Introduction to Big Data

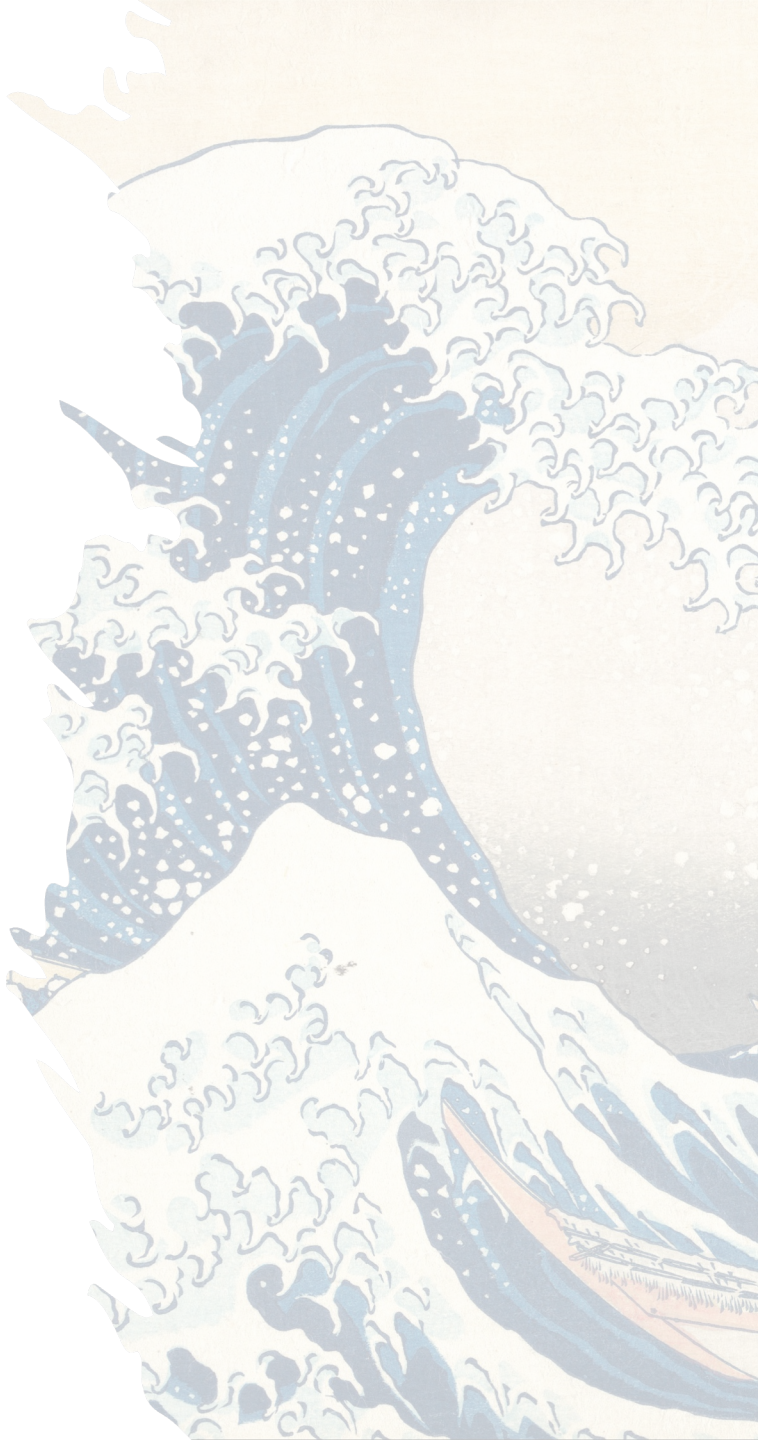
Stelios Sotiriadis

About me!

- Lecturer at CS, PhD in scheduling in distributed systems
- I worked to solve modern industry-based problems to improve systems' performance
  - Projects at the University of Toronto with Huawei, Autodesk, IBM and other companies and various startups worldwide

Agenda

- Introduction to BDA
  - Module admin
- Big data analytics and algorithms
- Computational complexity
- Searching and sorting (part 1)
- Python lab



Module administration

BDA is a designed for face-to-face

- Lecture sessions are in Malet St MAL B34, and online
- Lab sessions are in Malet St MAL—404/405
- The class starts at 6 pm
  - Please join 5 minutes earlier
- Bring laptops/tablets in lectures – pen and paper

Let’s have an interactive class!

- Interrupt me any time you like
- **Participate in class. Making mistakes is good!**
- If you don’t get it, ask!
- Be gentle with MS Teams if you join online…

What is this module about?

- Small solutions for big problems!

Big data analytics is a new module

- Theory:
  - Fundamental algorithms
  - Data processing methods
  - Parallel and concurrent processing
  - Databases and Data warehousing
  - ML for Distributed data processing
  - Large language models
- Practice:
  - Python (100%)
  - MySQL
  - Cassandra
  - Hadoop MapReduce
  - BigQuery
  - Spark

Who should take this module

- This is a module for those who want to become programmers:
  - Programmers vs. Coders?
  - Software developers who want to learn solutions for developing applications using data!
  - Our goal is to learn how to develop code that scales to any problem

How to contact?

- **MS Teams (preferred way)**
  - Feel free to send at any time
- My office:
  - Room 151A (Office hours: Wednesday 5-6 pm)
- Virtual Office hours:
  - Any day and anytime, including weekends ☺
- Me email:
  - s.sotiriadis@bbk.ac.uk

Prerequisites

- **Excellent knowledge of programming with Python**
  - Or willing to work hard!
- Experience with advanced programming methods
  - Object-oriented programming, Functional programming, exception handling etc.

This is a heavily involved programming class!

The module is not for you if...

- You are not genuinely interested in the topic of programming for big data
  - This is a practical module
- You cannot put in the time: **1 hour in class requires 2-5 hours of study** outside of the class

Assessment

- No exam ☺
- 100% assignment (split into sub-parts)
  - **All tasks are programming-based with Python**
  - More to come soon!

Questions?

- Thank you!
- Ready to start?

Are you ready?

Patience you must have...

*Yoda

Let’s start with a short quiz!

Introduction to Big Data

What is big data about?

What is big data about?

