



# Stelios Sotiriadis

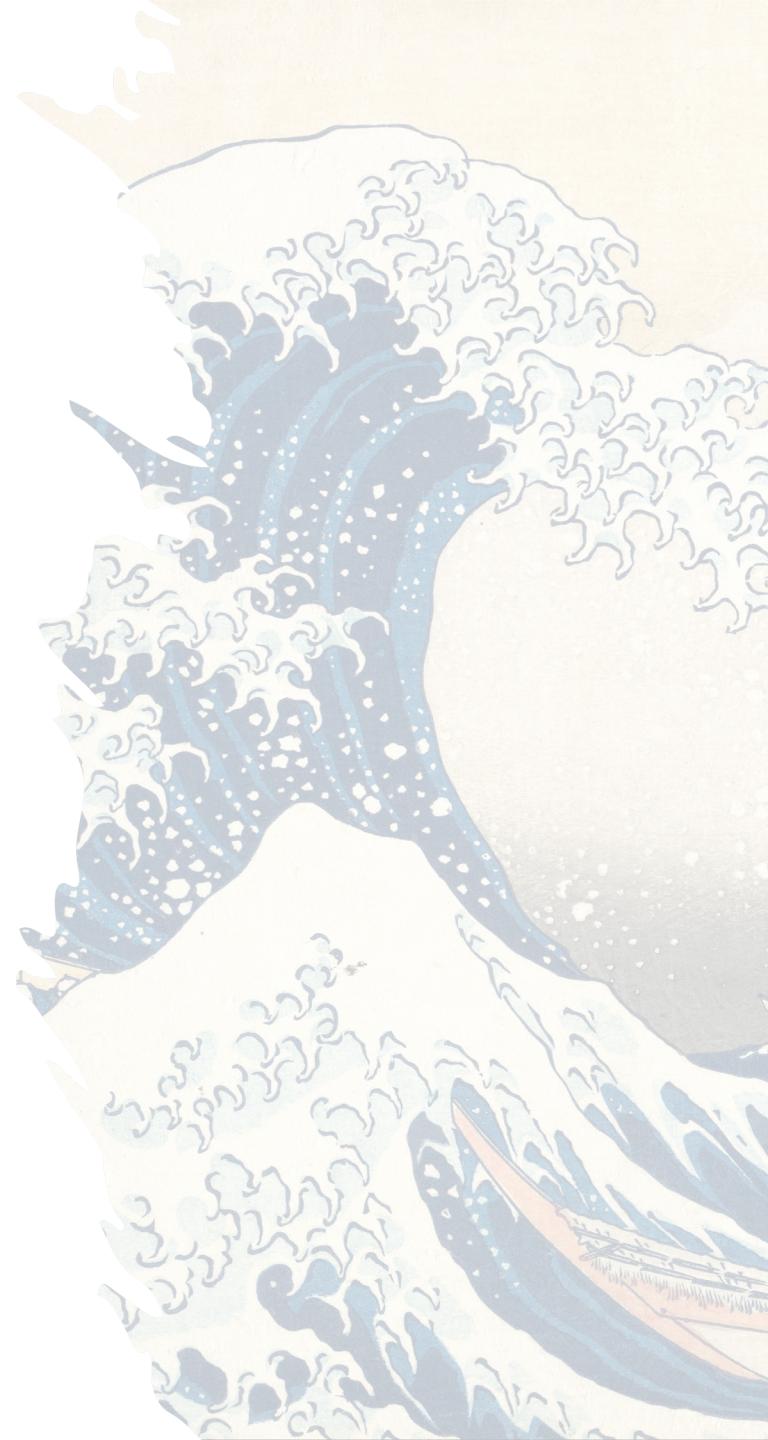
# 1. Introduction to Big Data Analytics

# About me!

- ▶ Lecturer at CS, PhD 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 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

