DE VINCI
INNOVATION
CENTER

# Data Structure and Algorithms

Workshop Sheet

# 1. Warm-up

## a. O.O.P

### i. Vec2

1. Implement a Vec2 class, representing a 2 dimensional vector, you have to implement methods to compute the L2 norm of the vector.
2. Add methods to support addition subtraction and multiplying by a scalar. Make these operations in-place, make them return a new Vec2
3. Create a Referential class representing the base in which this vector is. Create a class BasedVec2 which extends from Vec2.
4. What is the problem if you add a Referential to the Vec2 class ?
5. Override the add, sub methods in BasedVec2 to throw an error if operation on 2 vectors in different bases is performed. Make these new methods call the ones from vec2.
6. Make a method in the Referential class to project a vector from another Referential in this Referential, effectively changing the vector's base.

### ii. Shapes

1. Using Matplotlib, find a way to draw a line between two points. Then multiple lines on the same graph.
2. Write a Shape class that takes a list of Line (You can also create a Line class), that can accept new lines (e.g with a accept(line)) and can draw them all and display a matplotlib window with a show() method.
3. Make a Square, Rectangle and Line classes that can be constructed with an origin, and the different elements required to build them. (Square has origin, size. Rectangle has origin, width, length)
4. Create a Circle class. Where should you call the plt.plot code ? Modify Shape to accept something else than Lines.
5. Create a Face class with a circle head, eyes and a smile :)  Print multiple faces :):):)

## b. Event Based

Event based programming is widely used in video games and in the web domain. The goal is to create a Event Based local web server using the http.server built-in Python module.

1. Use the code snippet available here to create a simple python web server. Call this file with python and go to http://127.0.0.1:8000

2. Create a MyHandler class which extends http.server.SimpleHTTPRequestHandler override the do_GET method to print something in the console, then call the super do_GET method
3. Make the server stop on the third page load

### c. Recursion

1. Write a program that calculates the sum of a list, using recursion
2. Using recursion, write a program that converts any integer to a string in a base between 2 and 9
3. Write a program, using recursion to sum all the elements of a list even with in-depth lists (Example f([1, [1, 2], [[1], [2,3]]) = 10)
4. Write a recursive to put a number to a certain power