- Amount of data
- Processing of data
- Real-time data
- Moving or transforming data

Example 1 – Real estate data

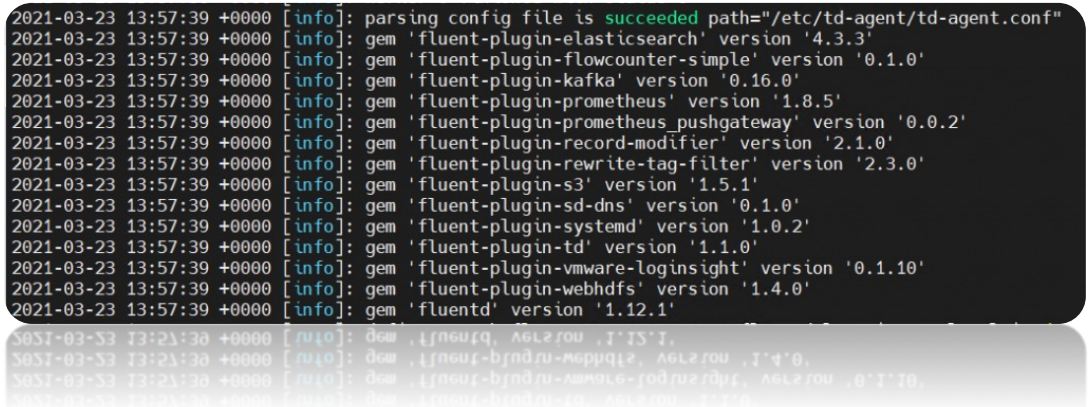
- Real estate company in London
  - 120GB of real estate data with US addresses
    - 160 million addresses (low dimensional data)
    - The provider gave us a CSV file (all the data)
  - Decide how to store the data
  - Decide how the app will use the data
  - Data needs to be updated once per month
    - New address added – fixes required

Example 2 – Real-time data analysis

- Use case:
  - A seizure, in the context of epilepsy, is a sudden surge of electrical activity in the brain that affects how a person appears or acts for a short time.
- Healthcare startup in Canada.
  - Requirement: 10GB of high-modality brain signal data
    - There were 24 channels to collect data - data streamed every 7 minutes.
    - Analyse data and decide within 7 minutes.
  - Decide how to collect, store and process data.
  - Run a complex ML algorithm and identify if there is a seizure.

Example 3 – Log data analytics

- Analyse log data from a database and determine if there are issues or anomalies.
- Requirement:
  - Apache Cassandra (NoSQL database)
  - Our setup generated 20TB of data per month!
- Problem: We don’t want to read the log files physically! → Impossible…
- Solution: Somehow, use a mathematical model to read our logs.



Big data analytics

- A set of methods and techniques to solve data-related problems.
- Related mainly to:
  - Data input/output operations
  - Computational operations

Velocity – Variety – Volume

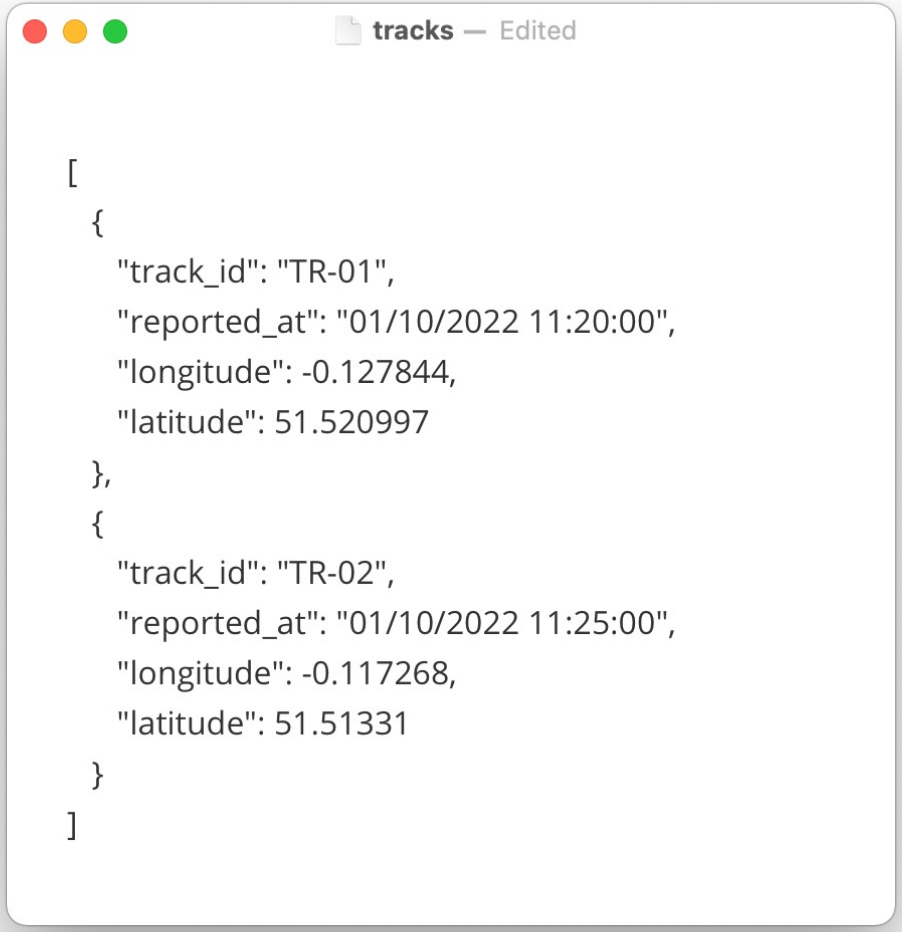
Velocity

- Batch:
  - Batch processing is about periodically processing high-volume, repetitive data jobs.
  - When you can wait for days (or longer) for processing (Payroll is a good example.).
- Near-time:
  - When speed is essential, but you don’t need it immediately.
  - Speed is essential but not instant.
- Real-time:
  - When you need information processed immediately (such as at a bank ATM).

Variety

- Structured
  - A customer database in a relational database management system (RDBMS) like MySQL, PostgreSQL, or Oracle.
- Unstructured
  - Customer feedback is collected through emails.
- Semi-structured
  - A JSON file containing user information.

What is a JSON file?

