Managing and Manipulating Data Using R

Introduction, part 2

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1. R basics

2. Classification of objects

3. Atomic vectors

4. Lists

R basics

R as a calculator

```
5
#> [1] 5
5+2
#> [1] 7
10*3
#> [1] 30
```

Executing commands in R

```r
5
#> [1] 5
5+2
#> [1] 7
10*3
#> [1] 30
```

Three ways to execute commands in R

1. Type/copy commands directly into the "console"
2. 'code chunks' in RMarkdown (.Rmd files)
   - Can execute one command at a time, one chunk at a time, or "knit" the entire document
3. R scripts (.R files)
   - This is just a text file full of R commands
   - Can execute one command at a time, several commands at a time, or the entire script

Shortcuts you should learn for executing commands

```
5+2
#> [1] 7
10*3
#> [1] 30
```

Three ways to execute commands in R

1. Type/copy commands directly into the "console"
2. 'code chunks' in RMarkdown (.Rmd files)
    - **Cmd/Ctrl + Enter**: execute highlighted line(s) within chunk
    - **Cmd/Ctrl + Shift + k**: "knit" entire document
3. R scripts (.R files)
    - **Cmd/Ctrl + Enter**: execute highlighted line(s)
    - **Cmd/Ctrl + Shift + Enter** (without highlighting any lines): run entire script

Assignment

Assignment means creating a variable – or more generally, an “object” – and assigning values to it

- <- is the assignment operator
  - in other languages = is the assignment operator
- good practice to put a space before and after assignment operator

```
# Create an object and assign value
a <- 5
a
#> [1] 5

b <- "yay!"
b
#> [1] "yay!"
```

Classification of objects

Objects

Most statistical software (e.g., SPSS, Stata) operates on datasets, which consist of rows of observations and columns of variables

- Usually, these packages can open only one dataset at a time

R is an "object-oriented" programming language (like Python, JavaScript). So, what is an "object"?

- formal computer science definitions are confusing because they require knowledge of concepts we haven't introduced yet
- More intuitively, I think objects as anything I assign values to
  - For example, below, "`a`" and "`b`" are objects I assigned values to

```
a <- 5
a
#> [1] 5
b <- "yay!"
b
#> [1] "yay!"
```

- Ben Skinner (my R guru) says "Objects are like boxes in which we can put things: data, functions, and even other objects."

Objects

- Objects can be categorized by "**type**" (which we will discuss today) and by "**class**" (which we will discuss in later weeks)
  - e.g., a date is an object with a numeric *type* and a date *class*
  - a dataset is an object with a particular type and class
- There is no limit to the number of objects R can hold (except memory)
- R "functions" do different things to different types/classes of objects e.g., date functions are meant to process objects with type=numeric and class=date; these functions don't work on objects with type=character (e.g., "yay!")

Vectors

The fundamental object in R is the "vector"

- A vector is a collection of values
- The individual values within a vector are called "elements"
- Values in a vector can be numeric, character (e.g., "Apple"), or some other *type*

Below we use the combine function `c()` to create a numeric vector that contains three elements

- Help file says that `c()` "combines values into a vector or list"

```
#?c()
x <- c(4, 7, 9)
x
#> [1] 4 7 9
```

Vector where the elements are characters

```
animals <- c("lions", "tigers", "bears", "oh my")
animals
#> [1] "lions"  "tigers" "bears"  "oh my"
```

Student task (do with the person next to you)

Either in the R console or within the R markdown file, do the following:

1. Create a vector called `v1` with three elements, where all the elements are numbers. Then print the values.
2. Create a vector called `v2` with four elements, where all the elements are characters (i.e., enclosed in single ” or double “” quotes). Then print the values.
3. Create a vector called `v3` with five elements, where some elements are numeric and some elements are characters. Then print the values.