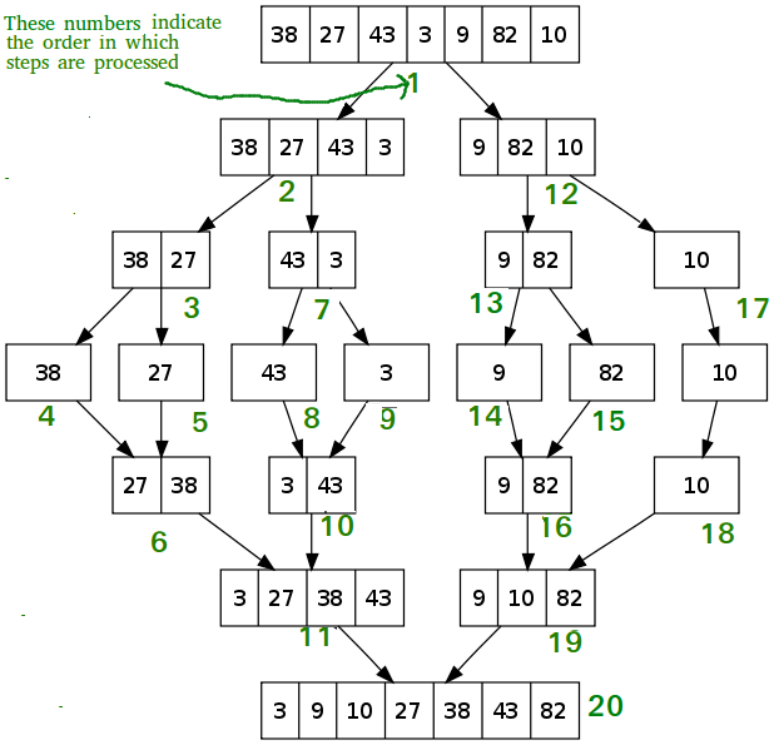
## 2. Essential Data Structures

### a. Stack

1. In Python, write a Stack class that has a add, pop and size method (use __len__ as an alias for size)
2. In C, create a Stack struct, determine what it should contain to be as general as possible, write stack and unstack methods.
3. In any language, write a program to check if a given string has balanced parenthesis. (Eg: “((())()())” is balanced, “)()(“, “(()” are not)
4. Write a calculator that accepts elements in Postfix notation. (E.g: Instead of 2+1, you would input 2 1 +. And instead of (2+1)*4 you would input 2 1 + 4 *)

### b. Array

1. Write a function that finds the smallest value in an array
2. Write a function that returns the index of the smallest element in the array
3. Write a function that finds duplicate values in an array. (Assume there is only one duplicate)
4. Write a function that moves all the 0 of an array at the end.
5. Write a recursive function that sorts an array using the Merge Sort method (see below)




6. Write a program to find two elements in an array whose sum is equal to a given number.
7. Given two ordered arrays, write a function that merges the two arrays while maintaining the order.

## c. Linked List

1. Implement a Linked List in C (with struct) or Python (with a class). Implement the methods to get the n-th element in the list, insert, remove, add an element at the end of the list and get the size of the list.
2. Write a function to check if a given element is in the list
3. Write a double linked list: each node has access to its next and previous element. Write the insert, delete methods for double linked list
4. Write a program to display a linked list in reverse order. Write a function that reverses the order of the list in place.

## d. Hash Map

1. Write a function to sort a Python dictionary
2. Write a function merge two dictionaries
3. Write a function that takes a string and returns a dictionary in which each key is a letter and value the number of times the letter appears in the string
4. Write a program that finds common keys in two dictionaries

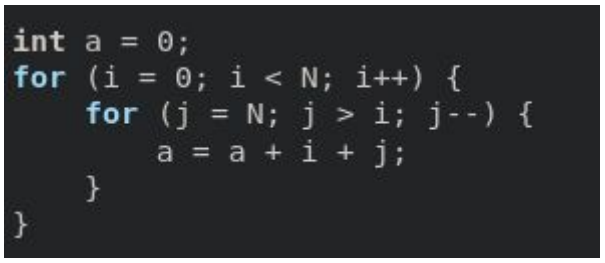
5. Write a program that take two dictionaries and merges them and sum the values of the keys that are in common
6. Write a program to save a dictionary to a file and to load a dictionary from a file

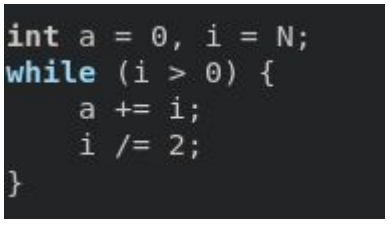
## e. Problems

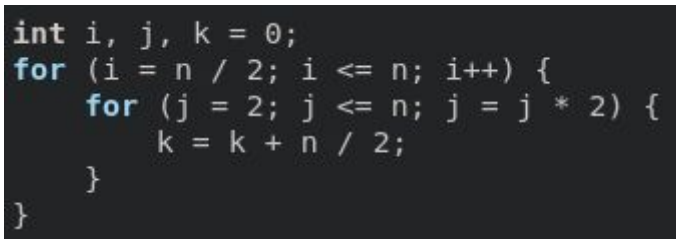
1. Write a function to encode a string in morse code
2. Write a function that take two arrays of integers and returns True if the two arrays combined would form a consecutive sequence (even if unordered)
3. Given an unordered array find the largest possible consecutive sequence in an array (E.g: [100, 2, 1, 50, 3] -> [1, 2, 3])

# 3. Complexity

Calculate the complexity of these algorithms:

1. 
```
int a = 0;
for (i = 0; i < N; i++) {
    for (j = N; j > i; j--) {
        a = a + i + j;
    }
}
```

2. 
```
int a = 0, i = N;
while (i > 0) {
    a += i;
    i /= 2;
}
```

3. 
```
int i, j, k = 0;
for (i = n / 2; i <= n; i++) {
    for (j = 2; j <= n; j = j * 2) {
        k = k + n / 2;
    }
}
```

4. What is the complexity of the Merge sort algorithm you wrote earlier ?
5. Write a recursive function to compute the fibonacci sequence. What is the complexity of this function? Write an iterative function that has better complexity.

# 4. Graphs

## a. Getting started

1. Create a graph node class and implement methods to connect/disconnect nodes
2. Make a method to print out the graph layout
3. Make a method to transpose an adjacency matrix to a graph node, make a method that does the opposite
4. Modify the class to make an oriented graph, modify the connect method
5. Modify the class to make a weighted graph, modify the connect method to specify the weight
6. The Dijkstra algorithm is an algorithm to find the shortest path between two nodes in a graph. Implement this algorithm using the structures you just created
7. A* is another form of algorithm to find the shortest path between two nodes in a graph. Implement it in a 2D plane. You first have to find a way to model your graph and represent walls.

## b. Applications

Some examples of how graphs are applied to everyday software.

1. State Machine: State machines are oriented graphs, with each edge being an action to perform. State Machines are a subset of Automaton, and are used to model a lot of real world problems, but are also used in video games for animation.
    - Write a state machine that has a default position and accepts actions, which update the state machine. Using actions such as “time passed”, “key pressed”, “key released”, “character touches ground” explain how to make a state machine to render character animation.
    - Optional: You can implement this state machine using PyGame and a simple listener.
2. Friend Graph: How would you model friendship the way it works on facebook ?
3. GPS: How would you model a roadway for a GPS application ? How would you find the shortest path between your location and destination ?

## c. (Very) Hard Graph Problems

A set of very hard problems, go as far as possible, don’t get discouraged if you can’t solve them: some of them are current research subjects.

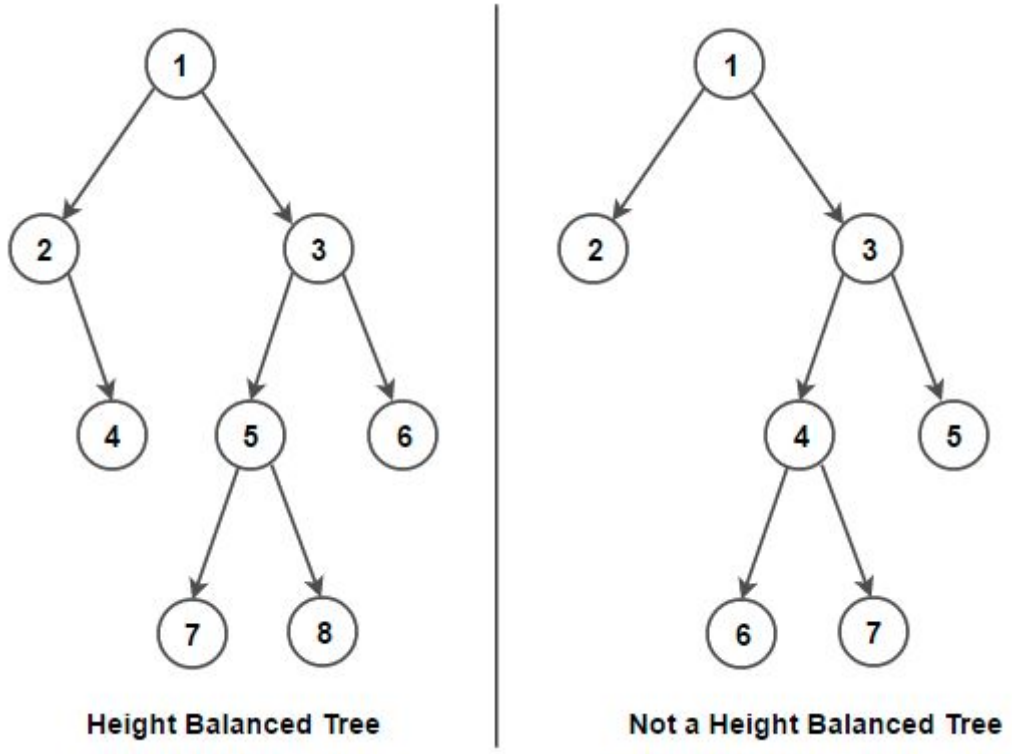
- Traveling salesman: Given a graph, find the cycle with the minimum cost (weight cost)
- Clique: Given a graph, find the largest subset of vertices that are fully connected
- Independent Set: Given a graph, find the largest subset of vertices that are not connected