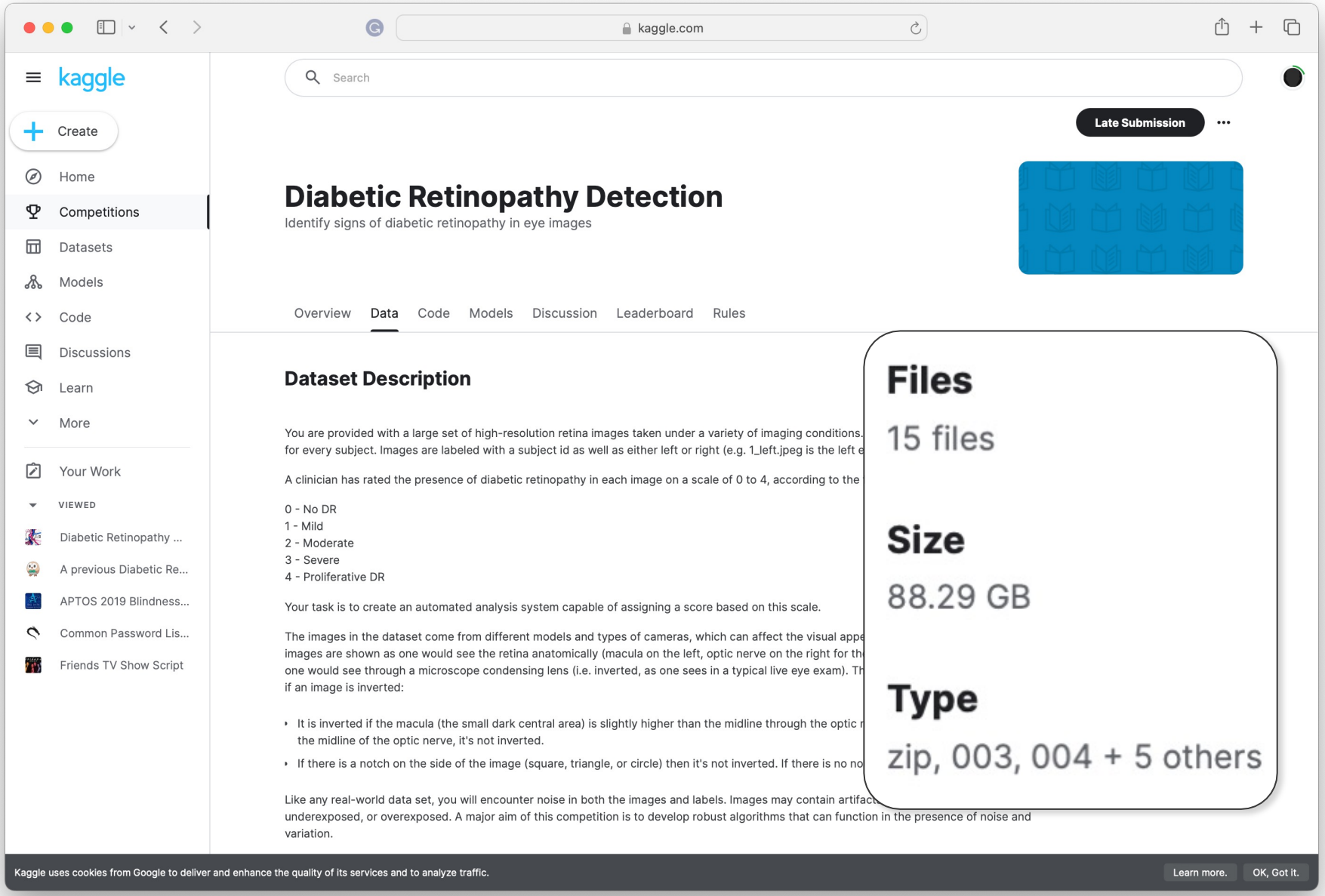


- A JSON file (tracks.json) data in a key:value format.
- It is primarily used for unstructured data storage.
- JSON files are lightweight, text-based, and human-readable.

[Link]

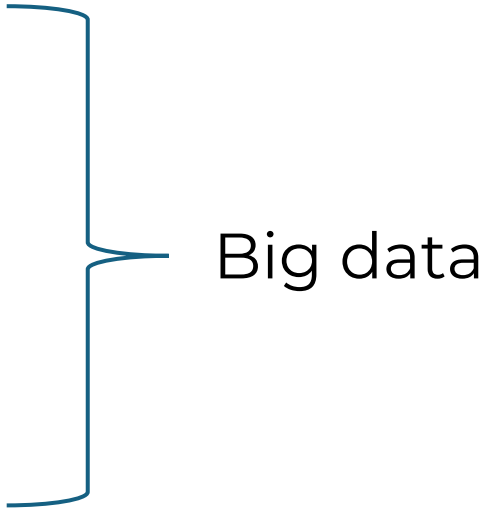
Volume

- Size of data.



Byte to Brontobyte

Unit	Equals
1 Bit	Binary digit (0/1)
8 Bits	1 Byte
1024 Bytes	1 Kilobyte
1024 Kilobytes	1 Megabyte
1024 Megabytes	1 Gigabyte
1024 Gigabyte	1 Terabyte
1024 Terabytes	1 Petabyte
1024 Petabytes	1 Exabyte
1024 Exabytes	1 Zettabyte
1024 Zettabytes	1 Yottabyte
1024 Yottabytes	1 Brontobyte

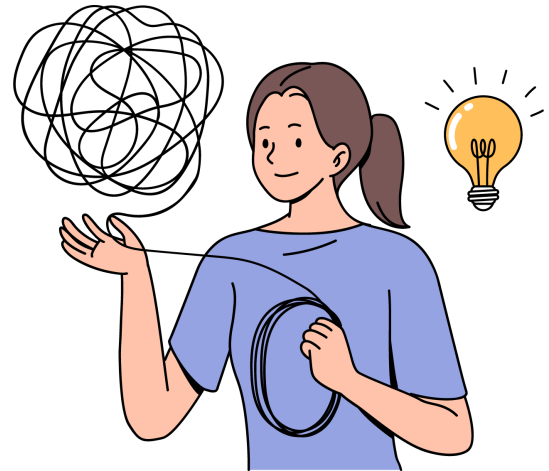


Why 1024B=1KB and not 1000?

- The **binary number system is base 2**, while the decimal number system is base 10.
- In the binary number system, every digit has a value of 1, 2, 4, 8, 16, etc. (powers of two).

Having a problem to solve...

- How to start?
  - Decide!
    - Is your problem CPU-bounded?
    - Is your problem Input/Output-bounded?
    - Or is it both?



Is it **CPU** or **data**-intensive?

- Matrix multiplication CPU-intensive
- Saving user input to text files Data-intensive
- Automating filtering of thousands of images (blur) Both

What about my examples?

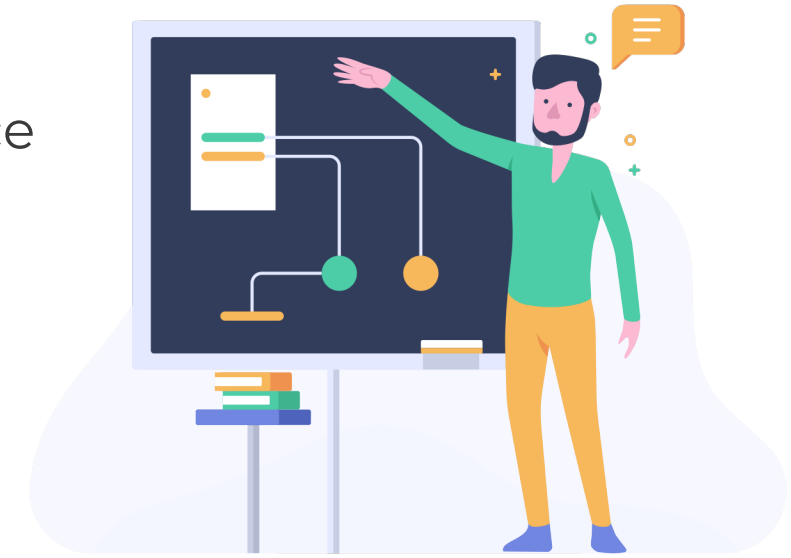
- Real estate data with US addresses.
- Brain signal analysis.
- Log data for anomaly detection.

What about my examples?