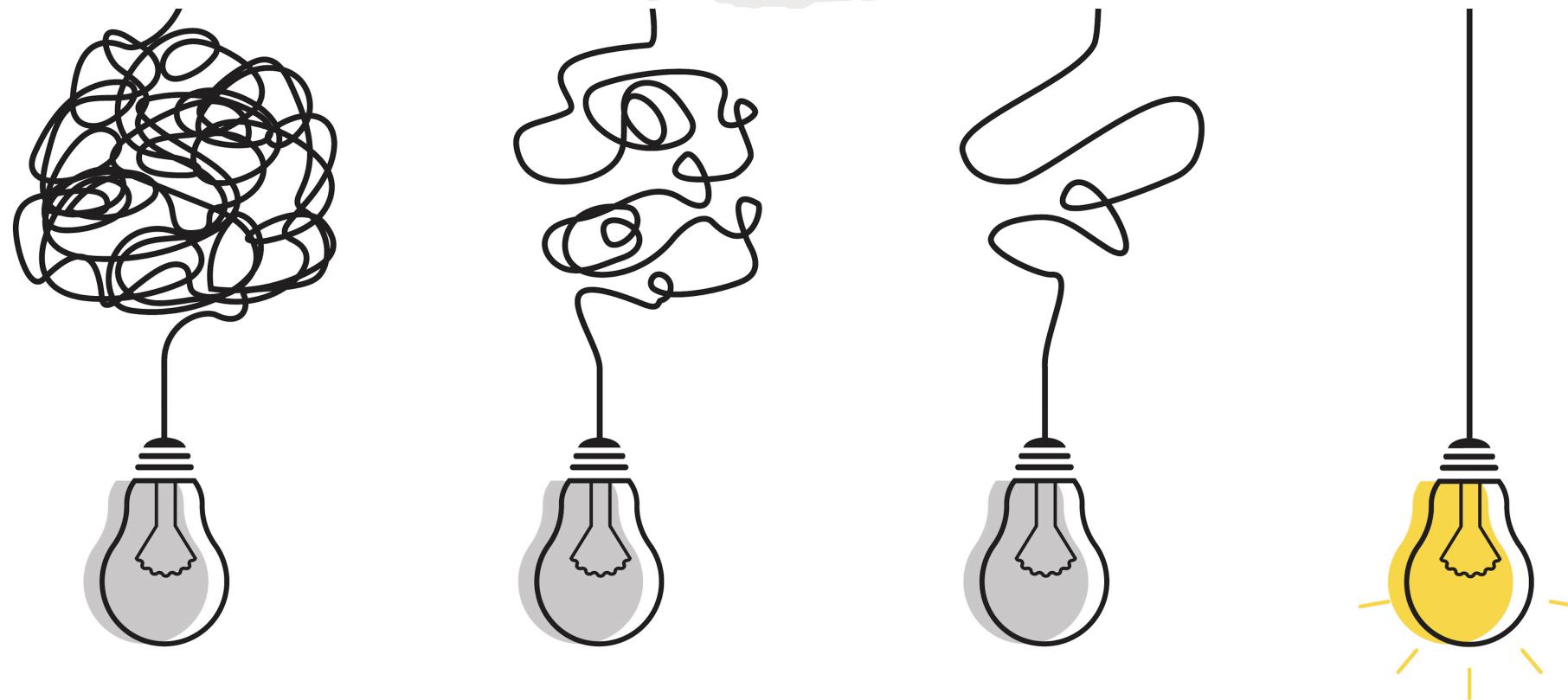
# Let's have an interactive class!

- ▶ Interrupt me any time you like
- ▶ Make mistakes...
- ▶ 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
  - Spark
  - Use of the Google Cloud platform  
(BigQuery, Buckets etc.)

# 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](mailto: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**
- ▶ There are two assessments:
  - Week 4 (release): Programming-based assignment (Python) – 40%
    - Web-crawler using parallel programming.
  - Week 7 (release): Programming-based assignment (Python) – 60%
    - Data warehouse application + analytics.
  - **Four weeks to complete.**

# Questions?

- ▶ Thank you!
  - Share your thoughts/feedback.
- ▶ 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



# Real estate data example

- ▶ 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



# Real-time data analysis example

- ▶ 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.

# Log data analytics example

- ▶ Analyse log data from a database and determine if there are issues or anomalies.
- ▶ Requirement:
  - Apache Cassandra (NoSQL database)
  - Our setup generated 20TB ≈ 3.33 trillion words 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.

```
2021-03-23 13:57:39 +0000 [info]: parsing config file is succeeded path="/etc/td-agent/td-agent.conf"
2021-03-23 13:57:39 +0000 [info]: gem 'fluent-plugin-elasticsearch' version '4.3.3'
2021-03-23 13:57:39 +0000 [info]: gem 'fluent-plugin-flowcounter-simple' version '0.1.0'
2021-03-23 13:57:39 +0000 [info]: gem 'fluent-plugin-kafka' version '0.16.0'
2021-03-23 13:57:39 +0000 [info]: gem 'fluent-plugin-prometheus' version '1.8.5'
2021-03-23 13:57:39 +0000 [info]: gem 'fluent-plugin-prometheus_pushgateway' version '0.0.2'
2021-03-23 13:57:39 +0000 [info]: gem 'fluent-plugin-record-modifier' version '2.1.0'
2021-03-23 13:57:39 +0000 [info]: gem 'fluent-plugin-rewrite-tag-filter' version '2.3.0'
2021-03-23 13:57:39 +0000 [info]: gem 'fluent-plugin-s3' version '1.5.1'
2021-03-23 13:57:39 +0000 [info]: gem 'fluent-plugin-sd-dns' version '0.1.0'
2021-03-23 13:57:39 +0000 [info]: gem 'fluent-plugin-systemd' version '1.0.2'
2021-03-23 13:57:39 +0000 [info]: gem 'fluent-plugin-td' version '1.1.0'
2021-03-23 13:57:39 +0000 [info]: gem 'fluent-plugin-vmware-loginsight' version '0.1.10'
2021-03-23 13:57:39 +0000 [info]: gem 'fluent-plugin-webhdfs' version '1.4.0'
2021-03-23 13:57:39 +0000 [info]: gem 'fluentd' version '1.12.1'

0..P..I., nofS19V_stbdddw-urjyq-trnusJt., map: [out]
```

# 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 screenshot of a Mac OS X application window titled "tracks — Edited". The window contains the following JSON data:

```
[  
  {  
    "track_id": "TR-01",  
    "reported_at": "01/10/2022 11:20:00",  
    "longitude": -0.127844,  
    "latitude": 51.520997  
  },  
  {  
    "track_id": "TR-02",  
    "reported_at": "01/10/2022 11:25:00",  
    "longitude": -0.117268,  
    "latitude": 51.51331  
  }]
```

- ▶ 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.