Formal classification of vectors in R

Here, I introduce the classification of vectors by Grolemund and Wickham

There are two broad types of vectors

1. **Atomic vectors**. An object that contains elements. There are six types of atomic vectors:
   - **logical**, **integer**, **double**, **character**, **complex**, and **raw**.
     - **Integer** and **double** vectors are collectively known as **numeric** vectors.
2. **Lists**. Like atomic vectors, lists are objects that contain elements
   - elements within a list may be atomic vectors
   - elements within a list may also be other lists; that is lists can contain other lists
   - This sounds vague and confusing; I'll explain and give examples below

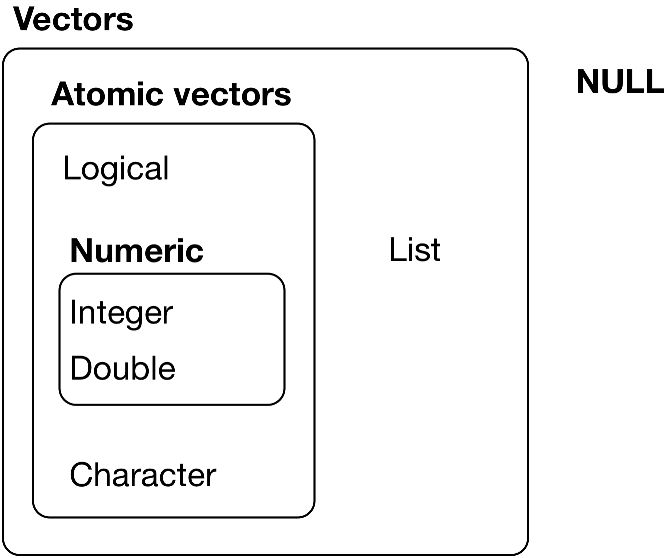
One difference between atomic vectors and lists: **homogeneous** vs. **heterogeneous** elements

- atomic vectors are **homogeneous**: all elements within atomic vector must be of the same type
- lists can be **heterogeneous**: e.g., one element can be an integer and another element can be character

Formal classification of vectors in R

Here is a visual representation of the Grolemund and Wickham classification

PATRICIA - PUT PIC ON WEBSITE AND PROVIDE LINK



Developing an intuitive understanding of vector types

Grolemund and Wickham classification:

1. **Atomic vectors**. six types: logical, integer, double, character, complex, raw.
2. **Lists**

Problem with this classification:

- Not conceptually intutive
- Technically, lists are a type of vector, but people often think of atomic vectors and lists as fundamentally different things

Classification used by my R Guru Ben Skinner:

- data **type**: logical, numeric (integer and double), character, etc.
- data **structure**: vector, list, matrix, etc.

I find Skinner's classification more intuitive conceptually. However, it isn't consistent with R functions or the way R thinks about objects.

If you find this classification of data *type* and data *structure* helpful, totally fine to think of objects in this way while you start to learn R.

Atomic vectors

“Length” of an atomic vector is the number of elements

For remainder of lecture, I’ll use the term **vector** to refer to atomic vectors

Use `length()` function to examine vector length

```
x <- c(4, 7, 9)
x
#> [1] 4 7 9
length(x)
#> [1] 3

animals <- c("lions", "tigers", "bears", "oh my")
animals
#> [1] "lions"  "tigers" "bears"  "oh my"
length(animals)
#> [1] 4
```

A single number (or a single string/character) is a vector with `length==1`

```
z <- 5
length(z)
#> [1] 1
length("Tommy")
#> [1] 1
```

Data type of a vector

The “type” of an atomic vector refers to the elements within the vector.

While there are six “types” of actomic vectors, we’ll focus on the following types:

- numeric:
  - “integer” (e.g., 5)
  - “double” (e.g., 5.5)
- character (e.g., “ozan”)
- logical (e.g., `TRUE`, `FALSE`)

Use `typeof()` function to examine vector type

```
x
#> [1] 4 7 9
typeof(x)
#> [1] "double"

p <- c(1.5, 1.6)
p
#> [1] 1.5 1.6
typeof(p)
#> [1] "double"

animals
#> [1] "lions"  "tigers" "bears"  "oh my"
typeof(animals)
#> [1] "character"
```

Data type of a vector, numeric

Numeric vectors can be "integer" (e.g., 5) or "double" (e.g., 5.5)

```
typeof(1.5)
#> [1] "double"
```

R stores numbers as doubles by default.

```
x
#> [1] 4 7 9
typeof(x)
#> [1] "double"
```

To make an integer, place an `L` after the number:

```
typeof(5)
#> [1] "double"
typeof(5L)
#> [1] "integer"
```

Data type of a vector, character

In contrast to “numeric” data types which are used to store numbers, the “character” data type is used to store **strings** of text.