- Real estate data with US addresses.
  - I/O-bounded
- Brain signal analysis.
  - CPU-bounded
- Log data analytics for anomaly detection.
  - Combination of both! ☹

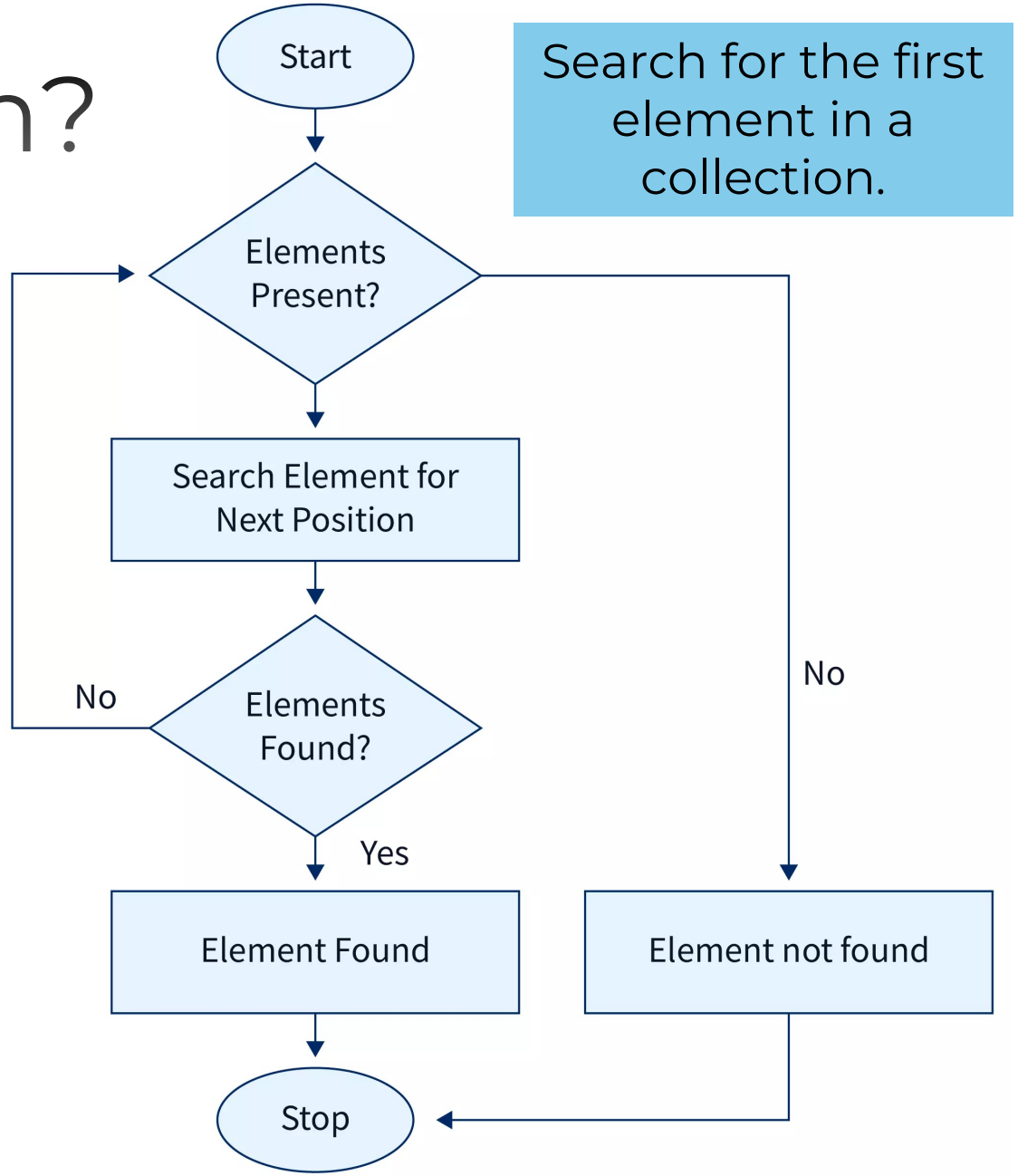
What is an algorithm?

- A set of steps to solve a problem.
- But is there only one way?
  - We must always answer the following question:
    - Is there a better way?
  - We need to find a way to quantify the performance of our algorithms (programs)



What is an algorithm?

- A set of steps to solve a problem.
  - There might be multiple ways...
- What does this algorithm graph?



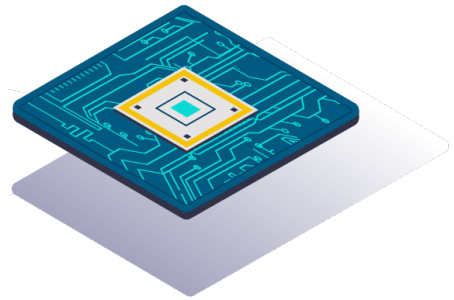
Algorithms can be complex

- Example:
  - Download stock market data from the web
  - Clean it
  - Transform it to a format (JSON)
  - Store it in a database
  - Apply ML to analyze it and find patterns to invest in
  - Get rich!

- This program includes sub-programs (sub-algorithms).
- Our programs can be seen as a set of tasks!
  - Computationally or data-intensive tasks

Computationally intensive tasks

- Use your mind to calculate 25*25
- Operations requiring significant computational power → CPU
  - Multiply two matrices
  - Blur thousands of images
  - Running a machine-learning model
- These tasks demand CPU/GPU and memory.



Data intensive tasks

- Use pen and paper to calculate 25*25
- Processing, managing, and manipulating large volumes of data
- Require significant data bandwidth and storage capabilities
- It is more about the amount of data rather than computations.
  - For example, downloading data from the web
  - Search for an address in a million addresses

How do we create good programs?

Does it make any difference (1)?

Script 1

That's better!

```
numbers = [10,20,30,40]

print(numbers[-1])
```

```
40
```

Script 2

```
numbers = [10,20,30,40]

for i in numbers:

  pass

print(i)
```

```
40
```

Does it make any difference ()?

Script 1

```
numbers = [1, 5, 2, 8, 3, 10, 4, 6]

results = []

for number in numbers:

    if number >= 100:

        results.append(number)

print(results)
```

```
[1, 5, 2, 8, 3, 10, 4, 6]
```