# Volume

- ▶ Size of data.

**Dataset Description**

You are provided with a large set of high-resolution retina images taken under a variety of imaging conditions, for every subject. Images are labeled with a subject id as well as either left or right (e.g. 1\_left.jpeg is the left eye).

A clinician has rated the presence of diabetic retinopathy in each image on a scale of 0 to 4, according to the following scale:

- 0 - No DR
- 1 - Mild
- 2 - Moderate
- 3 - Severe
- 4 - Proliferative DR

Your task is to create an automated analysis system capable of assigning a score based on this scale.

The images in the dataset come from different models and types of cameras, which can affect the visual appearance. Images are shown as one would see the retina anatomically (macula on the left, optic nerve on the right for the left eye). One would see through a microscope condensing lens (i.e. inverted, as one sees in a typical live eye exam). This is if an image is inverted:

- It is inverted if the macula (the small dark central area) is slightly higher than the midline through the optic nerve. If the macula is lower than the midline of the optic nerve, it's not inverted.
- If there is a notch on the side of the image (square, triangle, or circle) then it's not inverted. If there is no notch, it's not inverted.

Like any real-world data set, you will encounter noise in both the images and labels. Images may contain artifacts such as dust specks, underexposed, or overexposed. A major aim of this competition is to develop robust algorithms that can function in the presence of noise and variation.

**Files**  
15 files

**Size**  
88.29 GB

**Type**  
zip, 003, 004 + 5 others

Kaggle uses cookies from Google to deliver and enhance the quality of its services and to analyze traffic.

Learn more. OK, Got it.

# Byte to Brontobyte

Unit	Equals	# Words
1 Bit	Binary digit	0/1
8 Bits	1 Byte	1 word ( <a href="#">ASCII</a> )
1024 Bytes	1 Kilobyte	≈ 166 words
1024 Kilobytes	1 Megabyte	≈ 166,667 words
1024 Megabytes	1 Gigabyte	≈ 166.67 million
1024 Gigabytes	1 Terabyte	≈ 166.67 billion
1024 Terabytes	1 Petabyte	≈ 166.67 trillion
1024 Petabytes	1 Exabyte	≈ 166.67 quadrillion
1024 Exabytes	1 Zettabyte	≈ 166.67 quintillion
1024 Zettabytes	1 Yottabyte	...
1024 Yottabytes	1 Brontobyte	...



Big data

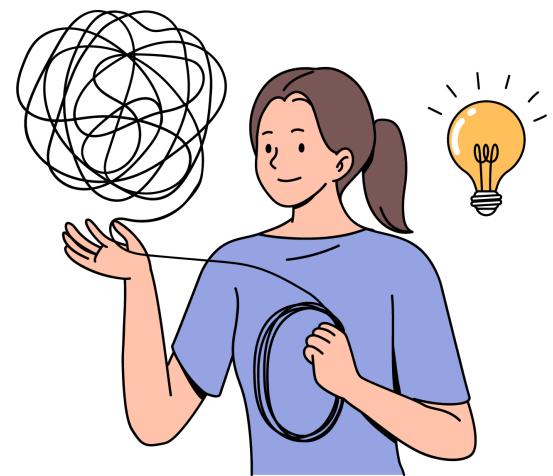
# Why $1024B=1KB$ and not 1000?

- ▶ 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?

- ▶ Rotating thousands of images    CPU-intensive (Matrix multiplication)
- ▶ Storing user input to text files    Data-intensive
- ▶ Blurring thousands of images)    Both!

