Programming for Data Analytics

2. Lists and Functions

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Course Overview

Lectures l-3	**R Fundamentals** *Atomic Vectors – **Functions** – **Lists** – Matrices – Data Frames*
Lectures 4-9	**Data Science with R** *ggplot2 – dplyr – tidyr – stringr – lubridate - purrr*
Lectures 10-11	**Advanced Programming with R** *Environments – Closures – S3 Object System*
Lectures 12	**Machine Learning with R – Case Studies** *Electricity Generation, Health*

Lecture Overview

- Lists
- Environments
- Functions
- Apply Functions

Lectures I-3	**R Fundamentals** *Atomic Vectors – **Functions** – **Lists** – Matrices – Data Frames*
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(1) Lists

	Homogenous	Heterogenous
1d	Atomic Vector	**List**
2d	Matrix	Data Frame
nd	Array	

- Lists are different from atomic vectors because their elements can be of **any type**, including lists.
- list() creates a list, instead of c()

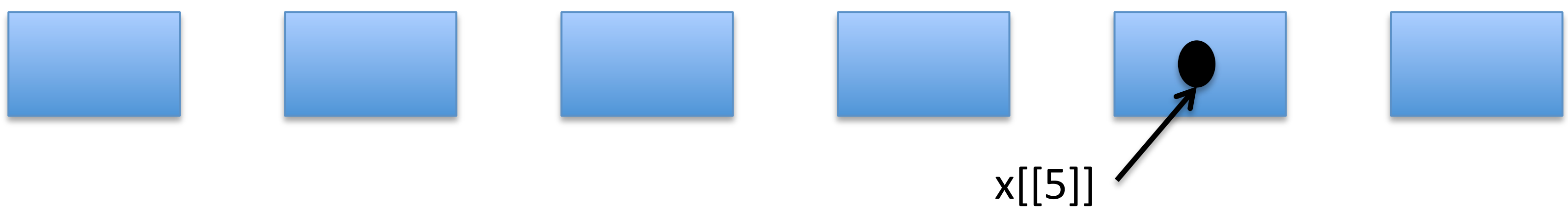
Creating a list…

```
>
> x<- list(1:3, "a", c(T,F,T), c(2.3, 5.9))
>
> str(x)
List of 4
 $ : int [1:3] 1 2 3
 $ : chr "a"
 $ : logi [1:3] TRUE FALSE TRUE
 $ : num [1:2] 2.3 5.9
```

Subsetting lists

- Works in the same way as subsetting an atomic vector
- Using [will always return a list
- [[and $ pull out the contents of a list

If list x is a train carrying objects, then x[[5]] is the object in car 5, x[4:6] is a train of cars 4-6” @RLangTip



Example

```
> x<- list(1:3, let="a", c(T,F,T))
>
> x
[[1]]
[1] 1 2 3

$let
[1] "a"

[[3]]
[1]  TRUE FALSE  TRUE
```

```
> x[1]
[[1]]
[1] 1 2 3

> str(x[1])
List of 1
 $ : int [1:3] 1 2 3

>
> x[[1]]
[1] 1 2 3
>
> str(x[[1]])
 int [1:3] 1 2 3
```

Simplifying vs Preserving Subsetting

- Simplifying subsets returns the simplest possible data structure that can represent the output
- Preserving subsetting keeps the structure of the input the same as the output.
- Omitting drop = FALSE when subsetting matrices and data frames is a common source of programming error.

	Simplifying	Preserving
Vector	x[[1]]	x[1]
List	x[[1]]	x[1]