Script 2

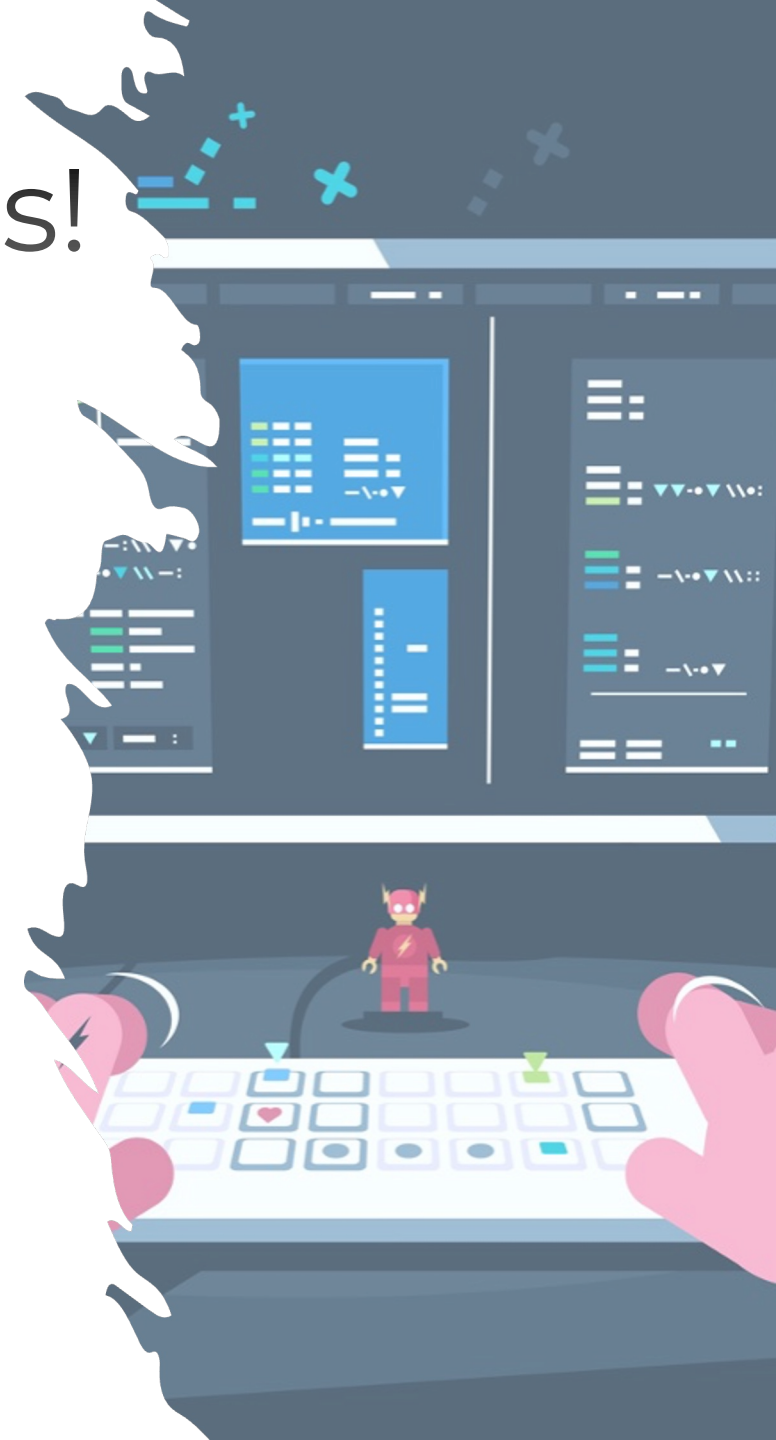
That's better (if we don't want to use extra space)!

```
numbers = [1, 5, 2, 8, 3, 10, 4, 6]

for i in range(len(numbers) - 1, -1, -1):

    if numbers[i] >=100:

        numbers.pop(i)

print(numbers)
```

```
[1, 5, 2, 8, 3, 10, 4, 6]
```

Operations & Space matters!

- Operations:
  - Number of iterations to solve a problem
  - How many times a for loop runs
- Space:
  - Amount of space needed to solve a problem
  - How many data do you store, temporarily or not



How do I quantify the quality of my solution?

Computational complexity

Time complexity examples

- Whenever you visit your local grocery store for some chocolate…
  - You know precisely which aisle/shelf has your favourite chocolate – you walk in and grab it.

    `Constant time (just one operation) – O(1)`
  - You need to find out its location, so you check each shelf in search of chocolate, one by one.

    `Linear time (one by one) – O(n)`
  - You are sorting all chocolates according to cocoa volume.

    `Quadratic time (compare all with all) – O(n^2)`

Space complexity examples

- You now grab a basket!
  - You find and pick your chocolate. Then you put your chocolate in your basket.

    Constant space (just one space used) - O(1)
  - You are unsure, you put all the chocolates in your basket, then you look again and select the one you prefer.

    Linear space (n space) - O(n)

Running time of an algorithm

- Algorithms:
  - Transform input into output
- Paradox:
  - Run time is not about the time to run a program!
  - It is about the amount of operations.

How many operations?

```
arr = [10,20,30,40]
  for i in arr:
    print(i)
```

4

```
arr = [1,2,3,...,n]
  for i in arr:
    print(i)
```

n

```
arr = [-10,-5,0,10,33]
  for i in arr:
    if i>0:
      print(i)
```

5

- We don't care about 4 or 5

  - it is always **n**!

Operations = len(arr)

Time complexity

Time complexity is about number of operations!

- Describes the amount of time it takes to run an algorithm as a function of the input length.
  - Expressed as Big O notations
- Best Case: The minimum time of program execution. **`Big-Omega(Ω)`**
- Average Case: The expected time for program execution. **`Big-Theta(Θ)`**
- Worst Case: The maximum time required for program execution. **`Big-Oh(O)`**
- Which one is the most important?
  - **`Big - Oh`**

Space complexity

- The total amount of the working storage that an algorithm needs.
- This memory usage might include not only the variables but also the space required for the input and output data:
  - Total Space: Includes input data space, auxiliary space (extra or temporary space), and output data.

Big O

- **`O(1) [Constant time]`**
  - Accessing an element in an array by index.
- **`O(N) [Linear time]`**
  - Linear search in an unsorted list or array.
- **`O(N2) [Quadratic time]`**
  - Nested loops where each loop iterates over the entire input size.

Group quiz

- What is the computational complexity?
  - Picking a random card from a deck of cards **O(1)**
  - Picking the last card **O(1)**
  - Searching for the first King of Spades **O(n)**
  - Counting the Queens **O(n)**
  - Sorting the cards **O(n^2)**
  - Picking the fifth card **O(1)**
  - Assuming you have 5 cards in your hand, you want to count Kings **O(5)**

Linear Search algorithm

- Linear search
  - An array of elements and a key. Does the key exist in the array?

```
def linearSearch(arr,key)
  for i in arr:
    if i==key:
      return True
  return False
```