# What about my examples?

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

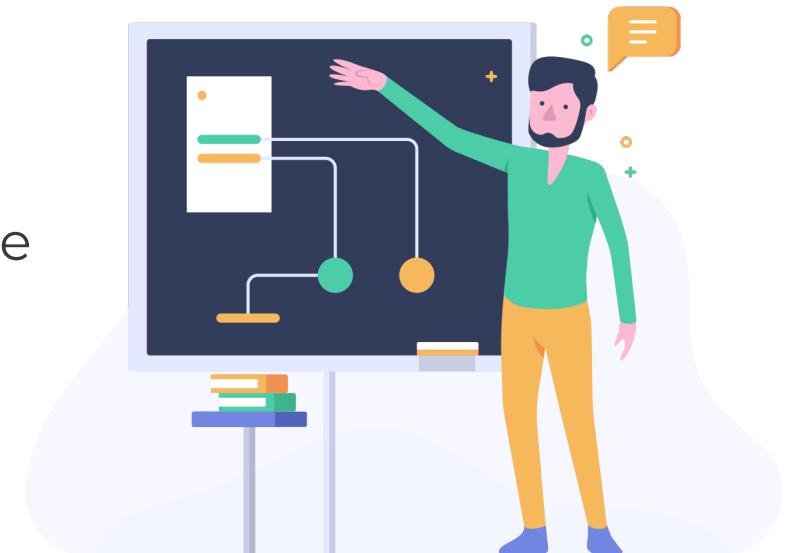


# What about my examples?

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

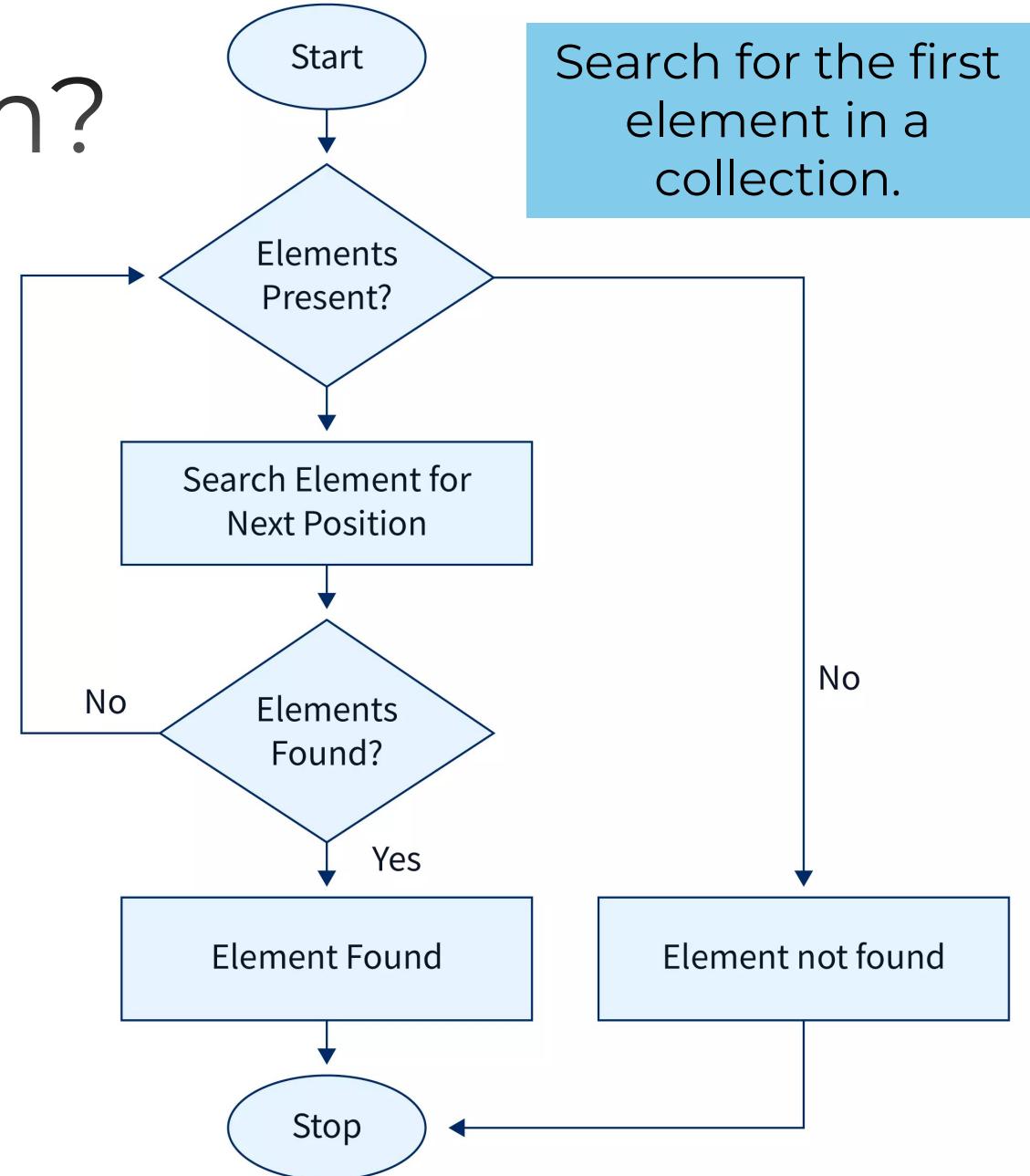
# Having a problem to solve, how do we start?

- ▶ Algorithms!
  - 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?

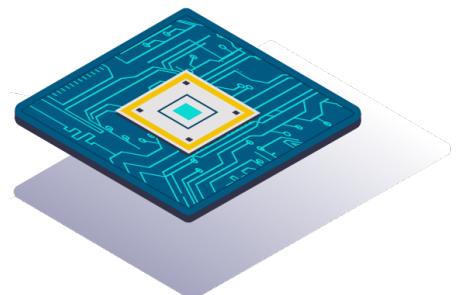


# Algorithms can be complex

- ▶ 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
  - Multiplying two matrices, 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 images 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

```
numbers = [10,20,30,40]  
  
print(numbers[-1])
```

That's  
better!

