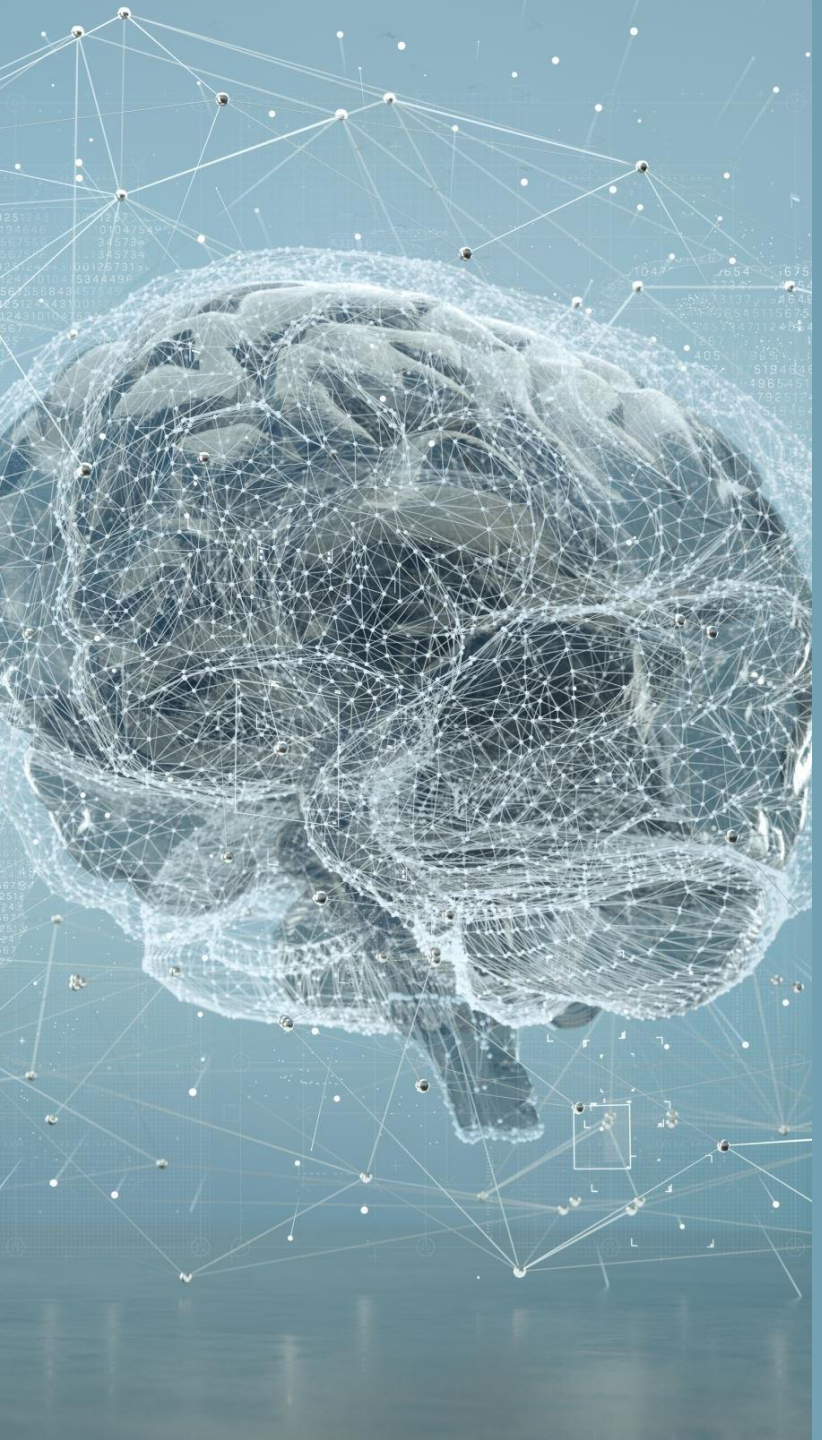


كلية الحاسبات والذكاء الاصطناعي
FACULTY OF COMPUTERS & ARTIFICIAL INTELLIGENCE

ARTIFICIAL INTELLIGENCE
LAB 06 – SEARCHING PROBLEMS (4)

AI Course Team

Eng. Yousef Elbaroudy – Eng Sahar Mohammed

Eng. Reham Ibrahim – Eng. Mawada Ashraf

Eng. Eman Nasser

2025/2026

GUIDELINES

You don’t need to memorize what will be mentioned. Instead, try to understand

Each PowerPoint Presentation will be available as PDF file on Google Drive Folder of the Course

REMEMBER !