Let’s see an example

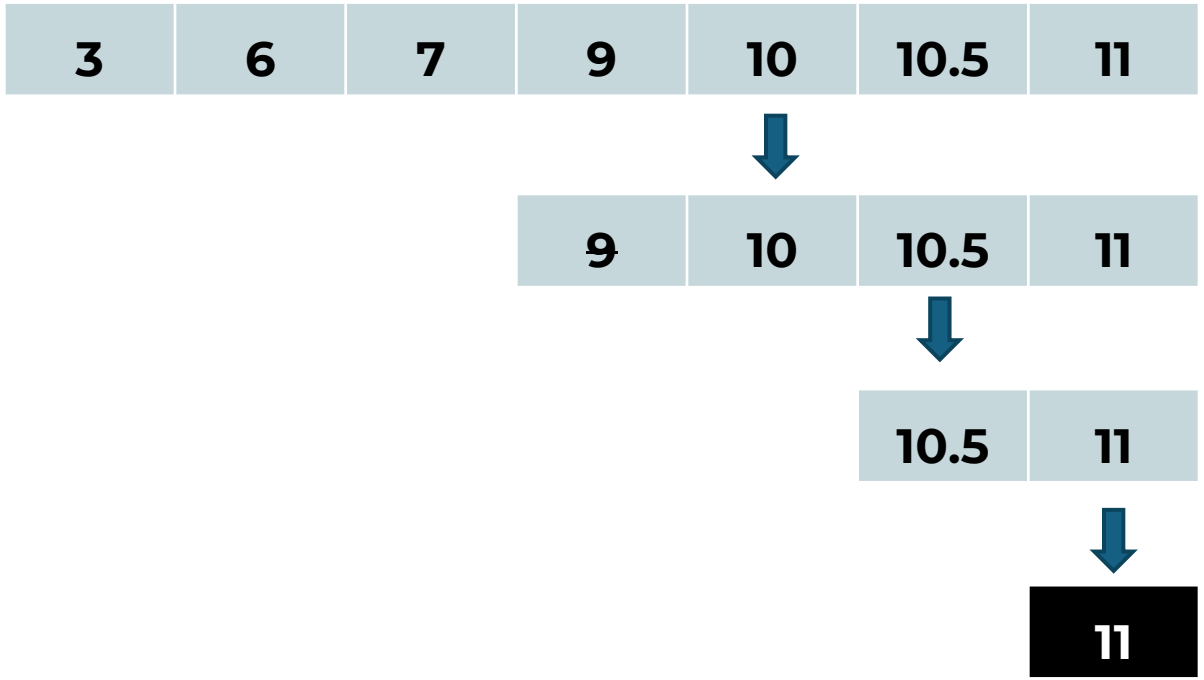
- **`A = [4, 9, 12, 16, 18], key=6`**
- In principle, there are ***`n`*** comparisons before we can say “no”.
  - We will spend five operations to search for a key.
  - We care about the worst-case scenario: **`5`** operations = **`O(5)`** = **`O(n)`**.
- What about this case?
  - **`B = [4, 9, 12, 16, 18], key=4`**
  - Still, we care about the worst-case scenario… **`O(n)`**

Can you do it better?

- You just opened a new deck of cards!
  - You removed the two jokers
  - You have 52 cards in order!
  - What is the time complexity to search for a King of hearts? **O(n)**
  - Can you do it better?

Can we do better?

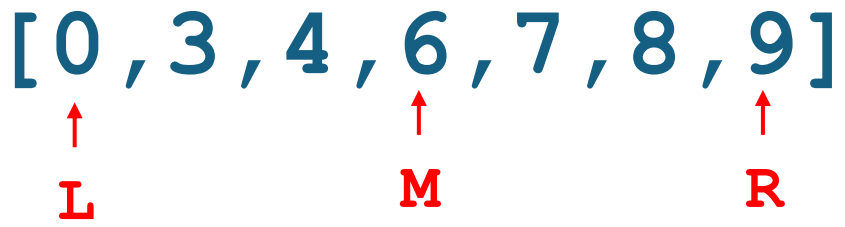
- `A = [3, 6, 7, 9, 10, 10.5, 11], key=11`



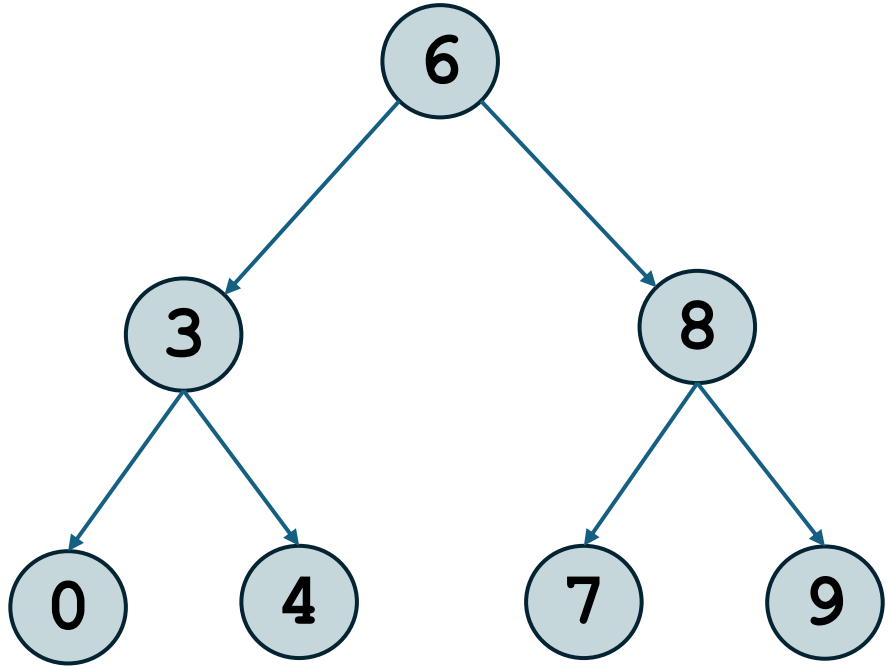
The search space is repeatedly divided in half during each iteration...

