List and Functional Programming

Song Liu (song.liu@bristol.ac.uk)
GA 18, Fry Building,
Microsoft Teams (search "song liu").

University of BRISTOL
School of Mathematics

MATHS AT WORK

When: From 1pm, 19th April

Where: Fry Building Atrium

Get a chance to interact with companies on a **one-to-one basis** and find out how the maths you study is applied in work.

You'll be able to ask about **internships, placements** and **graduate positions.**

Free lunch will be provided as well as a maths goody bag for the first 100 people to arrive!

We've invited top employers, including:

Jane Street

GSK

BURBERRY

UK Health Security Agency

EY

University of BRISTOL Careers Service

Scan to sign up and find out more!

https://mathsatwork-19-April-2023.eventbrite.com

List

- We have seen vector and matrix as data structures in R.
- List is another important data structure in R.
- It combines objects **with different types**.
    - Matrix/vector only supports a single type of data.
    - Similar to the `struct` in C programming.
- See ART: Section 4.

Creating List

```
song_liu <- list(name = "song", male = T, salary = 10)
```

- This creates a list contains three elements:
  - Character data: `name`
  - Logical data: `male`
  - Numeric data: `salary`
- `name`, `male` and `salary` are called "tags" for values `"song", "T", 10` respectively.

Displaying List

You can list all tags and their corresponding values by simply typing the name of the list at the console.

```
> song_liu
$name
[1] "song"

$male
[1] TRUE

$sal
[1] 10
```

Indexing List

- To obtain the value bound to a specific tag, we can use the `$` sign.

```
song_liu$male
[1] TRUE
```

- Or you can index a list without using tags:

```
song_liu[[2]]
[1] TRUE
```

  where `[[2]]` is the position of the element.

Creating List without Tags

- In fact, you can create a list without using any tag:

```
song_liu <- list("song", T, 10)
> song_liu
[[1]]
[1] "song"
[[2]]
[1] TRUE
[[3]]
[1] 10
```

- Then you will have to access all elements in the list using their indices.

```
> song_liu[[2]]
[1] TRUE
```

  - You **cannot** use vector to index list:

```
> song_liu[[2:3]]
Error in song_liu[[2:3]] : subscript out of bounds
```

Add Element to List

```
song_liu <- list(name = "song", male = T, sal = 10)
song_liu$department <- "math"
song_liu[[5]] <- 1987
> song_liu
$name
[1] "song"

$male
[1] TRUE

$sal
[1] 10

$department
[1] "math"

[[5]]
[1] 1987
```

Delete Element from List

```
song_liu$department <- NULL
> song_liu
$name
[1] "song"
$male
[1] TRUE
$sal
[1] 10
[[4]]
[1] 1987
```

- Notice that after deleting `department`, the value 1987 moved up by one position, with a new tag `4`.
- In R, all modifications to an existing vector/list involves creating a modified copy of the old vector/list, and reassigning it to the original variable.
    - Extra memory allocation! Slow when list is large!

Nested List

List itself can contain lists.

```
song_liu <- list(name = "song", male = T, sal = 10,
                 grades = list(CPP=90, MAT = 100, CALC = 70))
> song_liu$grades$CPP
[1] 90
> song_liu[[4]][[1]]
[1] 90
```

```
jack <- list(name = "jack", male = T, sal = 10,
                 grades = list(CPP=90, MAT = 100, CALC = 70))
students <- list(song_liu, jack)  # Now the list students
# contains two elements, which are both lists.
```

Functional Programming

- So far, we have introduced two programming paradigms
  - **Procedural Programming (PP)**: Your program is divided into several subtasks and you write **functions** for each subtask.
  - **Object Oreinted Programming (OOP)**: Your program is divided into several pieces called "objects" and objects contain **data as well as procedures**.
- PP and OOP divide the program **by features** thus is suitable for developing APPs with complicated logics and components.

Functional Programming

- However, most data science program has a simple programming pipeline:
  - Apply(Op1, Data1) -> Data2-> Apply(Op2, Data2) -> Data3 -> ... -> Final Result
- Functional Programming (FP) views our program as a pipeline, focusing on writing data-operating functions and applying such functions to our data.
- R supports functional programming natively.
  - C/C++ also supports functional programming via some advanced language features.
  - Function pointers, templates, etc.

A Simple FP Example

- Write a simple data operating function

```
# add the input by 1.
add <- function(x) {return(x+1)}
```

- Applying this function on some dummy data.

```
l <- list(1,2)
lapply(l, add)
[[1]]
[1] 2

[[2]]
[1] 3
```

- Here, `lapply` applies the `add` function to each element of the list `l`, producing a new list.