$ operator

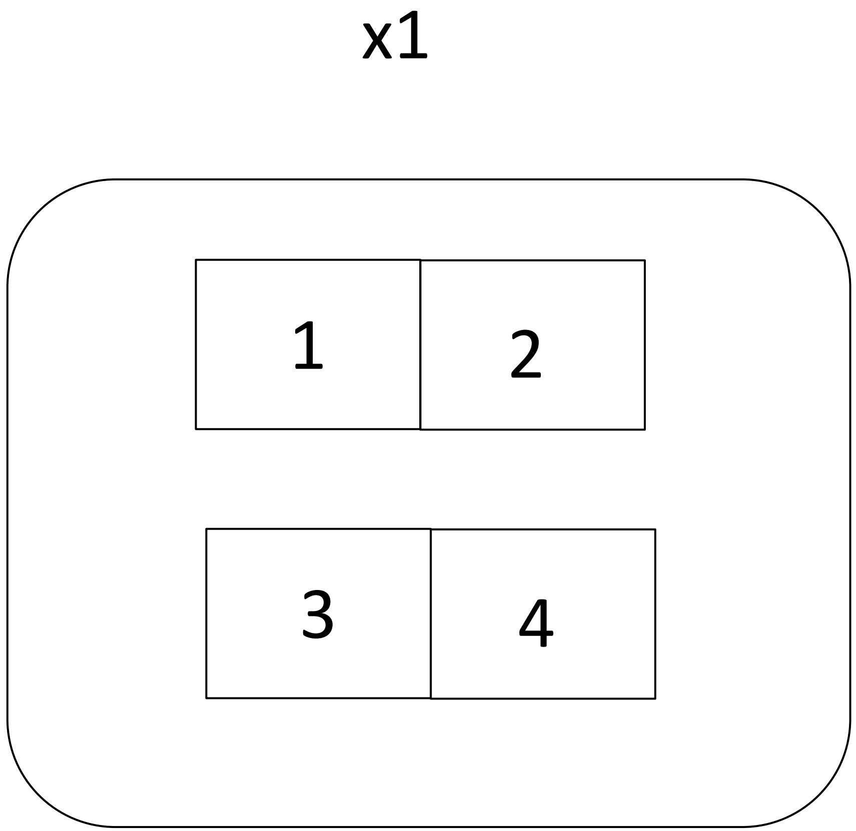
- $ is a shorthand operator, where x$y is equivalent to **x[[“y”,exact=FALSE]]**
- Often used to access variables in a data frame
- $ does partial matching

```
> x
[[1]]
[1] 1 2 3

$let
[1] "a"

[[3]]
[1]  TRUE FALSE  TRUE

> x$let
[1] "a"
>
> x$l
[1] "a"
```