`O(logn)`

Binary search example



Binary Search

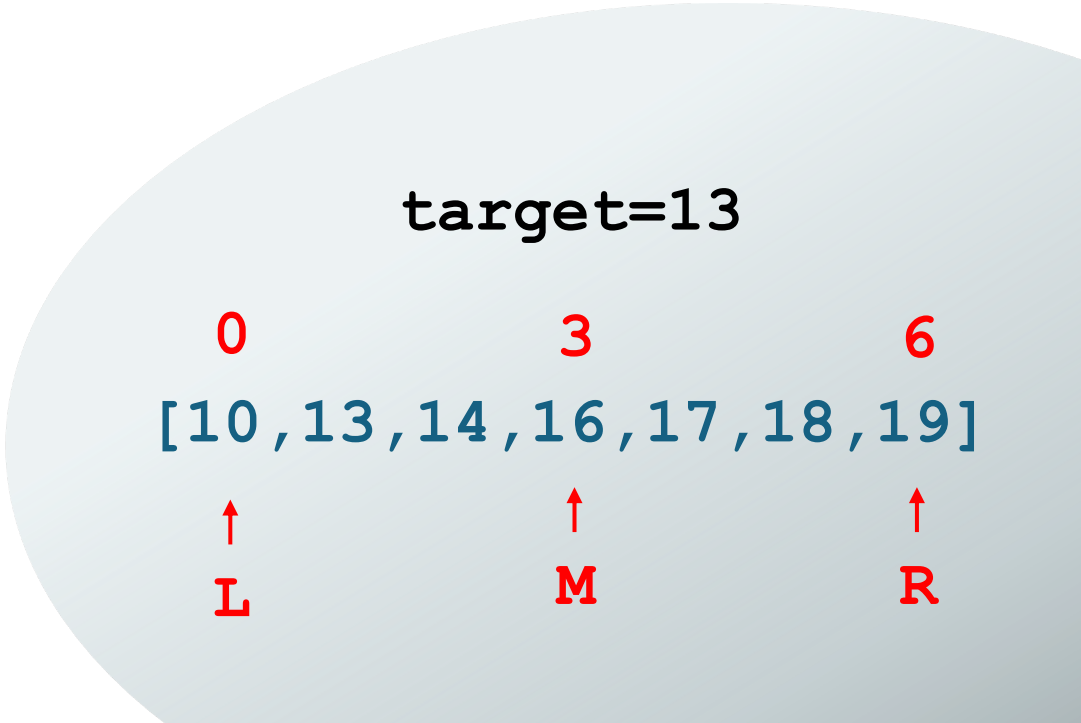


Binary Search Tree

Binary search

- Search in a **sorted array** by repeatedly dividing the search interval in half.
  - Begin with an interval covering the whole array.
  - If the value of the search key is less than the item in the middle of the interval, narrow the interval to the lower half.
  - Otherwise, narrow it to the upper half.

```
def binary_search(arr, target):
    left, right = 0, len(arr) - 1
    while left <= right:
        mid = left + (right - left) // 2
        if arr[mid] == target:
            return mid
        elif arr[mid] < target:
            left = mid + 1
        else:
            right = mid - 1
    return -1
```

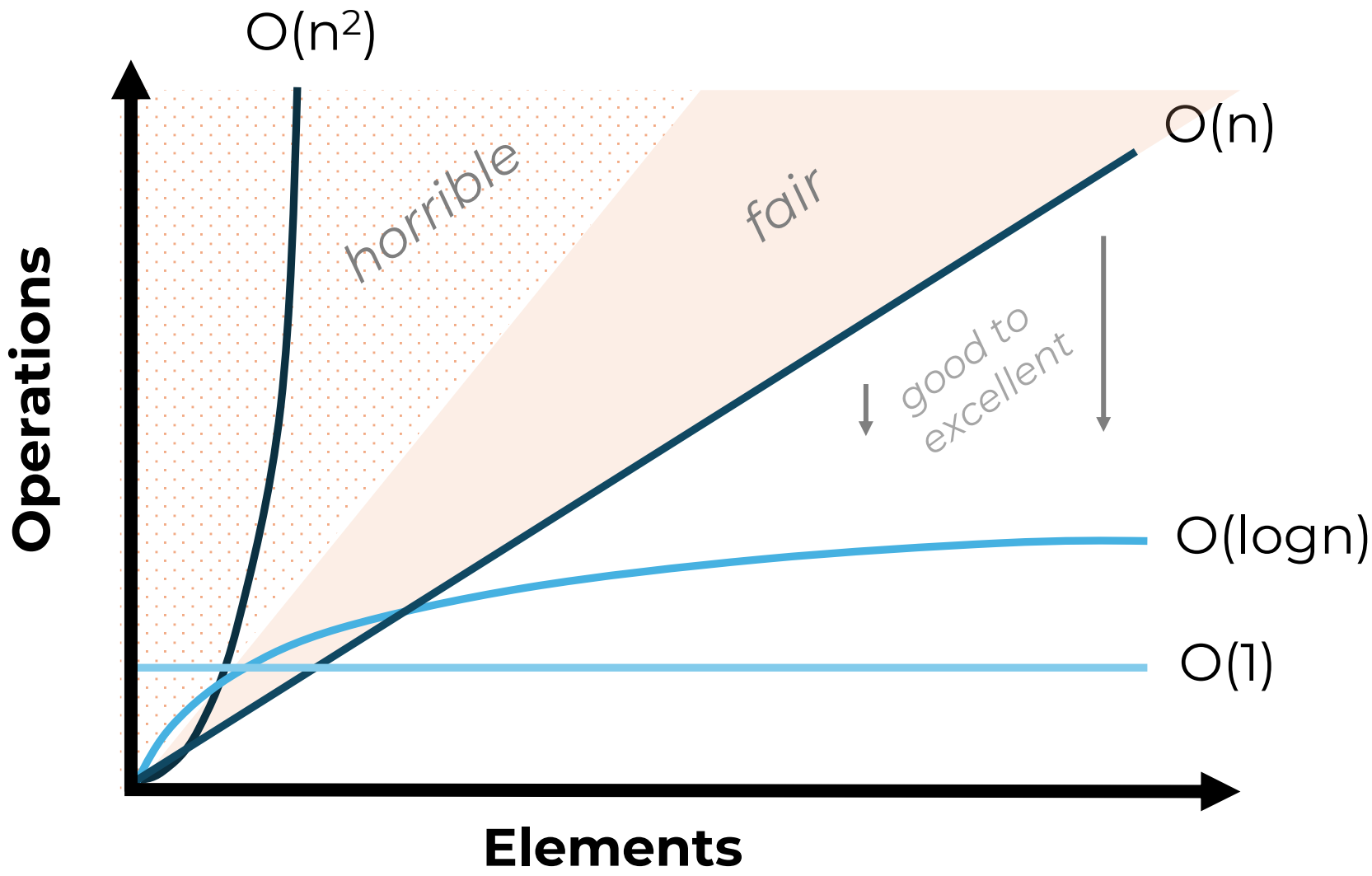


💡 Quiz

- How many iterations to find 23? **3**

```
[2,5,8,12,16,23,38,56,72]
```

Big-O Complexity Chart



Group quiz

- Write down all the possible permutations of ABC?

- **ABC**
- **ACB**
- **BAC**
- **BCA**
- **CAB**
- **CBA**

Can you think of a mathematical formula to generalise this example?

```
3! = 1*2*3 = 6
```

O(N!) [Factorial time]

- Generating all possible permutations of a set of elements is inherently factorial.
  - Consider a set of N elements
  - There are N! permutations to be generated

Group quiz

- You have been tasked with guessing a password.
  - The password includes three digits, each of which can be either 1 or 0. A digit may appear multiple times or not at all in the combination. Write down all the possible combinations!
  - Can you think of a mathematical formula to generalise this example?

```
2^3 = 8 = 2^n
```

- 000
- 001
- 010
- 011
- 100
- 101
- 110
- 111

O(2^N) [Exponential time]

