

Data Structures I: Vectors, Matrices, and Arrays

BSDS 100 - Intro to Data Science with R



- Vectors
- Matrices



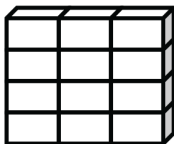
- A **data structure** is a format or organization of data in software that enables efficient use.
- Every programming language has its own types of data structures
- In \mathbb{R} , you can create your own type of data structure; however, there are some that are automatically recognized by the software.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



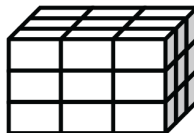
(a) Vector



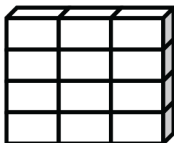
(b) Matrix



(c) Array

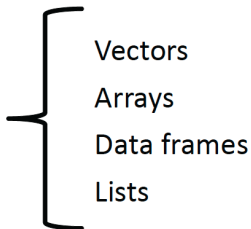


(d) Data frame



Columns can be different modes

(e) List





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



- 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()`



Four Common Types of Vectors

- Logical
- Integer
- Double (numeric)
- Character

```
> double_atomic_vector = c(1, 3.14, 99.999)
```

```
# use L prefix to get integers instead of doubles
```

```
> integer_atomic_vector = c(1L, 3L, 19L)
```

```
> logical_atomic_vector = c(TRUE, FALSE, T, F)
```

```
> character_atomic_vector = c("this", "is a", "string")
```


Example: Try This



- 1 Create the vector `my_frac` of a single fractional number
- 2 Create the vector `my_nums` of seven arbitrary numbers
- 3 Create the vector `first_names` of the first names of two people next to you
- 4 Create the vector `my_vec` 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

```
> (my_atomic_vector = 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

```
> my_atomic_vector[5]  
[1] -99
```

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

```
> my_atomic_vector[10]  
[1] NA
```

#look at the third through eighth elements of the vector

```
> my_atomic_vector[3:8]  
[1] 3 4 -99 5 NA 4
```



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

```
> (my_atomic_vector = 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(my_atomic_vector)  
[1] 1.000 2.000 3.000 4.000 -99.000 5.000
```

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

Example, continued



- ➊ Add `my_frac` to the seventh entry of `my_nums` and store the result in a variable named `my_sum1`
- ➋ Add `my_frac` to each of the seven entries of `my_nums` and store the result in a variable named `my_sum2`
- ➌ Add `my_frac` to the sum of **all** of the values in `my_nums` and store the result in a variable named `my_sum3`
- ➍ Add `my_frac` to the smallest number in `my_nums` and store the result in a variable named `min_sum`
- ➎ Add the second element of `my_nums` to the age of the person you select for `my_vec` and store the result in a variable named `hmm`
 - Does what we did make sense? Did it work? Why?



```
# preamble
myFavNum = 17
my_nums = c(2, 3, 5, 7, 11, 13, 17)
# also works my_nums = 1:7
first_names = c("Cornelia", "Dan")
my_vec = c("Cody", 30)

❶ my_sum1 = myFavNum + my_nums[7]
❷ my_sum2 = myFavNum + my_nums
❸ my_sum3 = myFavNum + sum(my_nums)
❹ min_sum = myFavNum + min(my_nums)
❺ hmm = sum(c(my_nums[2], my_vec[2]))
Error in sum(c(my_nums[2], my_vec[2])) :
  invalid 'type' (character) of argument
```



Be sure to **thoroughly read** the `tidyverse` Style Guide. You will be held to that standard in your coding style moving forward.

<https://style.tidyverse.org/index.html>



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[1]
[1] 1
```

```
> x = c(1, 2, 3, NA)
```

```
> x[4]
[1] NA
```

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

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




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

```
> my_atomic_vector_01 = c(99.1, 98.2, 97.3, 96.4, NA)
```

```
[1] 99.1 98.2 97.3 96.4    NA
```

```
> sum(my_atomic_vector_01)
```

```
[1] NA
```

```
> mean(my_atomic_vector_01)
```

```
[1] NA
```



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

```
> sum(my_atomic_vector_01, na.rm = TRUE)
[1] 391
```

```
> mean(my_atomic_vector_01, na.rm = TRUE)
[1] 97.75
```



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

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



Coercion is a great feature in \mathbb{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** ↓
 - 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 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



- 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:

```
> (my_atomic_vector_01 = c(99.1, 98.2, 97.3, 96.4))  
[1] 99.1 98.2 97.3 96.4
```

```
> my_atomic_vector_01[my_atomic_vector_01 > 98]  
[1] 99.1 98.2
```

What is actually happening in the last slide:

- 1 The `my_atomic_vector_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 `my_atomic_vector_01`, which returns the first two elements and omits the final two
 - An equivalent statement would be
`my_atomic_vector_01[c(T, T, F, F)]`



Function	Action
----------	--------

<code>seq(from, to, by)</code>	Creates a vector of numbers from <code>from</code> to <code>to</code> in increments of <code>by</code>
--------------------------------	--

<code>rep(x, times)</code>	Creates a vector that repeats the values in <code>x</code> exactly <code>times</code> number of times
----------------------------	---

<code>x + (-, /, *) y</code>	For <code>x</code> and <code>y</code> of the <i>same length</i> , calculates a vector of the same length where each entry is the entry-wise summation (subtraction, division, or product) of <code>x</code> and <code>y</code>
------------------------------	---



- 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
<code><</code>	Less than
<code><=</code>	Less than or equal to
<code>></code>	Greater than
<code>>=</code>	Greater than or equal to
<code>==</code>	Exactly equal to
<code>!=</code>	Not equal to
<code>!x</code>	Not x
<code>x y</code>	x or y
<code>x & y</code>	x and y
<code>isTRUE(x)</code>	Test if x is TRUE

Attribute 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



- 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 dimensions, where $n \geq 2$
- Matrices and arrays are created with `matrix()` and `array()`



```
> 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



```
> 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
```



1-D Function n-D Functions

<code>length()</code>	<code>nrow()</code> , <code>ncol()</code> , <code>dim()</code>
<code>names()</code>	<code>rownames()</code> , <code>colnames()</code> , <code>dimnames()</code>
<code>c()</code>	<code>cbind()</code> , <code>rbind()</code>

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()`

Common R Functions for Working with Data



Function	Purpose
<code>length(object)</code>	Number of elements/components.
<code>dim(object)</code>	Dimensions of an object.
<code>str(object)</code>	Structure of an object.
<code>class(object)</code>	Class or type of an object.
<code>mode(object)</code>	How an object is stored.
<code>names(object)</code>	Names of components in an object.
<code>c(object, object, ...)</code>	Combines objects into a vector.
<code>cbind(object, object, ...)</code>	Combines objects as columns.
<code>rbind(object, object, ...)</code>	Combines objects as rows.
<code>object</code>	Prints the object.
<code>head(object)</code>	Lists the first part of the object.
<code>tail(object)</code>	Lists the last part of the object.
<code>ls()</code>	Lists current objects.
<code>rm(object, object, ...)</code>	Deletes one or more objects. The statement <code>rm(list = ls())</code> will remove most objects from the working environment.
<code>newobject <- edit(object)</code>	Edits object and saves as newobject.
<code>fix(object)</code>	Edits in place.