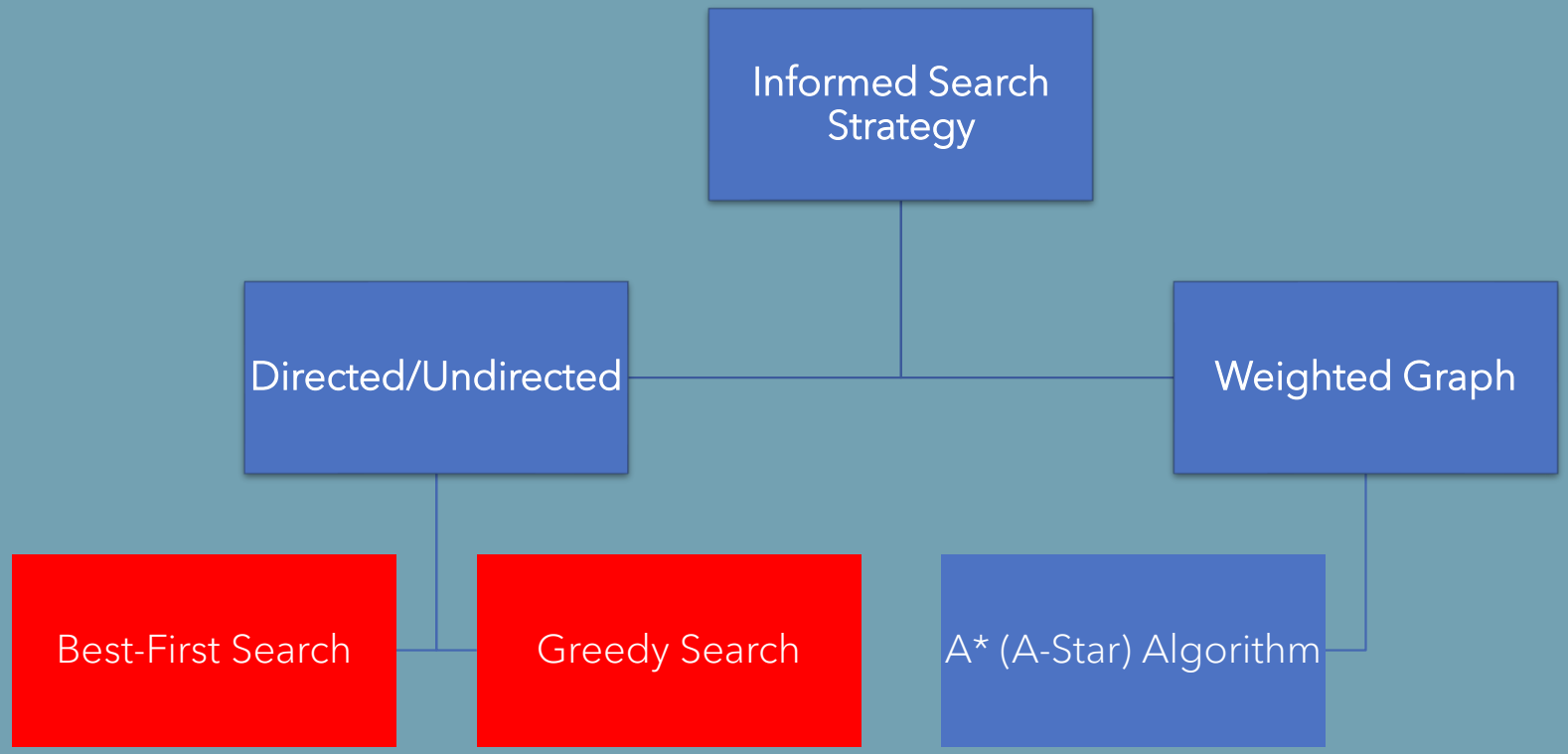
In our course, we are targeting

Goal-based agent in fully observable, deterministic and discrete environments

Which means, all of our problems will be in the form of states that shows all possible forms of the environment

INFORMED SEARCH (REVISION)

- Informed Search (Heuristic Search): a type of search strategy in artificial intelligence that uses additional knowledge (heuristics) about the state to make better decisions about which path to follow toward the goal.



WHAT IS "HEURISTIC" ? (REVISION)

How close are we currently to the goal ?