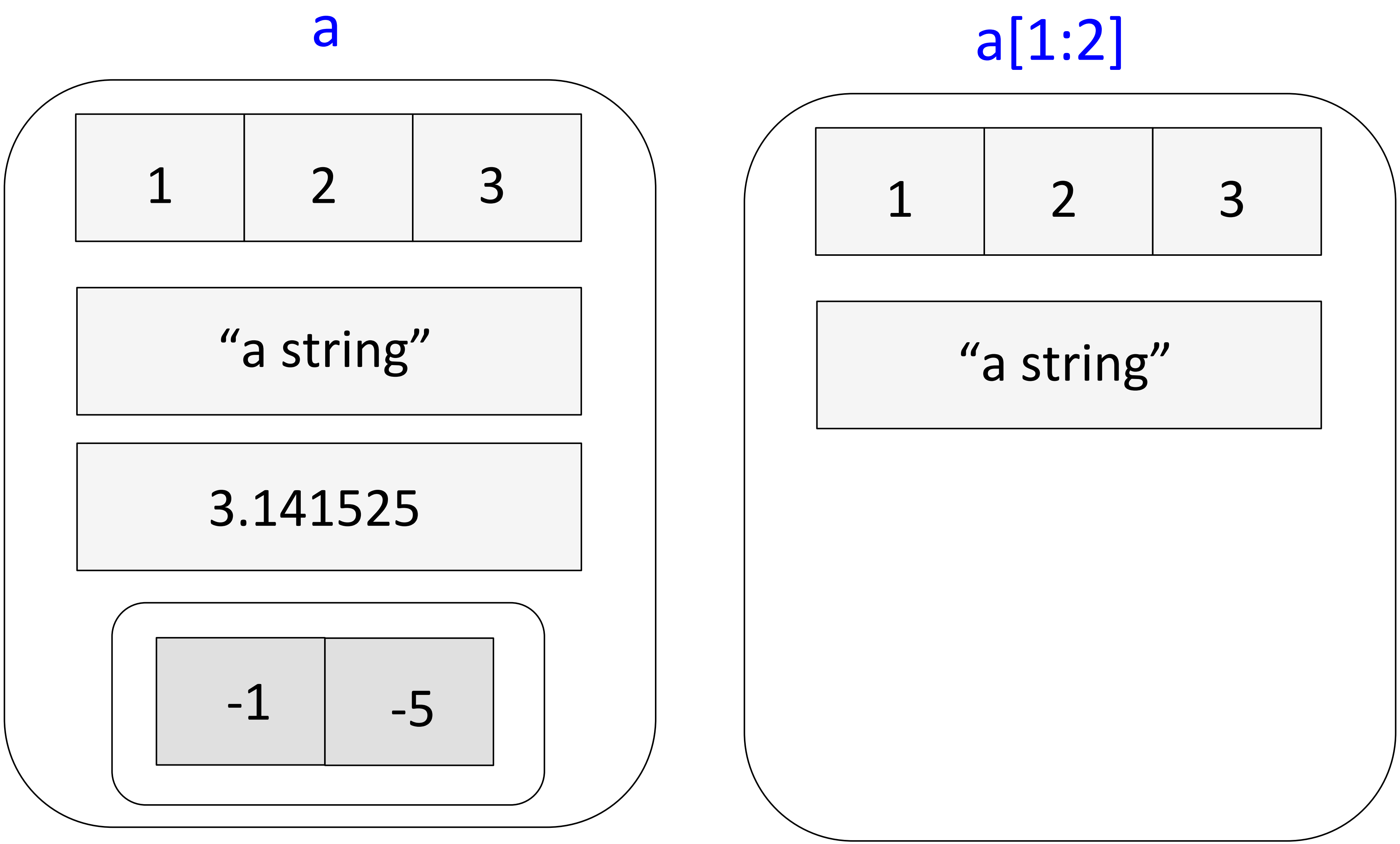
Visualising Lists and Subsetting

- Lists have rounded corners. Atomic vectors have square corners
- Children are drawn inside their parent, and have a slightly darker background.
- Orientation of children not important