- Strings may contain any combination of numbers, letters, symbols, etc.
- Character vectors are sometimes referred to as string vectors

When creating a vector where elements have `type==character` (or when referring to the value of a string), place single ‘ or double “” quotes around text

- the text within quotes is the “string”

```
c1 <- c("cat",'cash','candy cane')
c1
#> [1] "cat"        "cash"       "candy cane"
typeof(c1)
#> [1] "character"
length(c1)
#> [1] 3
```

Numeric values can also be stored as strings

```
c2 <- c("1","2","3")
c2
#> [1] "1" "2" "3"
typeof(c2)
#> [1] "character"
```

Data type of a vector, logical

Logical vectors can take three possible values: `TRUE`, `FALSE`, `NA`

- `TRUE`, `FALSE`, `NA` are special keywords; they are different from the character strings `"TRUE"`, `"FALSE"`, `"NA"`
- Don't worry about `"NA"` for now

```
typeof(TRUE)
#> [1] "logical"
typeof("TRUE")
#> [1] "character"

typeof(c(TRUE,FALSE,NA))
#> [1] "logical"
typeof(c(TRUE,FALSE,NA,"FALSE"))
#> [1] "character"

log <- c(TRUE,TRUE,FALSE,NA,FALSE)
typeof(log)
#> [1] "logical"
length(log)
#> [1] 5
```

We'll learn more about logical vectors later

All elements in (atomic) vector must have same data type.

Atomic vectors are **homogenous**;

- An atomic vector has one data type
- all elements within an atomic vector must have the same data "type"

If a vector contains elements of different type, the vector type will be type of the most "complex" element

Atomic vector types from simplest to most complex:

- logical < integer < double < character

```
typeof(c(TRUE,TRUE,NA))
#> [1] "logical"
typeof(c(TRUE,TRUE,NA,1L)) # recall L after an integer forces type to be integer
#> [1] "integer"
typeof(c(TRUE,TRUE,NA,1.5))
#> [1] "double"
typeof(c(TRUE,TRUE,NA,1.5,"howdy!"))
#> [1] "character"
```

Named vectors

All vectors can be “named” (i.e., name individual elements within vector)

Example of creating an unamed vector

- the `str()` function “compactly display[s] the internal structure of an R object” [from help file]; very useful for describing objects

```
#?str
x <- c(1,2,3,"hi!")
x
#> [1] "1"   "2"   "3"   "hi!"
str(x)
#>  chr [1:4] "1" "2" "3" "hi!"
```

Example of creating a named vector

```
y <- c(a=1,b=2,3,c="hi!")
y
#>     a     b           c 
#>   "1"   "2"   "3" "hi!"
str(y)
#>  Named chr [1:4] "1" "2" "3" "hi!"
#>  - attr(*, "names")= chr [1:4] "a" "b" "" "c"
```

Sequences

(Loose) definition: a sequence is a set of numbers in ascending or descending order

A vector containing a "sequence" of numbers (e.g., 1, 2, 3) can be created using the colon operator `:` with the notation `start:end`

```
-5:5
#>  [1] -5 -4 -3 -2 -1  0  1  2  3  4  5
5:-5
#>  [1]  5  4  3  2  1  0 -1 -2 -3 -4 -5
s<- 1:10 #same as this: s<- c(1:10)
s
#>  [1]  1  2  3  4  5  6  7  8  9 10
length(s)
#> [1] 10
```

Creating sequences using `seq()` function

- basic syntax [with default values]:

```
seq(from = 1, to = 1, by = 1)
```

```
seq(10,15)
#> [1] 10 11 12 13 14 15
seq(from=10,to=15,by=1)
#> [1] 10 11 12 13 14 15
seq(from=100,to=150,by=10)
#> [1] 100 110 120 130 140 150
```