Heuristic values are such an **indicators (hints)** that ESTIMATES how close a given state to the goal in a search problem

It is used in Informed search algorithms to help decide which path to explore next

Remember !
Just an estimation, but not the actual !

Could be something similar ☺

HEURISTIC PROPERTIES

We will investigate the heuristic properties using A* algorithm

Admissibility

- The heuristics never OVERESTIMATES the actual true cost !
- Yes, the heuristic values could be a trap ! Not always accurate and cannot be a prior.
  - Given Heuristic value <= Actual cost

Consistency (Monotonic)

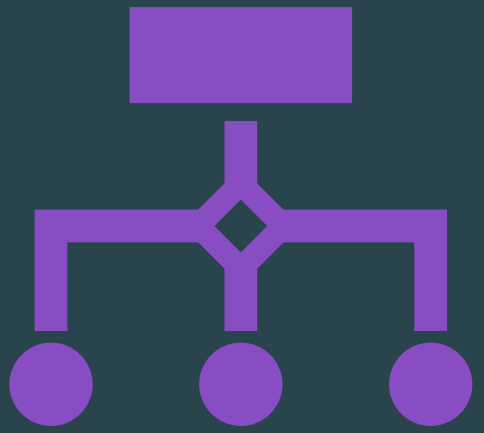
- The estimated cost from node A to node B plus B to a goal is at least as much as A to goal
- It guarantees that the estimated cost + actual cost never decreases along a path
  - Given Heuristic value <= Cost from A to B + Heuristic of B

WHAT IS THE NOTATION ?

We will refer to the actual path cost as g(n)

As we will refer to the heuristic function (estimated value) as h(n)

BASIC SEARCH



1. Initialize an **empty list** and put the **initial state** in it
2. Take the first state in the **list as the current if it is not visited yet otherwise skip it**, and remove it from the list
3. **Check if the current is the goal state**, if it is, then terminate the search and **return the solution path**
4. Otherwise, expand the current of its successors, **and add them into the list using a queuing function**
5. Repeat from (2) to (4)
6. If the current becomes empty, then there is no solution and **return "fail"**

A* (A-STAR) ALGORITHM

- **A* (pronounced A-Star)** is a powerful and popular **informed search algorithm** used to find the **shortest or most optimal path** from a start node to a goal node. It combines the **cost to reach a node (Actual)** and the **estimated cost to reach the goal (Heuristic)**.

- In A* algorithm, it combines between Uniform-Cost Search and Best-First Search. **In other words, it computes f(n) = accumulated g(n) + h(n) for each state**

They chose the name **"A"** as a general label for an algorithm (like algorithm A, B, etc.)

The (* star) It's the **BEST OR OPTIMAL VERSION** among all similar algorithms using the same kind of evaluation function

