Data Structures I: Vectors, Matrices, and Arrays

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BSDS 100 - Intro to Data Science with R

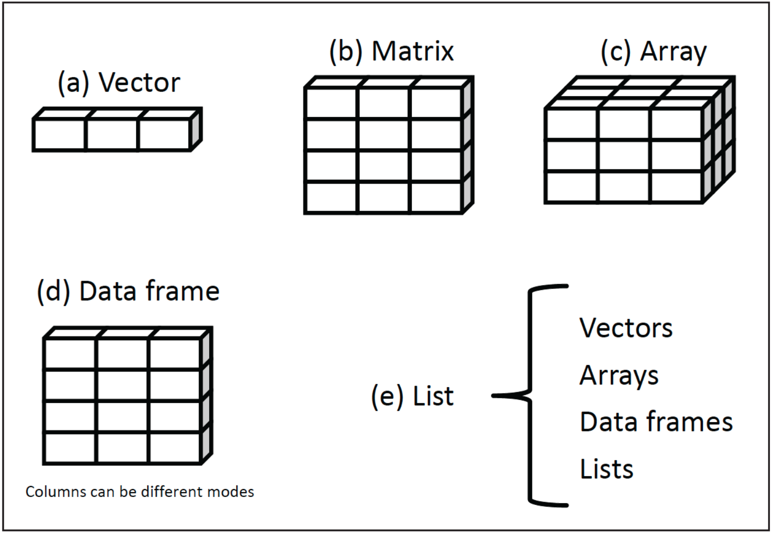
Outline

- Vectors
- Matrices

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

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

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

New Day Interlude

- Coding/Debugging, continue to practice
- If you need more R Markdown Practice try the second activity (let me know how it goes!):

  https://github.com/abbiepopa/BSDS100/blob/master/class_code/More_Practice_Knitting.pdf
- Will continue with vectors and data structures today!

A brief review...

- Data structures hold data (numbers, strings, logicals...)
- A vector is one-dimensional (think of it like a shopping list), and can only hold one type of data
- We build a vector by concatenating (connecting) items of data with `c()`
  - e.g., `number_vector <- c(1, 2.4, -88)`

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 use 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("Sarah", "Terence", "Habibi")
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
```

Recycling in R

Why did (2) `myFavNum + myNums` work?

R "recycles" the shorter vector to get the length of the longer vector

Try this:

```
my_n1_vector <- 5
my_n3_vector <- 1:3
my_n7_vector <- c(3, 7, 28, 43, 1, 5.5, 19)
my_n9_vector <- sample(1:100, 9)
```

1. What happens if you add `my_n1_vector` to `my_n3_vector`?
2. What happens if you add `my_n3_vector` to `my_n9_vector`?
3. What happens if you add `my_n7_vector` to `my_n9_vector`?

Solution Problem 1

```
# What happens when you add a vector of length 1 to
# a vector of length 3?

> my_n1_vector + my_n3_vector
[1] 6 7 8

# The single item is added to each of the three
# elements of the vector of length 3.
```

Solution Problem 2

```
# What happens when you add a vector of length 3 to
# a vector of length 9?

> my_n3_vector + my_n9_vector
[1] 62  4 50 27 17 47 87 43 99

# The three elements are added (in order) to the first
# three, second three, and third three elements of the
# length nine vector
```

Solution Problem 3

```
# What happens when you add a vector of length 7 to a vector of
# length 9?

> my_n7_vector + my_n9_vector
[1]  64.0   9.0  75.0  69.0  16.0  49.5 105.0  44.0 103.0

Warning message:
In my_n7_vector + my_n9_vector :
  longer object length is not a multiple of shorter object length

# The first two elements of the length-7 vector will be recycled,
# the last five will be used once
```

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 | y	x or y
x & y	x and y
`isTRUE(`x`)`	Test if x is `TRUE`

Vector example: names

- A name is a vector attribute
- Can be identified using the `names()` function

```
> 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" ""
```

Part II: Matrices and Arrays

Matrices and Arrays

- By giving an atomic vector a dimension attribute, it behaves like a multi-dimensional array
- A special case of the array is a matrix, a two-dimensional array
- A matrix has 2 dimensions, and an array has n $\geq$ 2 - dimensions.
- Matrices and arrays are created with `matrix()` and `array()`

Matrix Example

```
> x <- matrix(1:10, nrow = 2, ncol = 5)
 # can drop nrow and ncol to shorten but keep in this order

 > x
     [,1] [,2] [,3] [,4] [,5]
[1,]    1    3    5    7    9
[2,]    2    4    6    8   10
```

Array Example

```
> y <- array(1:12, c(2, 3, 2))
> y
, , 1

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

, , 2

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

Selected Functional Generalizations

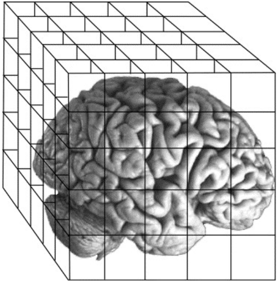
1-D Function	n-D Functions
`length()`	`nrow()`, `ncol()`, `dim()`
`names()`	`rownames()`, `colnames()`, `dimnames()`
`c()`	`cbind()`, `rbind()`

Note: a matrix or array can also be one-dimensional, e.g., an object that is defined as a matrix is permitted to only have one column or one row; although they may look and behave alike, a vector and a one-dimensional matrix behave differently and may generate strange output when using certain functions, e.g., `tapply()`

New Day Interlude

- More practice with vectors/matrices/arrays... we'll finish off slides then do an activity
- Real world examples: Vectors, matrices, and arrays...
  - Vectors and matrices, let's imagine stocks
  - NB: These numbers are all made up, don't go buying and selling stocks based on this activity!

Arrays in the Real World



- You can divide the brain into voxels that are identified by a row, a column, and a layer
- Activity in voxels can be stored in an array
- We can compare two arrays to compare which voxels (parts of the brain) are active when viewing pictures versus at rest

Common R Functions for Working with Data

Function	Purpose
`length(object)`	Number of elements
`dim(object)`	Dimensions of an object
`str(object)`	Structure of an object
`class(object)`	Type of an object
`c(object, object, ....)`	Combines objects into a vector
`cbind(object, object, ....)`	Combines objects as columns
`rbind(object, object, ....)`	Combines objects as rows
`object`	Prints the object
`head(object)`	Prints the first part of the object
`tail(object)`	Prints the last part of the object
`ls()`	Lists current objects
`rm(object, object, ...)`	Deletes one or more objects

Subsetting Matrices

- When subsetting matrices, we specify row, then column, (e.g., `my_matrix[2, 3]` will get you the second row of the 3rd column.
- We can also select multiple rows or columns, as with vector indices
- Leaving one of the positions blank will retrieve all of that dimension (e.g., `my_matrix[ ,3]` will give you all of the rows for the 3rd column.
- Omitting the comma is not recommended, and will get you values based on a different indexing system

Subsetting Arrays

- For a 3-dimensional array you would order by row, column, layer
- More than 3 dimensions is hard to visualize, but you will call the index based on the order you specified when making the array
- A useful feature of indexing, is if you give indexes out of order you can rearrange the output (for example put the 3rd column before the 1st column)

Vectors, Matrices, Arrays Activity

Go To: https://github.com/abbiepopa/bsds100 and click on "Coding Challenge" under **In Class Code**