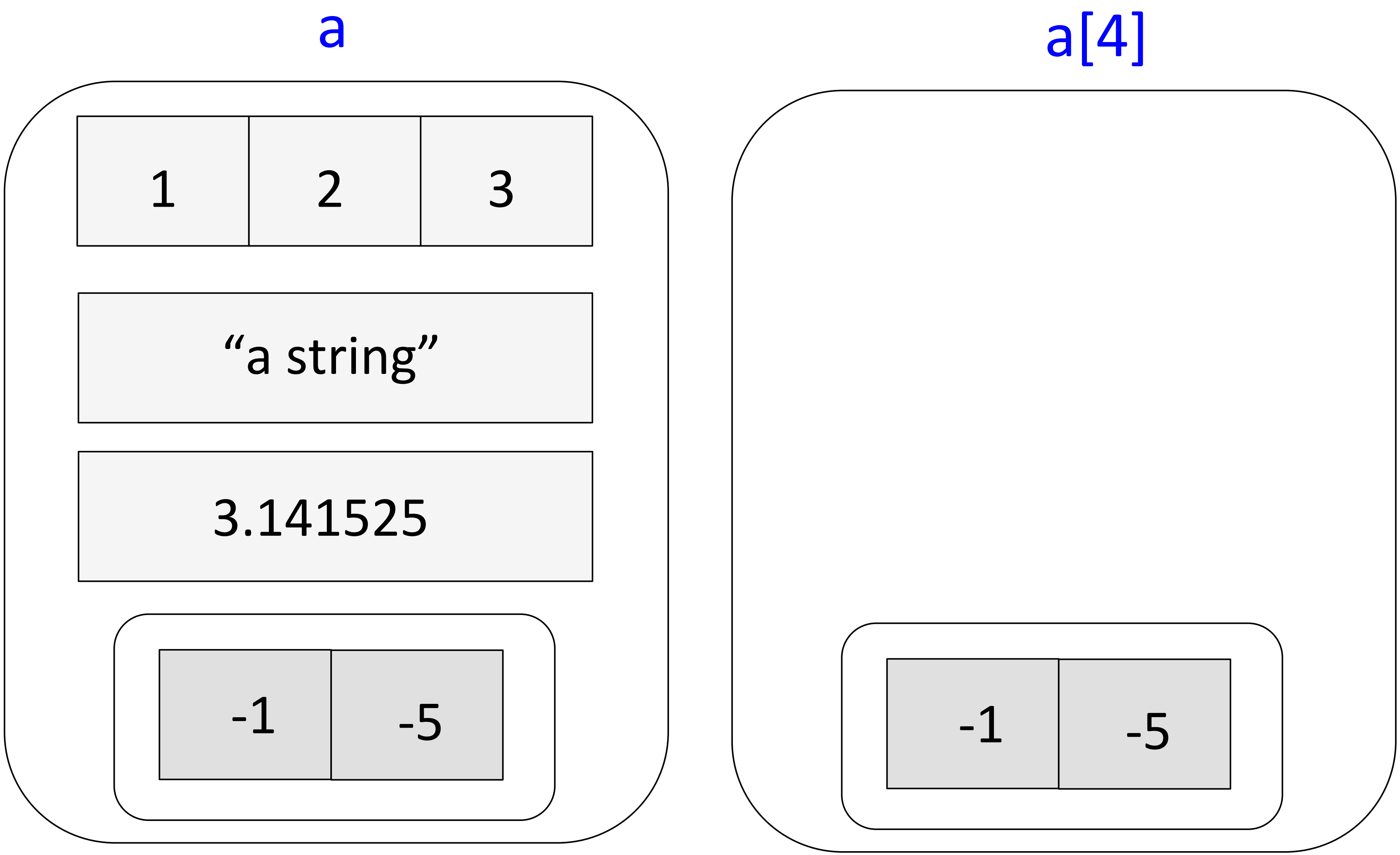
```
x1 <- list(c(1,2),c(3,4))
```

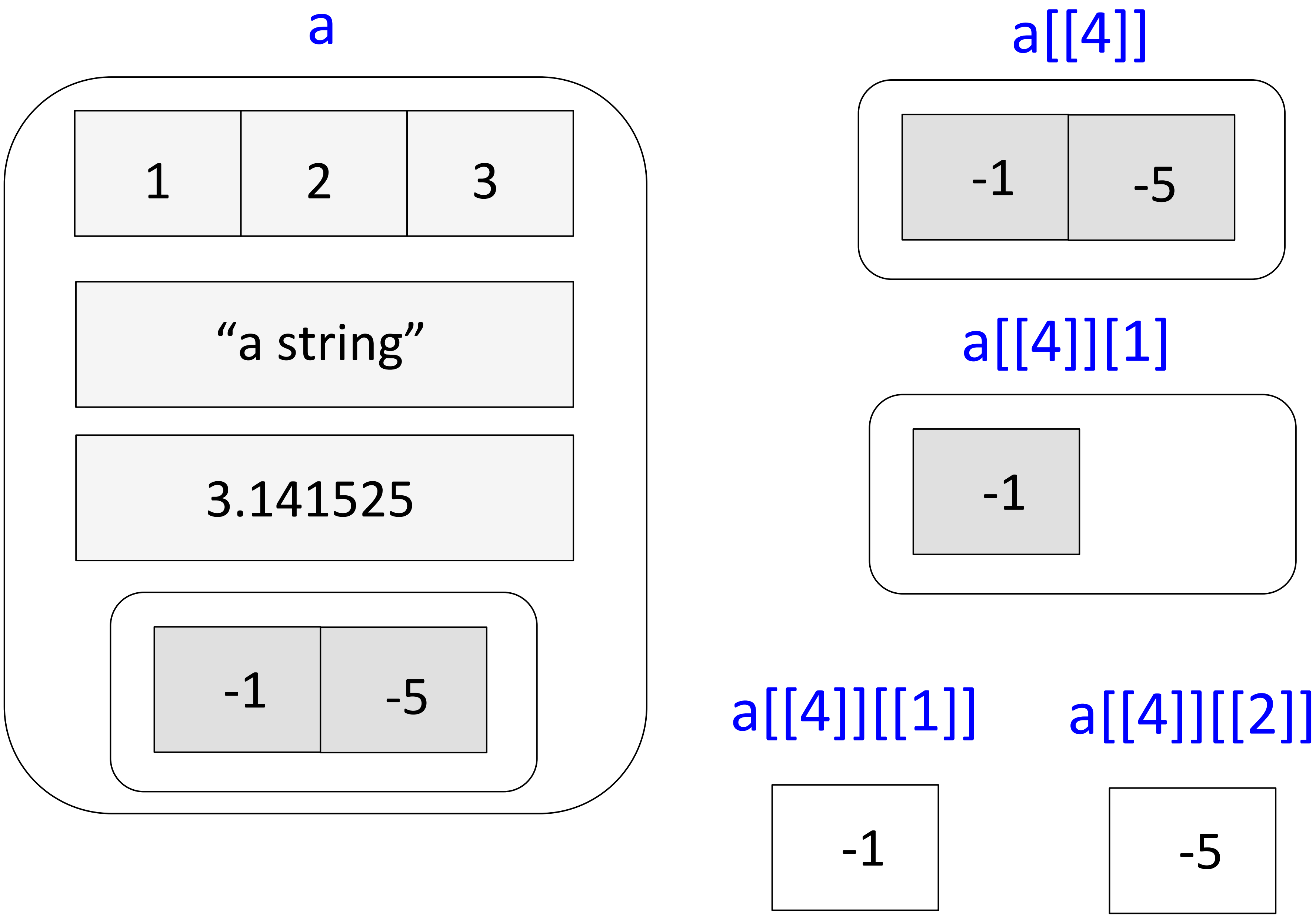


```
a <- list(a=1:3, b = "a string",  c=pi, d = list(-1,-5))
```



```r
a <- list(a=1:3, b = "a string",  c=pi, d = list(-1,-5))
```




a
1
2
3
“a string”
3.141525
-1
-5
a[[4]]
-1
-5
a[[4]][1]
-1
a[[4]][[1]]
-1
a[[4]][[2]]
-5