## Script 2

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

# Does it make any difference (2)?

## Script 1

```
arr = [1, 5, 2, 8]

results = []

for number in arr:

    if number >= 5:

        results.append(number)

print(results)
```

[5,8]

## Script 2

```
arr = [1, 5, 2, 8]

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

    if arr[i] < 5:

        arr.pop(i)

print(arr)
```

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

[5, 8]

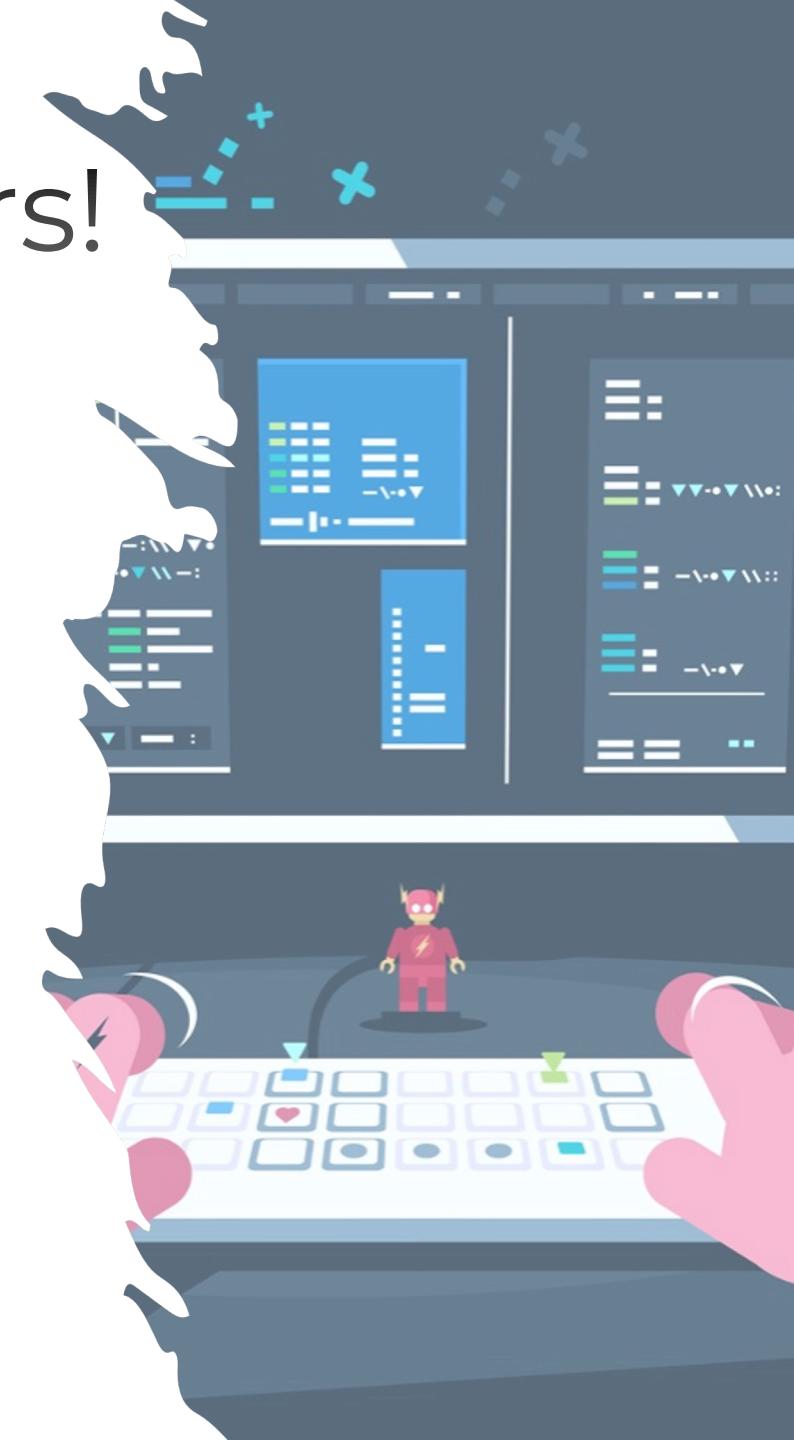
# Operations & Space matters!

- ▶ 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 ( $\Omega$ )**
- ▶ Average Case: The expected time for program execution. **Big-Theta ( $\Theta$ )**
- ▶ Worst Case: The maximum time required for program execution. **Big-Oh ( $O$ )**

# Big O notations

- ▶ Searching an element of a list
- ▶ Best Case
  - $\Omega(1)$  - Element is first 😊
- ▶ Average Case
  - $\Theta(n/2)$  - Element in the middle 😊
- ▶ Worst Case
  - $O(n)$  - Element is last 😞
- ▶ Which case should we focus on the most?
  - Big - Oh - Worst case!**