A Simple FP Example

- The input and output of `lapply` are both lists.
  - list in, list out.
- We can also convert the list output to a vector by using `unlist`:

```
    l <- list(1,2)
    unlist(lapply(l, add))
    [1] 2 3
```

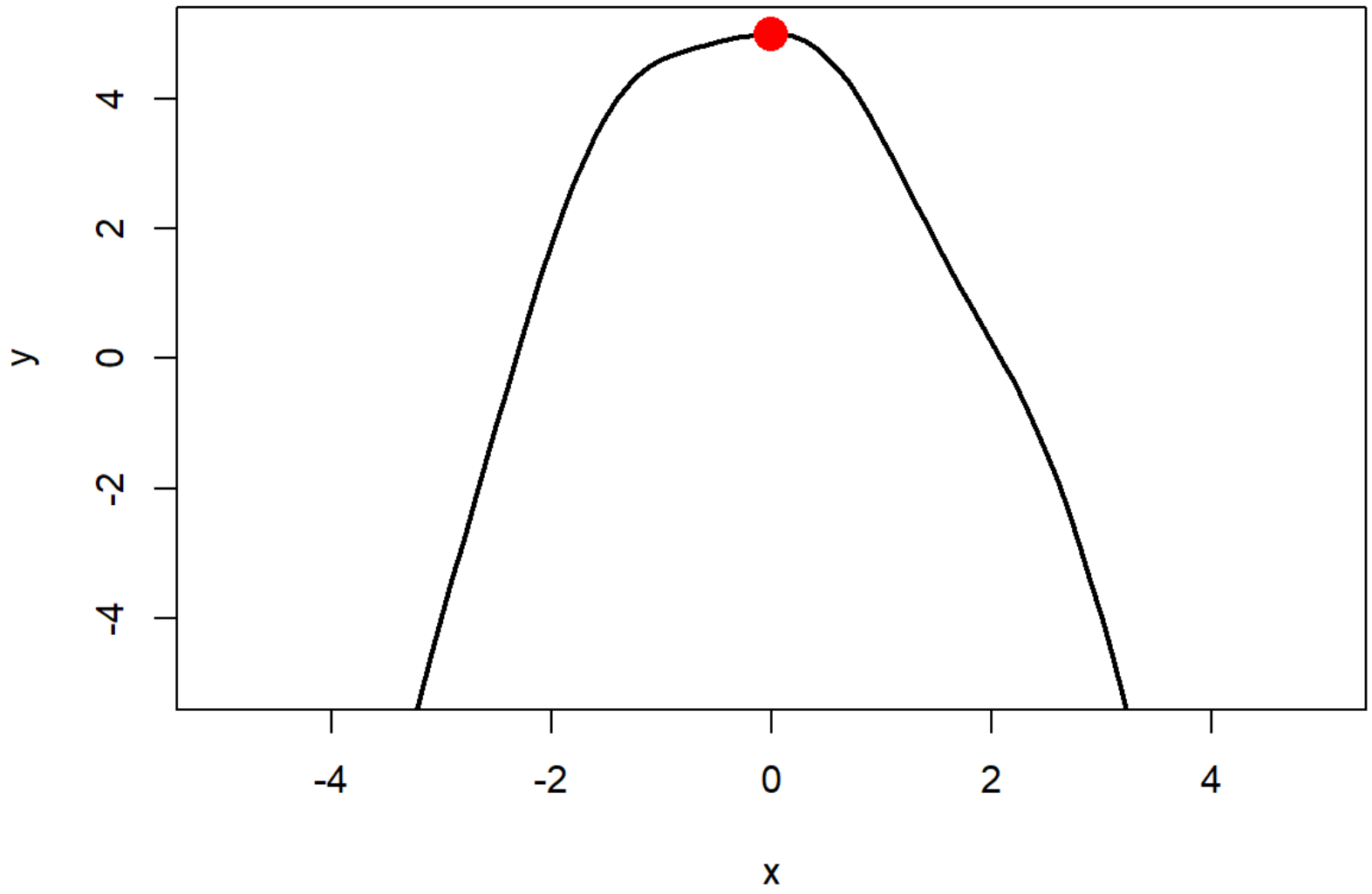
- or using `sapply`

```
    l <- list(1,2)
    sapply(l, add)
    [1] 2 3
```

Functions are Variables

- In FP, functions are variables too, **thus they can be passed to other functions as input arguments.**
- In the previous example, `add` is a function that was passed to the `lapply` function as an input argument.
- This property allows us to write clean and more readable code.