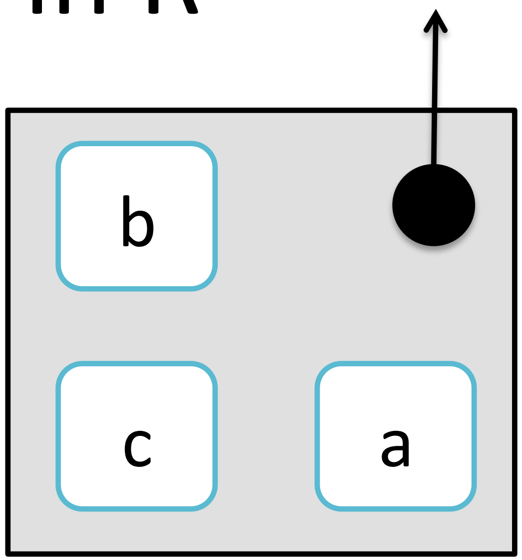
Challenge 2.1

```
l <- list(1:4, list(2:4,c(T,F)), c("A","B"))
```

- Based on the list:
  - Extract the 2nd list element, and calculate the sum of all the resulting elements. What do you expect the sum to be?
  - Calculate the sum of the first list element
  - Convert the entire list to a vector and predict what the vector type will be

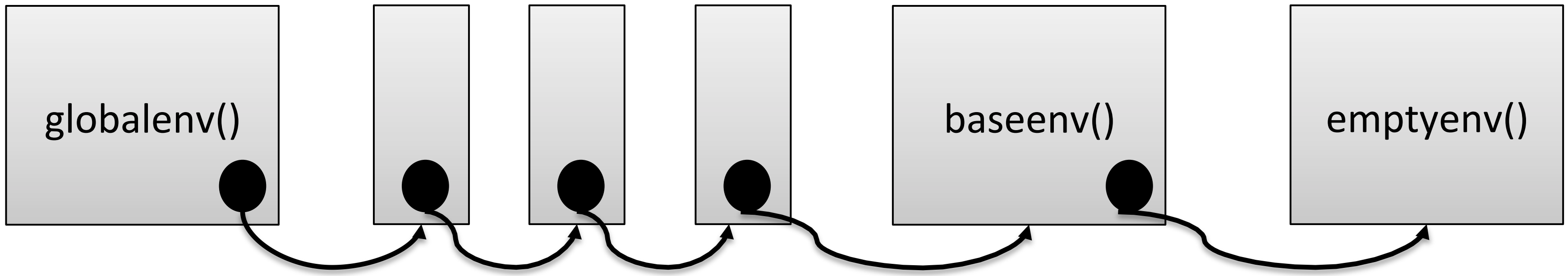
(2) Environments in R

- Environments can be thought of as consisting of two things: a frame, which is a set of symbol-value pairs, and an enclosure, a pointer to an enclosing environment
- Every object (variable or function) in an environment has a unique name
- The working environment is known as the Global Environment




```
> a <- 10
> b <- 20
> c <- 30
>
> environment()
<environment: R_GlobalEnv>
```

Hierarchy of Environments



- Environments form a tree structure in which the enclosures play the role of parents. The tree of environments is rooted in an empty environment, available through emptyenv(), which has no parent

```
> ls()
[1] "a" "b" "c"
```

Examining the hierarchy with search()

```
> search()
 [1] ".GlobalEnv"        "tools:rstudio"     "package:stats"
 [4] "package:graphics"  "package:grDevices" "package:utils"
 [7] "package:datasets"  "package:methods"   "Autoloads"
[10] "package:base"
>
> library(ggplot2)
>
> search()
 [1] ".GlobalEnv"        "package:ggplot2"   "tools:rstudio"
 [4] "package:stats"     "package:graphics"  "package:grDevices"
 [7] "package:utils"     "package:datasets"  "package:methods"
[10] "Autoloads"         "package:base"
```

Challenge 2.2

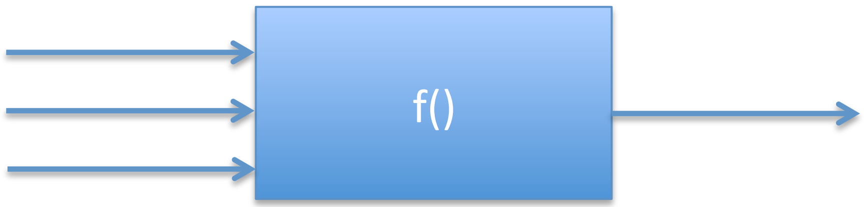
- Given the following environments:
  - **globalenv()** is the interactive workspace. The parent of this is the last package attached with library() or require()
  - **baseenv()** is the environment of the base package
  - **emptyenv()** is the ultimate ancestor of all environments, and the only one without a parent
  - **environment()** is the current environment
- Create a vector that contains all of the objects in the **base environment**. How many of these are functions? (Hint try the is.function() method)