Vectorized math

Most mathematical operations operate on each element of the vector

- e.g., add a single value to a vector and that value will be added to each element of the vector

```
1:3
#> [1] 1 2 3
1:3+.5
#> [1] 1.5 2.5 3.5
(1:3)*2
#> [1] 2 4 6
```

Mathematical operations involving two vectors with the same length behave differently

- e.g., for addition: add element 1 of vector 1 to element 1 of vector 2, add element 2 of vector 1 to element 2 of vector 2, etc.

```
c(1,1,1)+c(1,0,2)
#> [1] 2 1 3
c(1,1,1)*c(1,0,2)
#> [1] 1 0 2
```

Lists

Lists

What is a **list**?

- Like (atomic) vectors, a list is an object that contains **elements**
- Unlike vectors, data types can differ across elements within a list
- An element within a list can be another list
    - this characteristic makes lists more complicated than vectors
    - suitable for representing hierarchical data

Lists are more complicated than vectors; today we'll just provide a basic introduction

Create lists using `list()` function

Create a vector (for comparison purposes)

```r
a <- c(1,2,3)
typeof(a)
#> [1] "double"
length(a)
#> [1] 3
```

Create a list

```r
b <- list(1,2,3)
typeof(b)
#> [1] "list"
length(b)
#> [1] 3
b # print list is awkward
#> [[1]]
#> [1] 1
#>
#> [[2]]
#> [1] 2
#>
#> [[3]]
#> [1] 3
```

Investigate structure of lists using `str()` function

When investigating lists, `str()` is better than printing the list

```
b <- list(1,2,3)
typeof(b)
#> [1] "list"
length(b)
#> [1] 3
str(b) # 3 elements, each element is a numeric vector w/ length=1
#> List of 3
#>  $ : num 1
#>  $ : num 2
#>  $ : num 3
```

```
c <- list(c(3,4),c(-5,1,3))
typeof(c)
#> [1] "list"
length(c)
#> [1] 2
str(c) # 2 elements; element 1=vector w/ length=2; element 2=vector w/length=3
#> List of 2
#>  $ : num [1:2] 3 4
#>  $ : num [1:3] -5 1 3
```

Elements within lists can have different data types

Lists are **heterogeneous**

- data types can differ across elements within a list

```
b <- list(1,2,"apple")
typeof(b)
#> [1] "list"
length(b)
#> [1] 3
str(b)
#> List of 3
#>  $ : num 1
#>  $ : num 2
#>  $ : chr "apple"
```

Vectors are **homogeneous**

```
a <- c(1,2,"apple")
typeof(a)
#> [1] "character"
str(a)
#>  chr [1:3] "1" "2" "apple"
```

Lists can contain other lists

```
x1 <- list(c(1,2), list("apple", "orange"), list(1, 2, 3))
typeof(x1)
#> [1] "list"
length(x1)
#> [1] 3
str(x1)
#> List of 3
#>  $ : num [1:2] 1 2
#>  $ :List of 2
#>   ..$ : chr "apple"
#>   ..$ : chr "orange"
#>  $ :List of 3
#>   ..$ : num 1
#>   ..$ : num 2
#>   ..$ : num 3
```

Note that:

- first element of list is a numeric vector with length=2
- second element is a list with length=2
  - first element is character vector with length=1
  - second element is character vector with length=1
- third element is with length=3
  - first element is numeric vector with length=1
  - second element is numeric vector with length=1
  - third element is numeric vector with length=1

You can name each element in the list

```r
x2 <- list(a=c(1,2), b=list("apple", "orange"), c=list(1, 2, 3))
str(x2)
#> List of 3
#>  $ a: num [1:2] 1 2
#>  $ b:List of 2
#>   ..$ : chr "apple"
#>   ..$ : chr "orange"
#>  $ c:List of 3
#>   ..$ : num 1
#>   ..$ : num 2
#>   ..$ : num 3
```