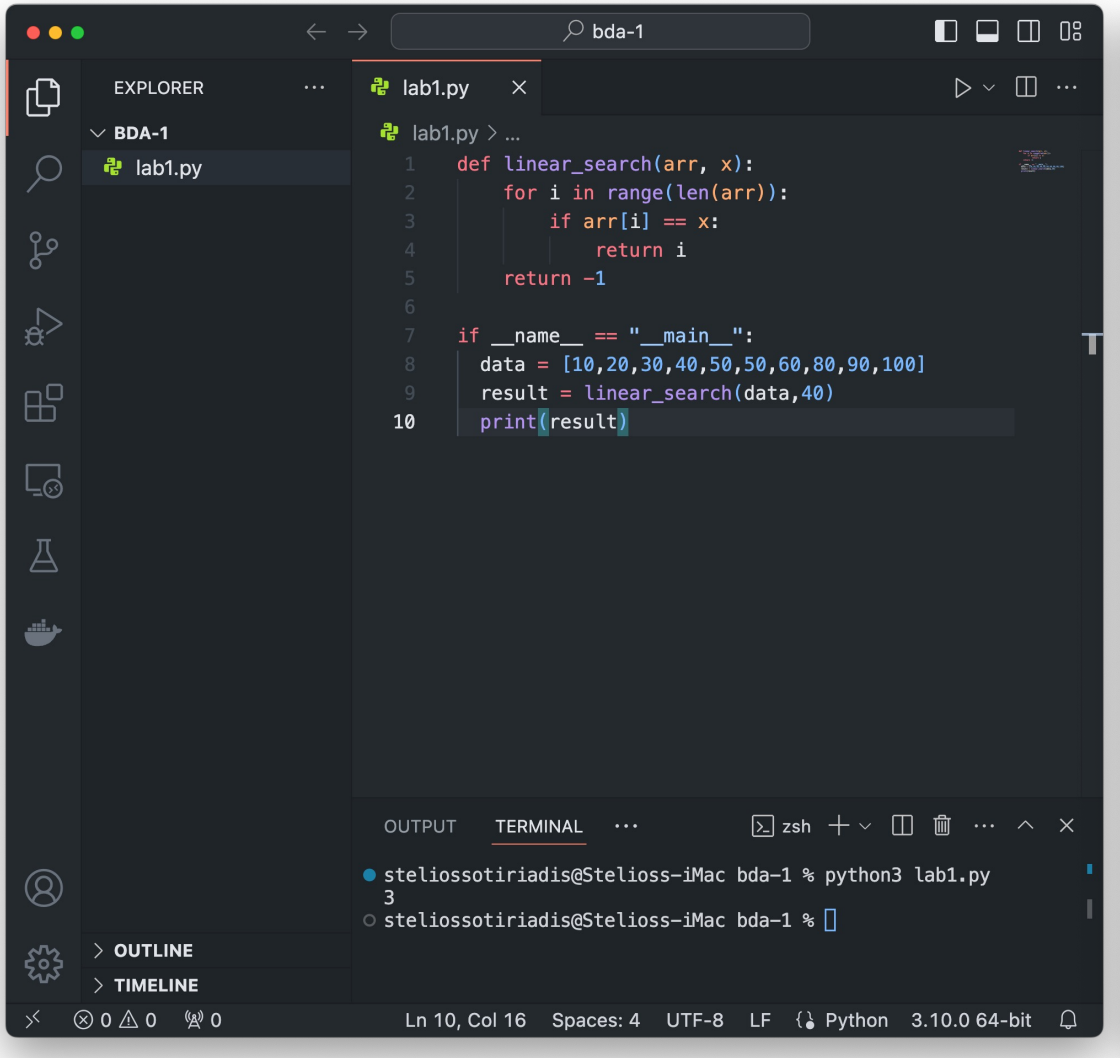
- All possible combinations!
  - Scenario: In security testing or hacking, generating all possible passwords up to a certain length, given a specific character set (brute-force password cracking).

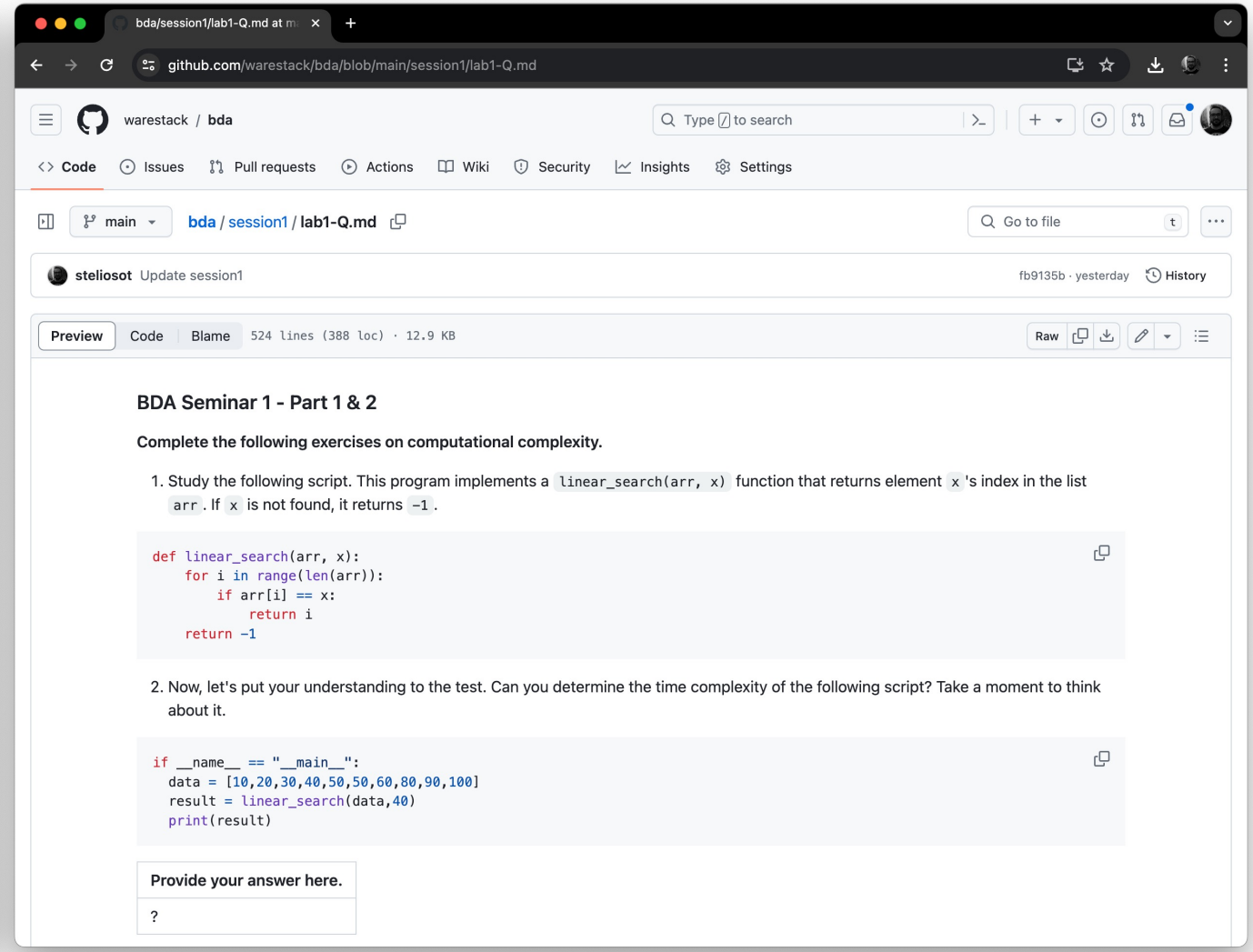
Lab 1

Big Data Analytics

How to run the lab?

[Link]





Lab activities

- Complete Lab1 activities and exercises
- Run the lab in your preferred Python editor
  - I recommend using Visual Studio Code
- Keep your notes as you prefer
- https://github.com/warestack/bda

Take home

- What are CPU and I/O bounded tasks?
- What is computational complexity?
- Discuss in practice how complexity affects code performance.