(3) Functions

- A function is a group of instructions that:
  - takes input,
  - uses the input to compute other value, and
  - returns a result (Matloff 2009).
- Functions are a fundamental building block of R (Wickham 2015)
- Users of R should adopt the habit of creating simple functions which will make their work more effective and also more trustworthy (Chambers 2008).
- Functions are declared:
  - using the **function** reserved word
  - are objects

General Form

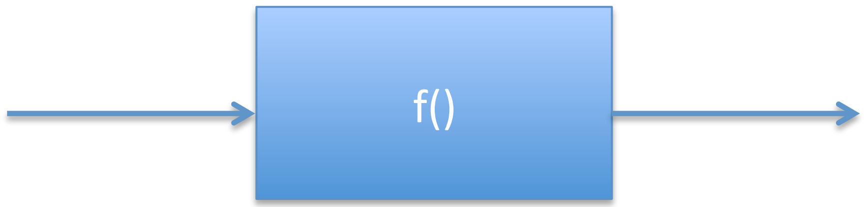
function(*arguments*)
   expression



- *arguments* gives the arguments, separated by commas.
- *Expression* (body of the function) is any legal R expression, usually enclosed in { }
- **Last evaluation is returned**
- return() can also be used, but usually for exceptions.

Example

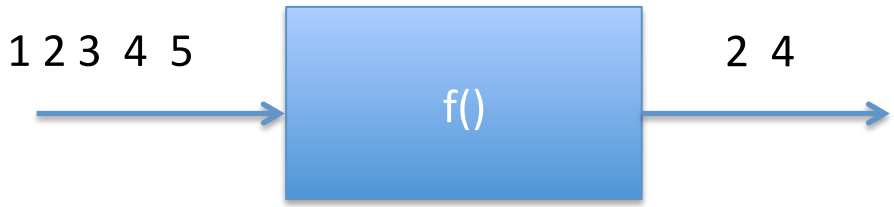
```
> f <- function(x){x^2}
>
> f(4)
[1] 16
```




```
> f(1:10)
 [1]   1   4   9  16  25  36  49  64  81 100
```

Challenge 2.3.1

- Write an R function that filters a vector to return all the even numbers



Functions and their Environment

- Functions are first class objects that exist in an environment
- **Functions can access all variables contained in their enclosing environment**
- When functions are executed, they have their own environment (to be covered later in the advanced topic)

```
> ls()
character(0)
>
> f1 <- function(x)x^2
>
> ls()
[1] "f1"
>
> x <- f1(2)
>
> ls()
[1] "f1" "x"
```

Looking for variables…

- If a name isn't defined inside a function, R will look one level up to the enclosing environment.

```
x <- 2
g <- function(){
  y <- 1
  c(x,y)
}

g()
```

```
>
> g()
[1] 2 1
```

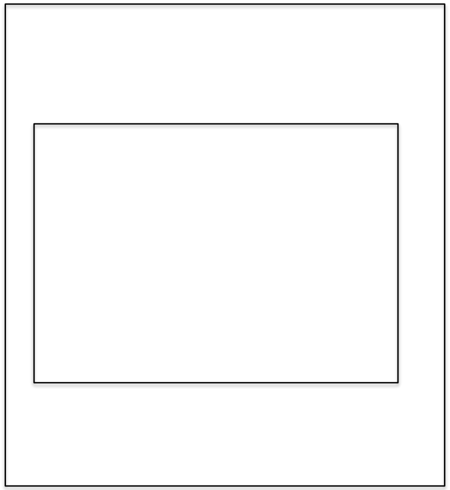
Similar search rules apply for nested functions

```r
x <- 1
h <- function(){
  y <- 2
  i <- function(){
    z <- 3
    c(x,y,z)
  }
  i()
}

h()
```

```
> h()
[1] 1 2 3
```

Challenge 2.3

- Predict the output of the following call h()
- Use a nested diagram to explain the solution



```
x <- 1; y <- 2; z <- 3
h <- function(){
  x <- 10
  z <- 30
  i <- function(){
    x <- 100
    z <- 300
    j<- function(){
      x <- 1
      c(x,y,z)
    }# end of j
    j()
  } # end of i
  i()
}# end of h
```

Function Arguments

- It is useful to distinguish between *formal arguments* and the *actual arguments*
  - **Formal arguments** are the property of the function
  - **Actual arguments** can vary each time the function is called.
- When calling functions, arguments can be specified by
  - Complete name
  - Partial name
  - Position

```r
f <- function(abcdef, bcde1, bcde2){
  c(a=abcdef, b1=bcde1, b2=bcde2)
}
```

```r
f(1,2,3)

f(2,3,abcdef = 1)

f(2,3,a = 1)

f(2,3,b = 1)
```

```
> f(1,2,3)
 a b1 b2
 1  2  3
>
> f(2,3,abcdef = 1)
 a b1 b2
 1  2  3
>
> f(2,3,a = 1)
 a b1 b2
 1  2  3
>
> f(2,3,b = 1)
Error in f(2, 3, b = 1) :
```