A* (A-STAR) ALGORITHM

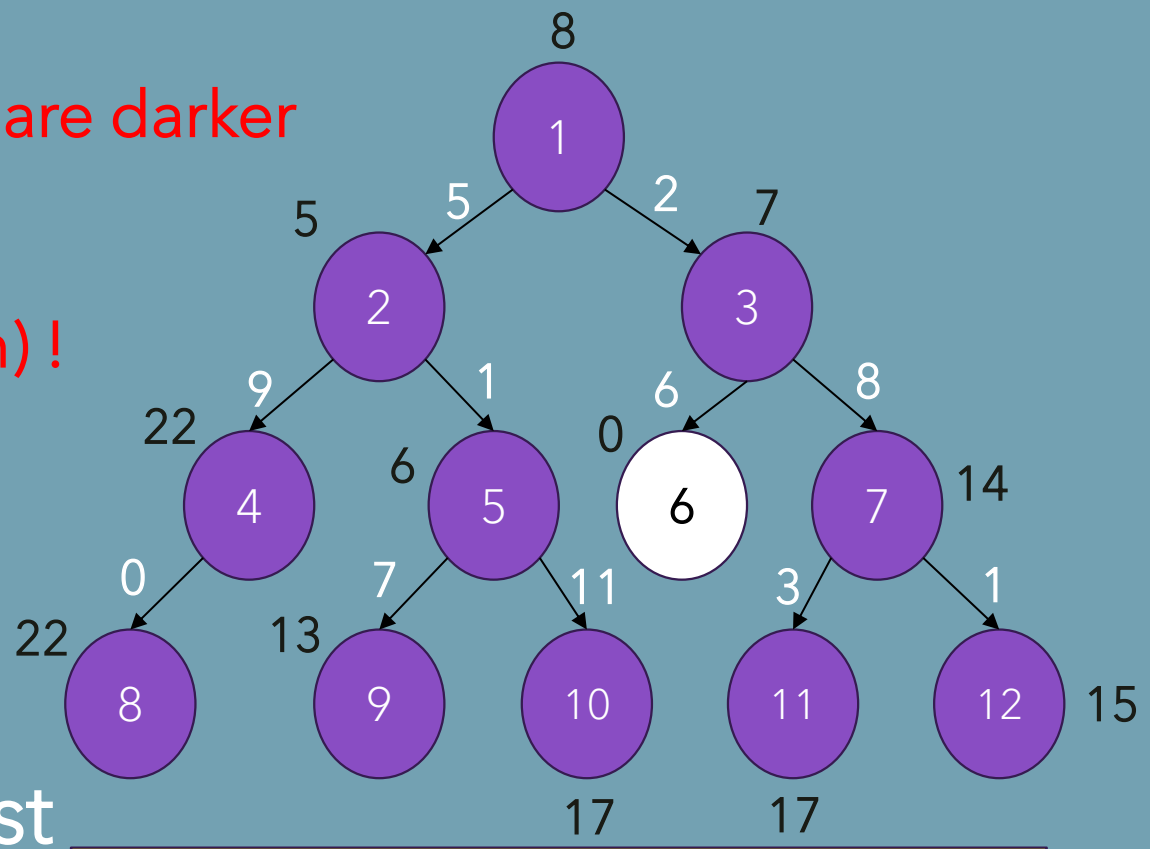
FIFO + Priority Function

Priority function is a data access principle that gives a priority for each element using FIFO, which the highest priority removed first. In A-Star algorithm, the priority for the TOTAL lowest cost f(n)=g(n)+h(n) **(Sort)**, and the ACTUAL cost of each path is **accumulative**.

A* (A-STAR) ALGORITHM

Goal: 6

Note:
The heuristic values are darker
Remember:
Pre-order traverse !
Priority for lowest f(n) !
f(n)=g(n)+h(n)