Gradient Ascent



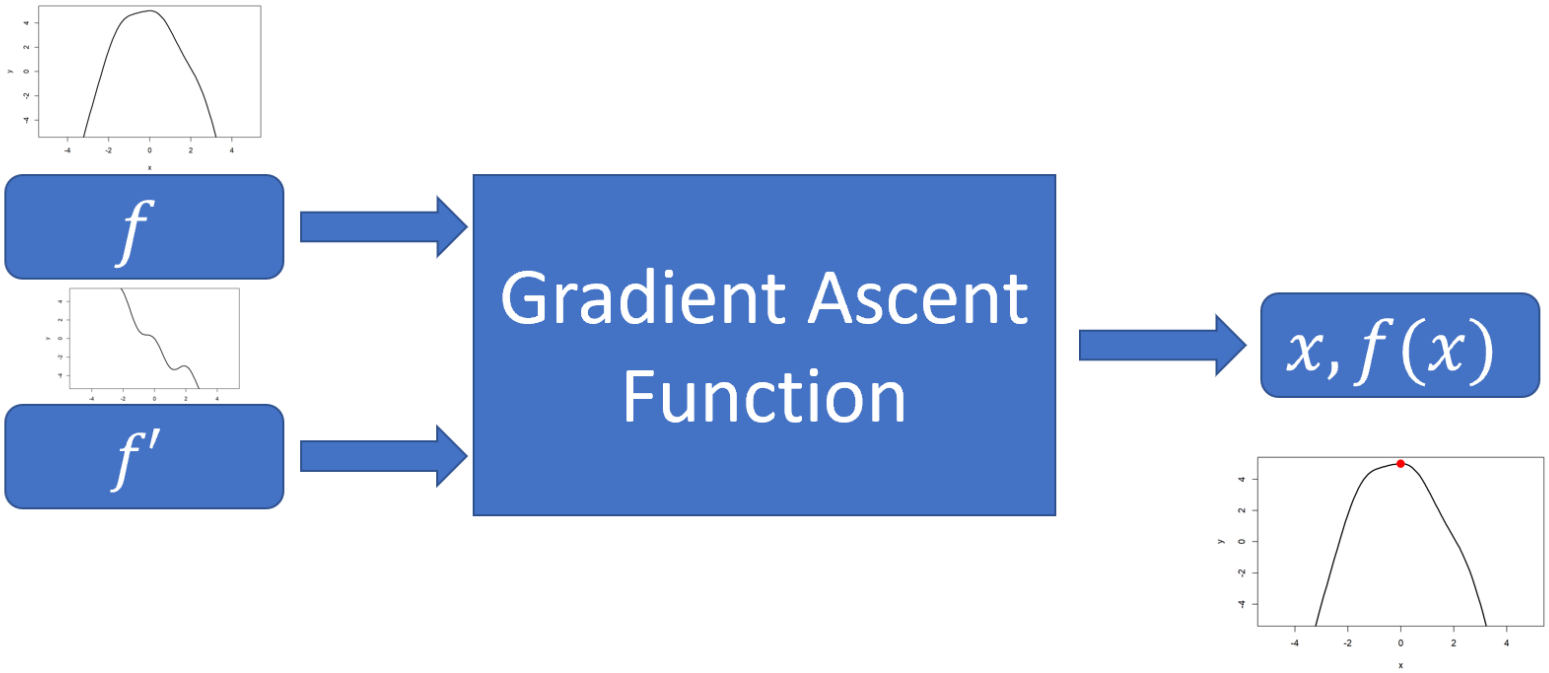
Gradient Ascent Revisited

```
f <- function (x){
  return(-sin(x)^3-x^2+ 5)
}

df <- function(x){
  return(-3*sin(x)^2*cos(x) - 2*x)
}

x <- -1.5
while( abs(df(x)) > .01){
  x <- x - .1*df(x)
}
```

- This code is clean enough. However, how can we wrap the gradient ascent algorithm using a function?

Gradient Ascent Function

- Gradient ascent algorithm depends on `f` and `df`, thus this gradient ascent function should take **two functional** inputs.



Gradient Ascent Function

```r
f <- function (x){
  return(-sin(x)^3-x^2+ 5)
}

df <- function(x){
  return(-3*sin(x)^2*cos(x) - 2*x)
}

# gradient descent, takes two functions as inputs
# f, function to be minimized, df, derivative of f,
# x, initial search point.
grad_asc <- function(f, df){
  x <- -1.5
  while( abs(df(x)) > .01){
    x <- x - .1*df(x)
  }
  return(list(x, f(x)))
}

print(grad_asc(f, df))
```

Gradient Ascent Function 2.0

- Since functions are variables, they can be elements of a list too. This leads to a further simplification of the input arguments of `grad_desc`.

```
grad_asc <- function(problem){
    f <- problem$func
    df <- problem$deri

    x <- -1.5

    while( abs(df(x)) > .01){
        x <- x + .1*df(x)
    }
    return(list(x, f(x)))
}

# creating a list with two functions as elements.
problem <- list(func = f, deri = df)
# more readable
print(grad_desc(problem))
```

Conclusion

1. List in R can contain data with different types.
2. Lists can be nested.
3. FP focuses on data operating functions and how these functions are applied on data.
4. In FP, functions are variables.