Guidelines (Wickham 2015)

- Use positional mapping for the first one or two arguments (most commonly used)
- Avoid using positional mapping for less commonly used attributes
- Named arguments should always come after unnamed arguments

Default and missing arguments

- Function arguments in R can have default values
- R function arguments are “lazy” – only evaluated if actually used

```r
g <- function(a=1, b=1){
  c(a,b)
}
```

```
>
> g()
[1] 1 1
> g(1)
[1] 1 1
> g(2,4)
[1] 2 4
```

Status of an argument

- You can determine if an argument was supplied by using the missing() function

```r
h <- function(a=1, b=1){
  c(missing(a),missing(b))
}
```

```
>
> h()
[1] TRUE  TRUE
>
> h(1)
[1] FALSE  TRUE
>
> h(1,1)
[1] FALSE FALSE
```

Creating robust functions

- Defensive programming "the art of making code fail in a well-defined manner even when something unexpected occurs" (Wickham 2015)
- Key principle:
  - Fail fast
  - As soon as something is wrong, signal an error
- Generally good style to reserve the use of an explicit **return()** when returning early from a function

Examples

```r
my_min <- function(v){
  if(!is.numeric(v))
    stop("Error, type should be numeric")
  min(v)
}
```

```
> my_min("ABC")
Error in my_min("ABC") : Error, type should be numeric
>
> my_min(c(T,F))
Error in my_min(c(T, F)) : Error, type should be numeric
>
> my_min(c(T,F,1))
[1] 0
>
> my_min(300:400)
[1] 300
```

Passing functions as objects

- Functions are first class objects, so they can be passed to other functions
- Provides flexibility, and widely used in R

```
> p1 <- function(f, v){
+   f(v)
+ }
>
> p1 (min,1:10)
[1] 1
>
> p1(max,1:10)
[1] 10
>
> p1(mean,1:10)
[1] 5.5
```

Challenge 2.4

Write a function that takes in a vector and returns a vector with no duplicates. Make use of the R function duplicated()

duplicated {base} R Documentation

Determine Duplicate Elements

Description

`duplicated()` determines which elements of a vector or data frame are duplicates of elements with smaller subscripts, and returns a logical vector indicating which elements (rows) are duplicates.

`anyDuplicated(.)` is a “generalized” more efficient shortcut for `any(duplicated(.))`.