`names()` function shows names of elements in the list

```r
names(x2) # has names
#> [1] "a" "b" "c"
names(x1) # no names
#> NULL
```

Access individual elements in a “named” list

Syntax: `list_name$element_name`

```
x2 <- list(a=1, b=list("apple", "orange"), c=list(1, 2, 3))
typeof(x2$a)
#> [1] "double"
length(x2$a)
#> [1] 1

typeof(x2$b)
#> [1] "list"
length(x2$b)
#> [1] 2

typeof(x2$c)
#> [1] "list"
length(x2$c)
#> [1] 3
```

Note: We’ll spend more time practicing “accessing elements of a list” in upcoming weeks

Compare structure of list to structure of element within a list

```r
str(x2)
#> List of 3
#>  $ a: num 1
#>  $ b:List of 2
#>   ..$ : chr "apple"
#>   ..$ : chr "orange"
#>  $ c:List of 3
#>   ..$ : num 1
#>   ..$ : num 2
#>   ..$ : num 3

str(x2$c)
#> List of 3
#>  $ : num 1
#>  $ : num 2
#>  $ : num 3
```

A dataset is just a list!

A data frame is a list with the following characteristics:

- Data type can differ across elements (like all lists)
- Each **element** in data frame must be a **vector**, not a **list**
  - Each element (column) is a variable
- Each element in a data frame must have the same length
  - The length of an element is the number of observations (rows)
  - so each variable in data frame must have same number of observations
- Each element is named
  - these element names are the variable names

```
names(df)
#> [1] "mpg" "cyl" "hp"
head(df, n=5) # print first 5 rows
#> # A tibble: 5 x 3
#>     mpg   cyl    hp
#> * <dbl> <dbl> <dbl>
#> 1  21       6   110
#> 2  21       6   110
#> 3  22.8     4    93
#> 4  21.4     6   110
#> 5  18.7     8   175
```

Additionally, data frames have “attributes”; we’ll discuss those in upcoming weeks

A data frame is a named list

```
typeof(df)
#> [1] "list"
names(df)
#> [1] "mpg" "cyl" "hp"
length(df) # length=number of variables
#> [1] 3
str(df)
#> 'data.frame':    32 obs. of  3 variables:
#>  $ mpg: num  21 21 22.8 21.4 18.7 18.1 14.3 24.4 22.8 19.2 ...
#>  $ cyl: num  6 6 4 6 8 6 8 4 4 6 ...
#>  $ hp : num  110 110 93 110 175 105 245 62 95 123 ...
```

Like any named list, we can examine the elements

- Individual elements of a data frame are the variables
- these variables are vectors with length equal to the number of rows/observations

```
typeof(df$mpg)
#> [1] "double"
length(df$mpg) # length=number of rows/obs
#> [1] 32
str(df$mpg)
#>  num [1:32] 21 21 22.8 21.4 18.7 18.1 14.3 24.4 22.8 19.2 ...
```

Main takeaways about atomic vectors and lists

Basic data stuctures

1. **(Atomic) vectors**: **logical**, **integer**, **double**, **character**.
   - each element in vector must have same data type
2. **Lists**:
   - Data type can differ across elements

Takeaways

- These concepts are difficult; ok to feel confused
- I will reinforce these concepts throughout the course
- Good practice: run simple diagnostics on any new object
  - `length()` : how many **elements** in the object
  - `typeof()` : what **type** of data is the object
  - `str()` : hierarchical structure of the object

Main takeaways about atomic vectors and lists

Basic data stuctures

1. **(Atomic) vectors**: **logical**, **integer**, **double**, **character**.
   - each element in vector must have same data type
2. **Lists**:
   - Data type can differ across elements

Takeaways

- These data structures (vectors, lists) and data types (e.g., character, numeric, logical) are the basic building blocks of all object oriented programming languages
- Application to statistical analysis
  - Datasets are just lists
  - The individual elements – columns/variables – within a dataset are just vectors
- These structures and data types are foundational for all "data science" applications
  - e.g., mapping, webscraping, network analysis, etc.