered) factors are sorted automatically by `R`, e.g., alphabetically, numerically, etc.
- **Note:** The terms *ordered* and *sorted* are **not** synonymous here

Nominal Factors [EXAMPLE]

```
> bodyType <- factor(c("healthy", "healthy", "healthy", "obese", ...
"overweight", "overweight", "skinny"))
> bodyType
[1] healthy    healthy    healthy    obese    overweight overweight skinny
Levels: healthy obese overweight skinny

> levels(bodyType)
[1] "healthy"    "obese"      "overweight" "skinny"

> str(bodyType)
 Factor w/ 4 levels "healthy","obese",..: 1 1 1 2 3 3 4

> bodyType  < "obese"
[1] NA NA NA NA NA NA NA
Warning message:
In Ops.factor(bodyType, "obese") : < not meaningful for factors
```

Nominal Factors Notes

As seen in the previous example,

- Even though nominal factors are ordered due to the underlying integer mapping, logical comparisons based on levels fail
- Nominal factors *can* be filtered if we access the underlying integer mapping, but weird results may arise

Ordinal Factors

- We can create ordinal factors by including the option `ordered = TRUE`
- By creating an ordinal set of factors, we are telling `R` to explicitly use the ordering we are providing
- Let's examine a messier version of `bodyType`, where instead of the body type being explicit (e.g., "`obese`"), the body types are coded for brevity

```
(bodyType <- factor(c("h", "h", "h", "ob", "ov", "ov", "s"),
                    levels = c("s", "h", "ov", "ob"),
                    labels = c("Skinny", "Healthy", "Overweight", "Obese")
                    ordered = TRUE))
```

Ordinal Factors

Let's examine exactly what is being executed

1. `c("h", "h", "h", "ob", "ov", "ov", "s")` is what we want to classify as a factor
2. `levels = c("s", "h", "ov", "ob")` provides the levels
   - Omitting this enables `R` to order the levels itself
3. `labels = c("Skinny", "Healthy", "Overweight", "Obese")` are the *nice* labels we want to see instead of the more obscurely-coded factors
   - `labels` are mapped directly to `levels`
4. `ordered = TRUE` instructs `R` to order the factors according to `levels`

Ordinal Factors [EXAMPLE]

```
(bodyType <- factor(c("h", "h", "h", "ob", "ov", "ov", "s"),
                    levels = c("s", "h", "ov", "ob"),
                    labels = c("Skinny", "Healthy", "Overweight", "Obese")
                    ordered = TRUE))
> levels(bodyType)
[1] "Skinny"     "Healthy"     "Overweight" "Obese"

> str(bodyType)
 Ord.factor w/ 4 levels "Skinny"<"Healthy"<..: 2 2 2 4 3 3 1

> bodyType  < "Obese"
[1]  TRUE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE

> bodyType[bodyType  < "Obese"]
[1] Healthy    Healthy    Healthy    Overweight Overweight Skinny
Levels: Skinny < Healthy < Overweight < Obese
```

Example: Try This

Use the following code to create the variable `myCyl` using the dataset `mtcars`

```
myCyl <- mtcars$cyl
```

1. Create an ordered factor from `myCyl`, mapping the levels to ‘Small’, ‘Medium’ and ‘Large’
2. How many observations have cylinders <= ‘Medium’?

Assignment 4

- Complete the Computational Assignment here.

Due: Next Tuesday at the beginning of class.