- Vertex Cover: Given a graph, find the smallest subset of vertices such as any edge in the entire graph contains at least one vexter in that subset

# 5. Trees

## a. Discovery

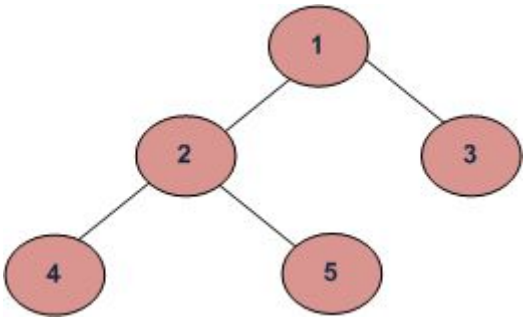
1. Trees and Graph can be implemented in very similar ways, but try to make a Tree and TreeNode classes. Add insert, delete methods in the same saw you did for graphs.
2. Using the Graph tools you made earlier, write a function that determine if a graph is a tree
3. Write a special structure for Binary Trees in which you can access the left and right children easily.
4. Write a function to find the depth of a given tree
5. A **Balanced Binary Tree** is a tree in which the depth of the two subtrees of every node never differ by more than 1. Eg:




6. Write a function that checks if a binary tree is balanced
7. Write a function to balance an unbalanced binary tree

## b. Manipulating trees

- Write a function that print values of a binary tree in a specific order




Eg; here Write 3 functions that write the values in the specified order when supplied this example graph:

| | |
|---|---|
| infix | 4 2 5 1 3 |
| prefix | 1 2 4 5 3 |
| postfix | 4 5 2 3 1 |

- **Kd-Trees** is a space segmentation technique very useful to find points in space that are close to each other. Given a set of points (2D), write a function that outputs the kd-tree of this set of points.

## c. Problems

- **Minimum Spanning Tree** is a subset of a graph that is acyclic and has the minimum weight sum. Write a function that, given a graph outputs its minimum spanning tree using Prim's algorithm.
- **Huffman** Tree is a structure used for data compression. (For instance, the .zip files use Huffman coding). Given a string of data, output its compressed value using Huffman coding.
    - Step 1: Make the frequency table of your message
    - Step 2: Build the Huffman tree
    - Step 3: Encode the input
- Binary Trees are also used in **database indexing**. Make an example table, with a username, an age and en email.
    - First, represent this table with a linked list. How would you look up a user ?
    - Add a random **but unique** index (integer) to all elements. How can the lookup time on the newly created index be improved ?
    - How can the lookup time be improved on the other elements ? (see the Python hash function)

# 6. Problems

- Connect 4

Connect 4 (Puissance 4) is a popular game as well as a popular computer science exercise. Write a connect four that can display in the console. The numbers of rows should be configurable.

- Tetris

Tetris is a popular game and its rules are very straightforward. It is however not a suitable game for the console. Use this script to get started with PyGame.
Your tetris game should accept inputs to rotate a piece, make pieces fall down automatically, detect a game over and remove lines.