# 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.

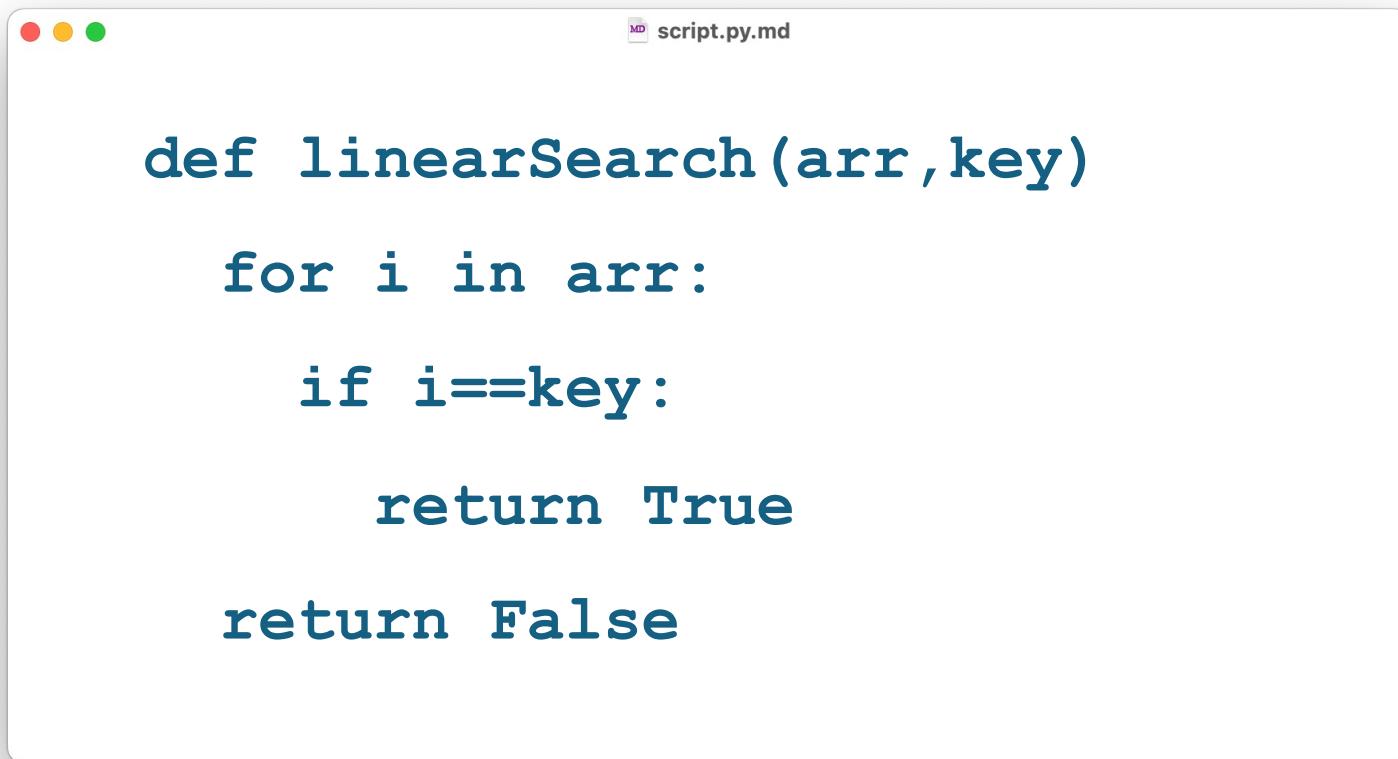
- ▶ **O(n^2) [Quadratic time]**

- 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  **$O(1)$**

# Linear Search algorithm



A screenshot of a code editor window titled "script.py.md". The code inside the window is:

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

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

# 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)**

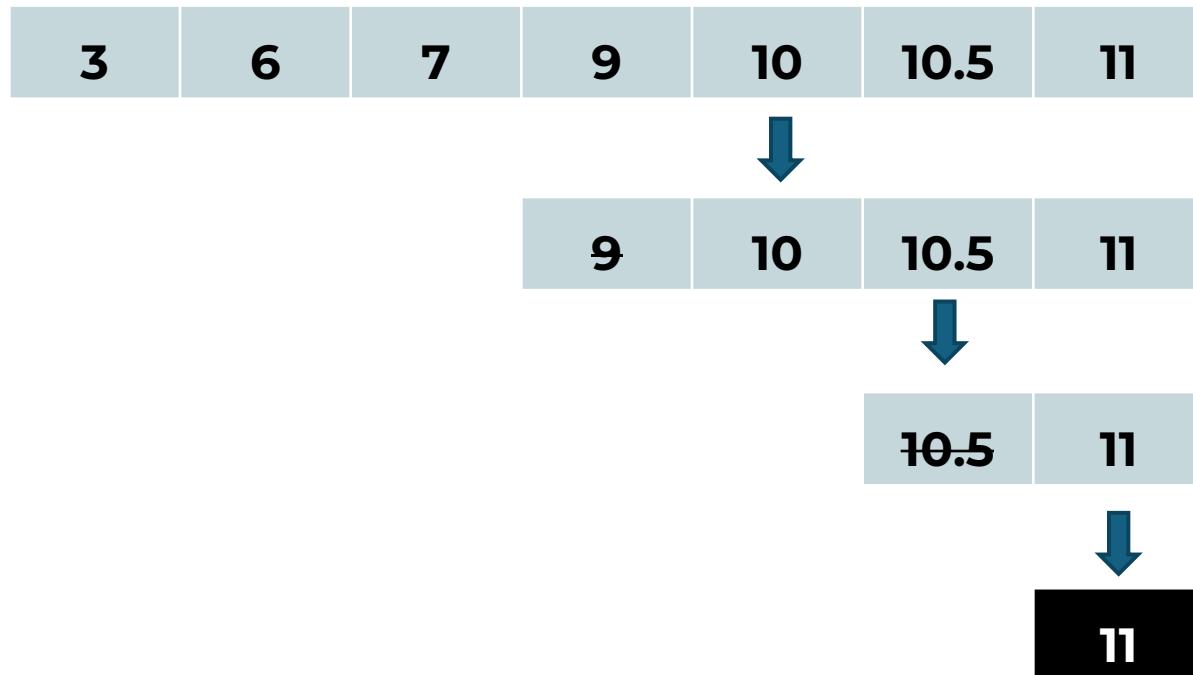
# Group quiz

- ▶ 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?
  - Can you do it better?
- ▶ Can you do it better than **n**?

**Yes!**

# Can we do better?

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



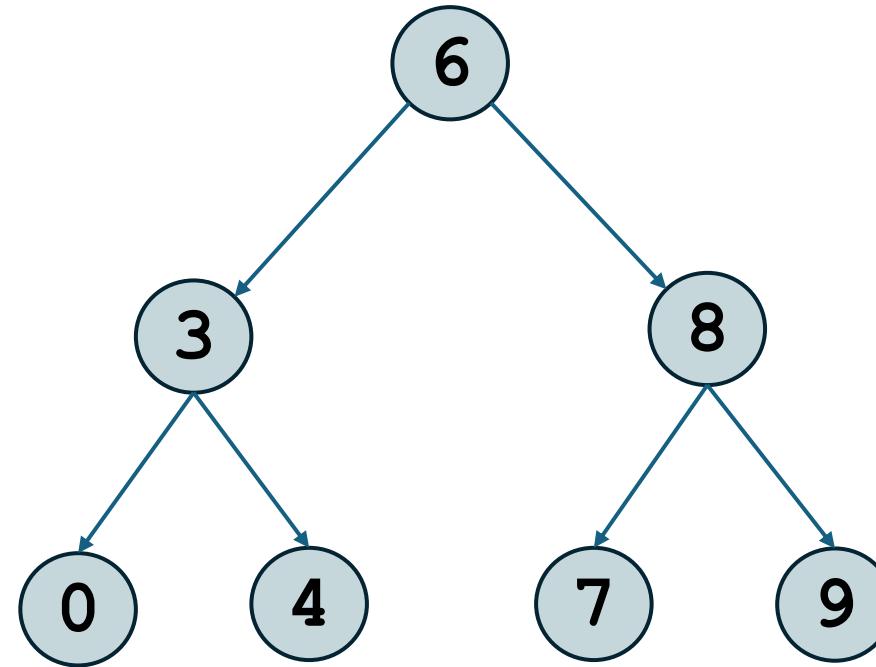
The search space is repeatedly divided in half during each iteration...