Usage

```
duplicated(x, incomparables = FALSE, ...)
```

(4) Apply Functions

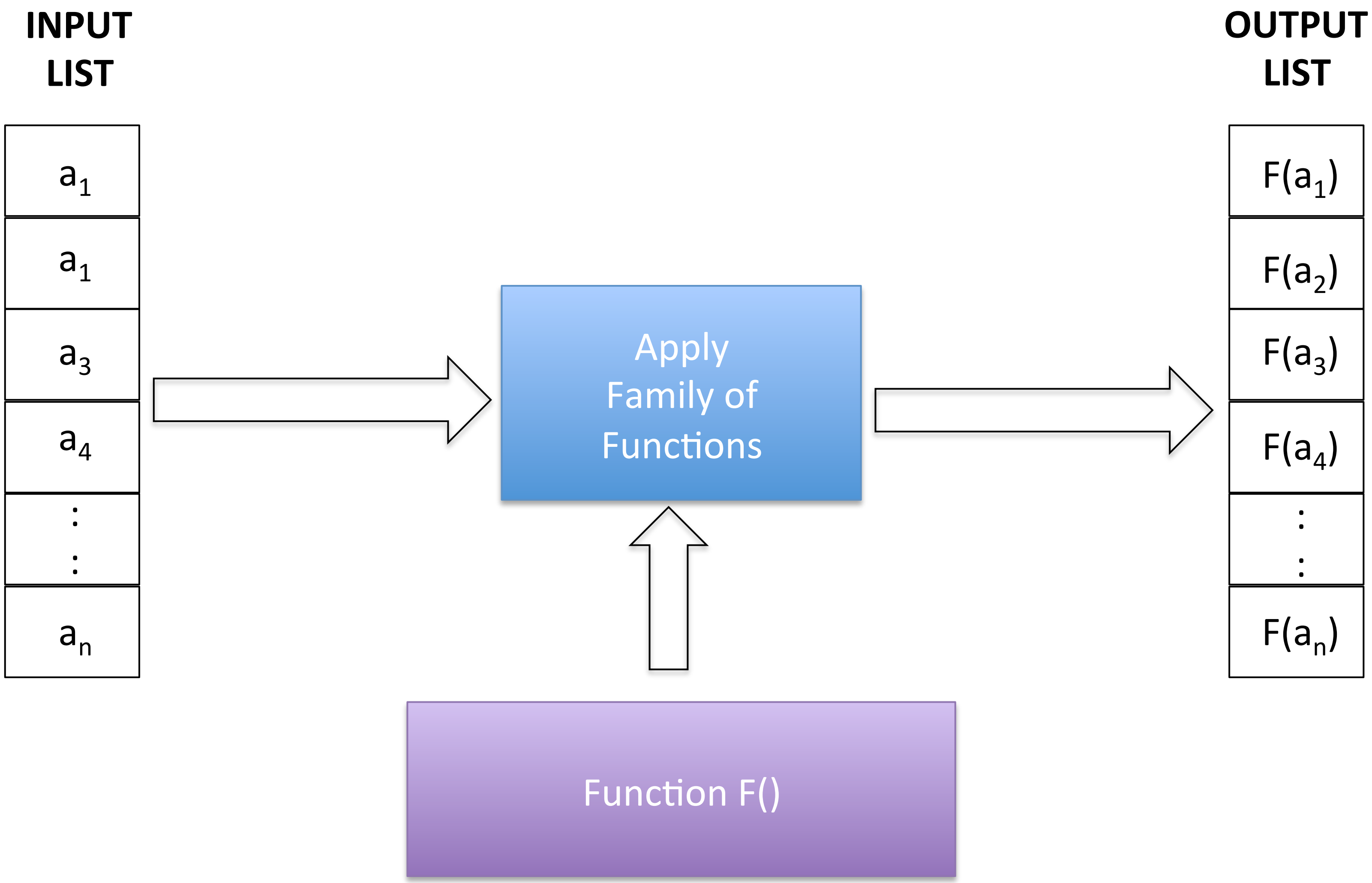
- There are three basic ways to iterate over a vector
  - Loop over the elements
  - Loop over numeric indices
  - Loop over names
- However, “the real downside of for loops is that they are not very expressive… do not convey a high level goal”

```
for (x in xs)print(x)

for(i in seq_along(xs))print(xs[i])

for(nm in names(xs))print(xs[nm])
```

Use of Functionals in R

- A functional… takes a function as input and returns a vector as output
- Functionals can be used instead of loops to iterate over vectors/lists
- Simplest functional is lapply(), sapply() and vapply() are also useful
- The purrr package (later) also provides functionals for processing vectors (map() etc)
- The apply() function (later) can be used to process matrices by row/column.

Overall idea



lapply(x,f)

- The general form of the **lapply(x,f,fargs)** function is as follows:
  - **x** is the target vector or list
  - **f is the function to be called and applied to each element**
  - **fargs** are the optional set of arguments that can be applied to the function f.
  - **sapply()** returns a vector, **lapply()** returns a list

lapply() – Example 1

- Vector input
- Function adds 2 to each element
- List output
- unlist() converts to vector.

```
> v1 <- 1:5
>
> out <- lapply(v1,function(x)x+2)
>
> str(out)
List of 5
 $ : num 3
 $ : num 4
 $ : num 5
 $ : num 6
 $ : num 7
>
> unlist(out)
[1] 3 4 5 6 7
```

lapply() – Example 2

```
> v2 <- list(1:3,4:6)
>
> out <- lapply(v2,
+               function(x)list(max=max(x),min=min(x)))
>
> str(out)
List of 2
 $ :List of 2
  ..$ max: int 3
  ..$ min: int 1
 $ :List of 2
  ..$ max: int 6
  ..$ min: int 4
```

sapply(x,f)

- The general form of the **sapply(x,f,fargs)** function is as follows:
  - **x** is the target vector or list
  - **f is the function to be called and applied to each element**
  - **fargs** are the optional set of arguments that can be applied to the function f.
  - returns a vector

sapply() – Example 3

- Vector input
- Function adds 2 to each element
- Vector output

```
> v3 <- 1:5
>
> out <- sapply(v3,function(x)x+2)
>
> out
[1] 3 4 5 6 7
>
> str(out)
 num [1:5] 3 4 5 6 7
```

Challenge 2.5

- Modify this example so that the quadratic parameters *a, b* and *c* are sent to the **sapply()** function, and f(x) is returned.
- Use the interval [-10,10] for x, and the **seq()** function to generate the values in steps of 0.1
- Plot the response using qplot()

$$f(x) = ax^2 + bx + c$$

References

- Wickham, H. 2015. Advanced R. Taylor & Francis