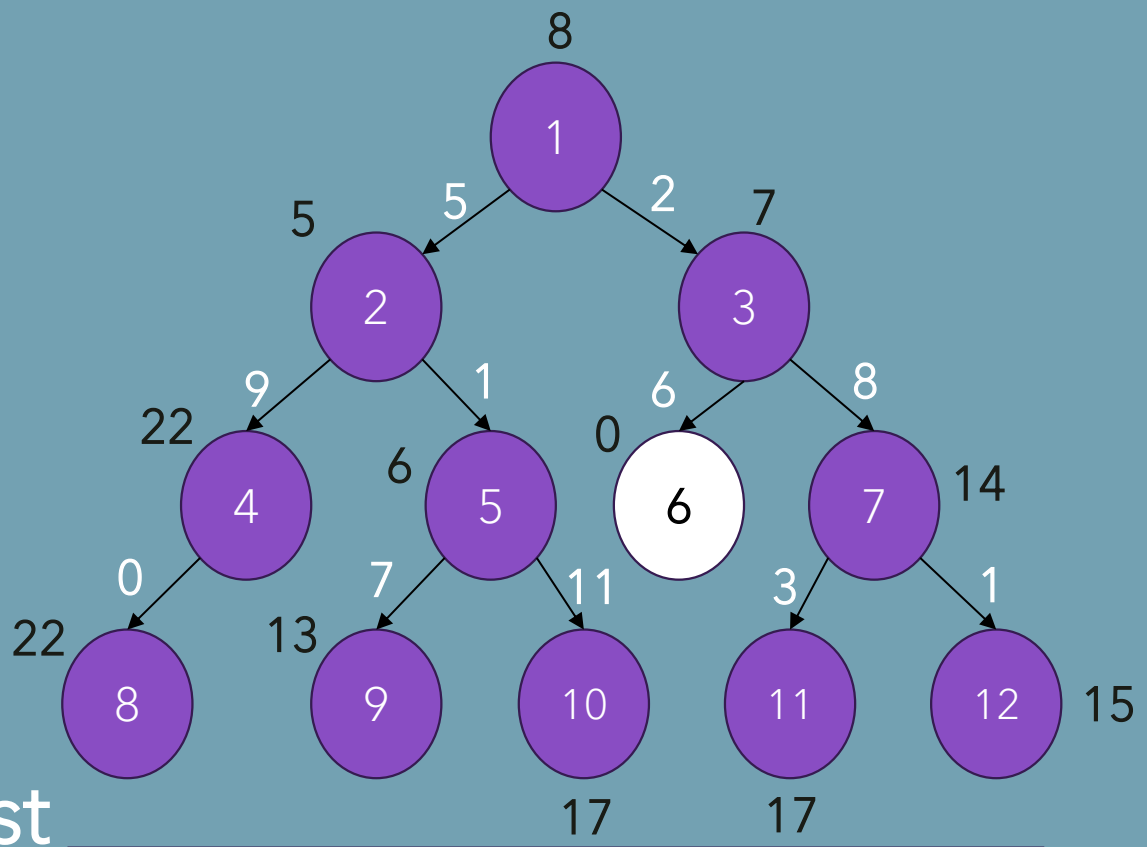


List

Insert → [ ] → Remove

A* (A-STAR) ALGORITHM

Goal: 6

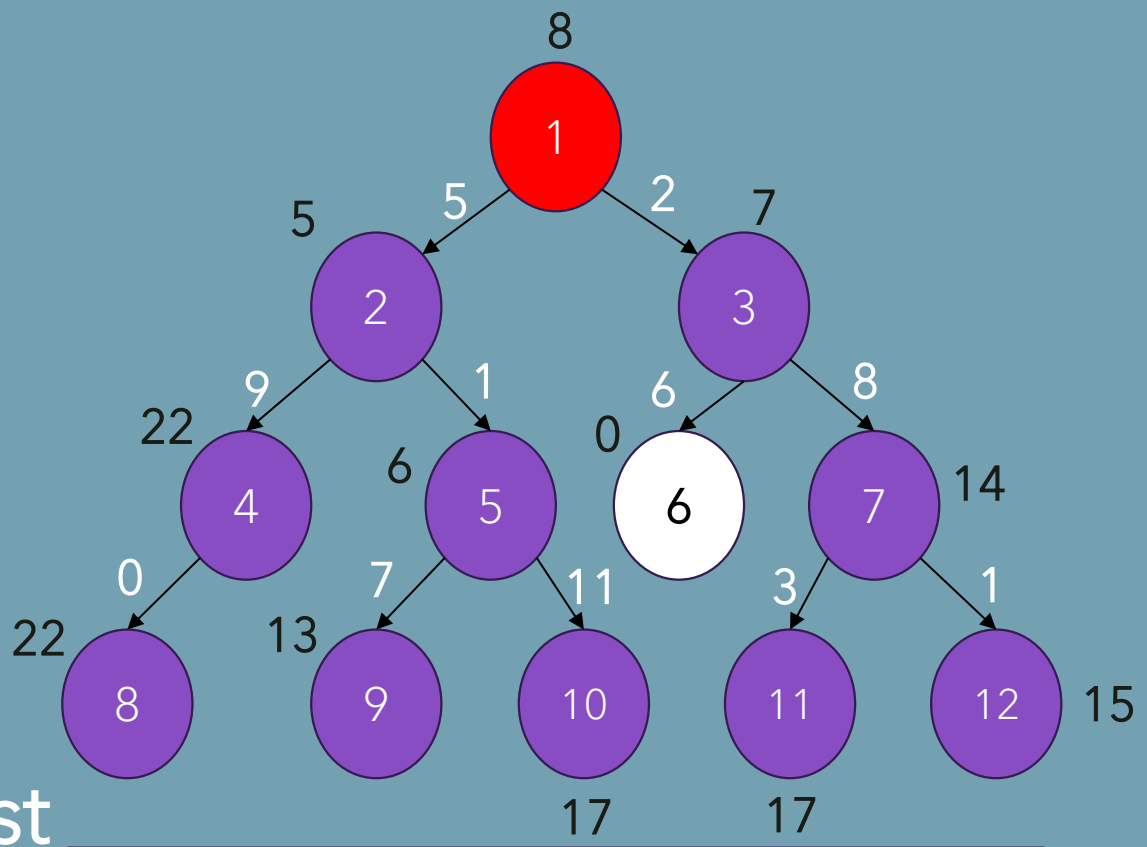


List

Insert → 1 (8) → Remove