$O(\log n)$

# Binary search example

[0, 3, 4, 6, 7, 8, 9]  
↑  
L      M      R

Binary Search



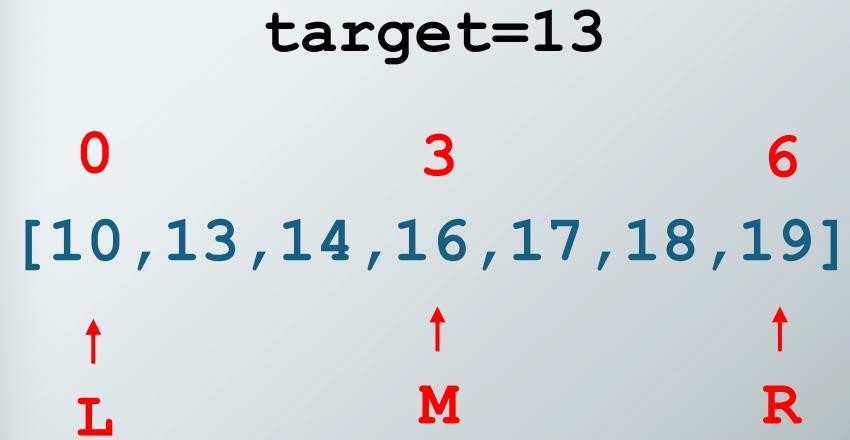
Binary Search Tree

# 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
```





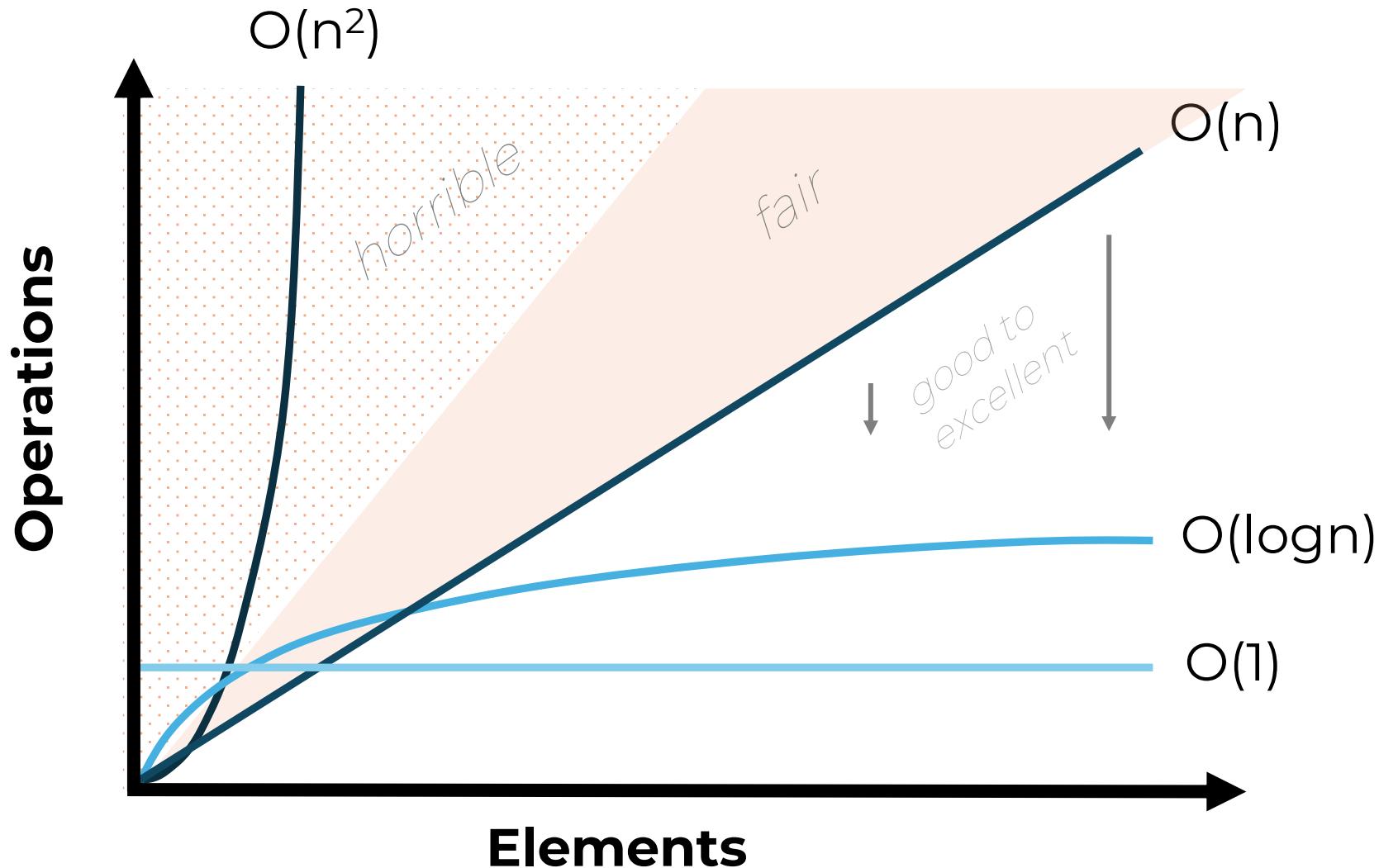
# Quiz

- ▶ 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?
  - 000
  - 001
  - 010
  - 011
  - 100
  - 101
  - 110
  - 111
- $2^3 = 8 = 2^n$**

# $O(2^N)$ [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).

# Thank you!

- The lab starts soon (404-405)!

O (no!)



# Lab 1

Big Data Analytics

# How to run the lab?

[Link]

A screenshot of the Visual Studio Code (VS Code) interface. The title bar says "bda-1". The left sidebar shows icons for Explorer, Search, Open, and others. The main area shows the "EXPLORER" view with a folder "BDA-1" expanded, containing "lab1.py". The code editor shows the following Python script:

```
def linear_search(arr, x):
    for i in range(len(arr)):
        if arr[i] == x:
            return i
    return -1

if __name__ == "__main__":
    data = [10,20,30,40,50,50,60,80,90,100]
    result = linear_search(data,40)
    print(result)
```

The terminal at the bottom shows the command "python3 lab1.py" being run, resulting in the output "3".

Bottom status bar: Ln 10, Col 16 Spaces: 4 UTF-8 LF Python 3.10.0 64-bit

A screenshot of a GitHub repository page for "warestack/bda". The repository name is "bda". The page shows a file named "lab1-Q.md". The content of the file is:

### BDA Seminar 1 - Part 1 & 2

Complete the following exercises on computational complexity.

1. Study the following script. This program implements a `linear_search(arr, x)` function that returns element `x`'s index in the list `arr`. If `x` is not found, it returns `-1`.

```
def linear_search(arr, x):
    for i in range(len(arr)):
        if arr[i] == x:
            return i
    return -1
```

2. Now, let's put your understanding to the test. Can you determine the time complexity of the following script? Take a moment to think about it.

```
if __name__ == "__main__":
    data = [10,20,30,40,50,50,60,80,90,100]
    result = linear_search(data,40)
    print(result)
```

Provide your answer here.

?

# 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.