A* (A-STAR) ALGORITHM

Goal: 6



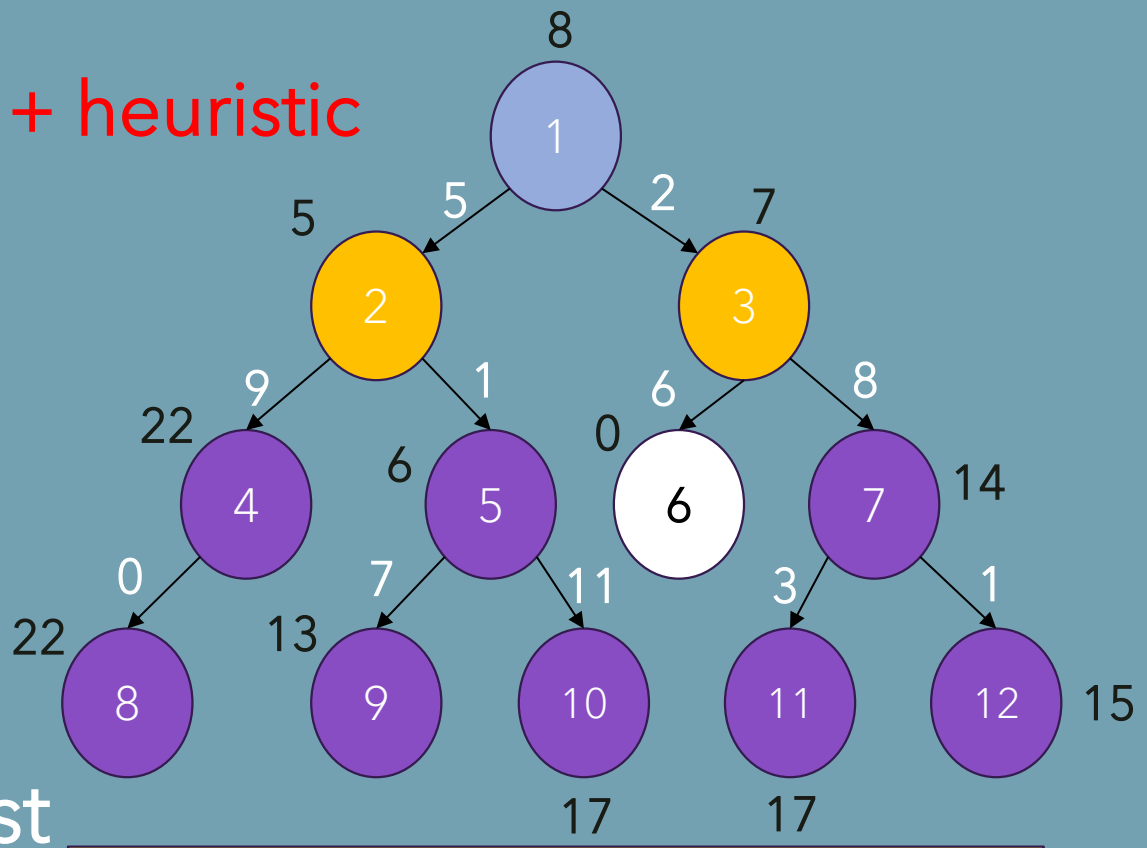
List

Insert → → Remove

A* (A-STAR) ALGORITHM

Goal: 6

f(n) = actual cost + heuristic

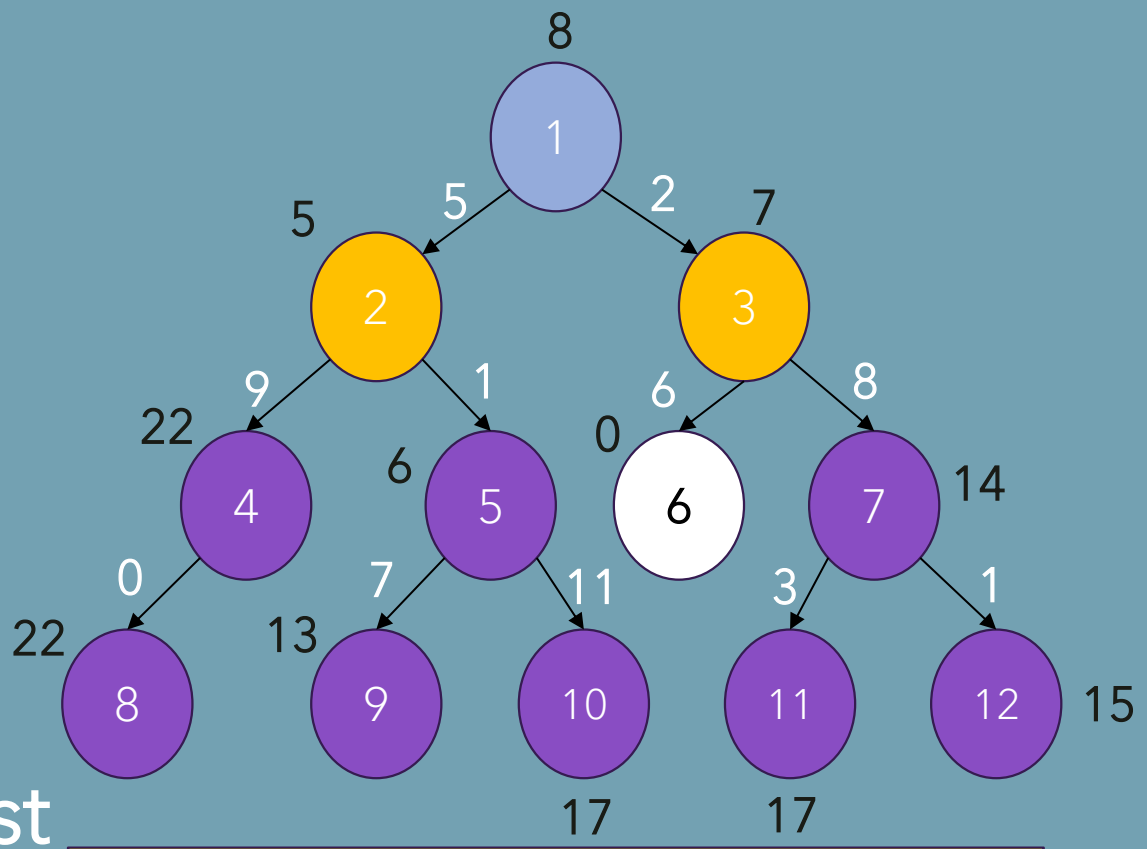


List

Insert → 3 (7+2), 2 (5+5) → Remove

A* (A-STAR) ALGORITHM

Goal: 6

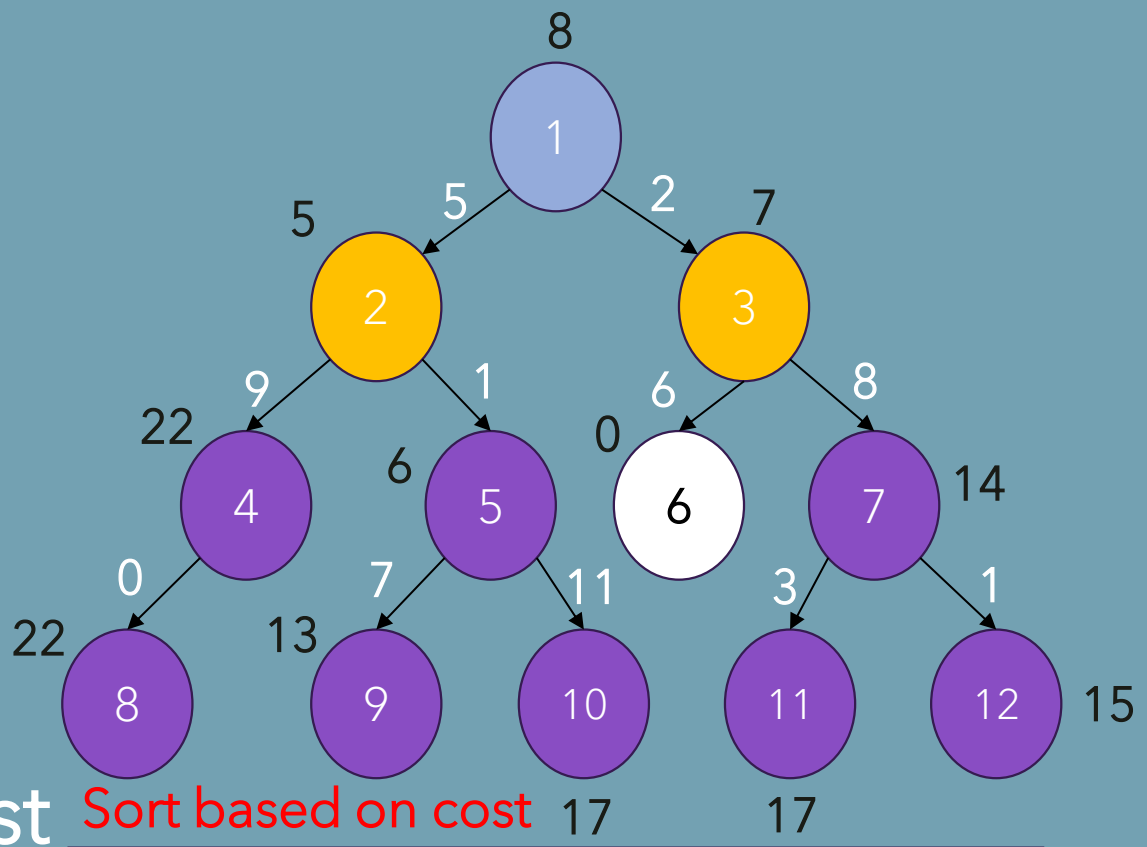


List

Insert → 3 (9), 2 (10) → Remove

A* (A-STAR) ALGORITHM

Goal: 6

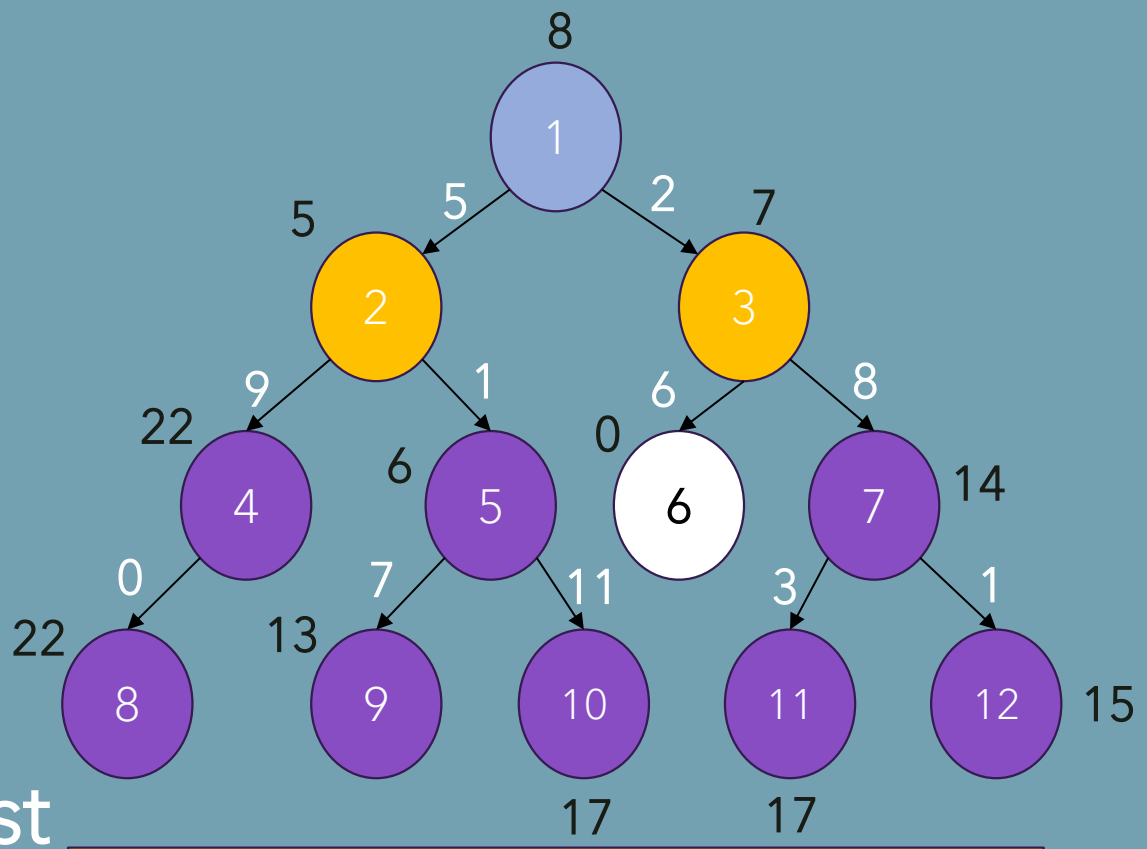


List Sort based on cost

Insert → 3 (9), 2 (10) → Remove

A* (A-STAR) ALGORITHM

Goal: 6

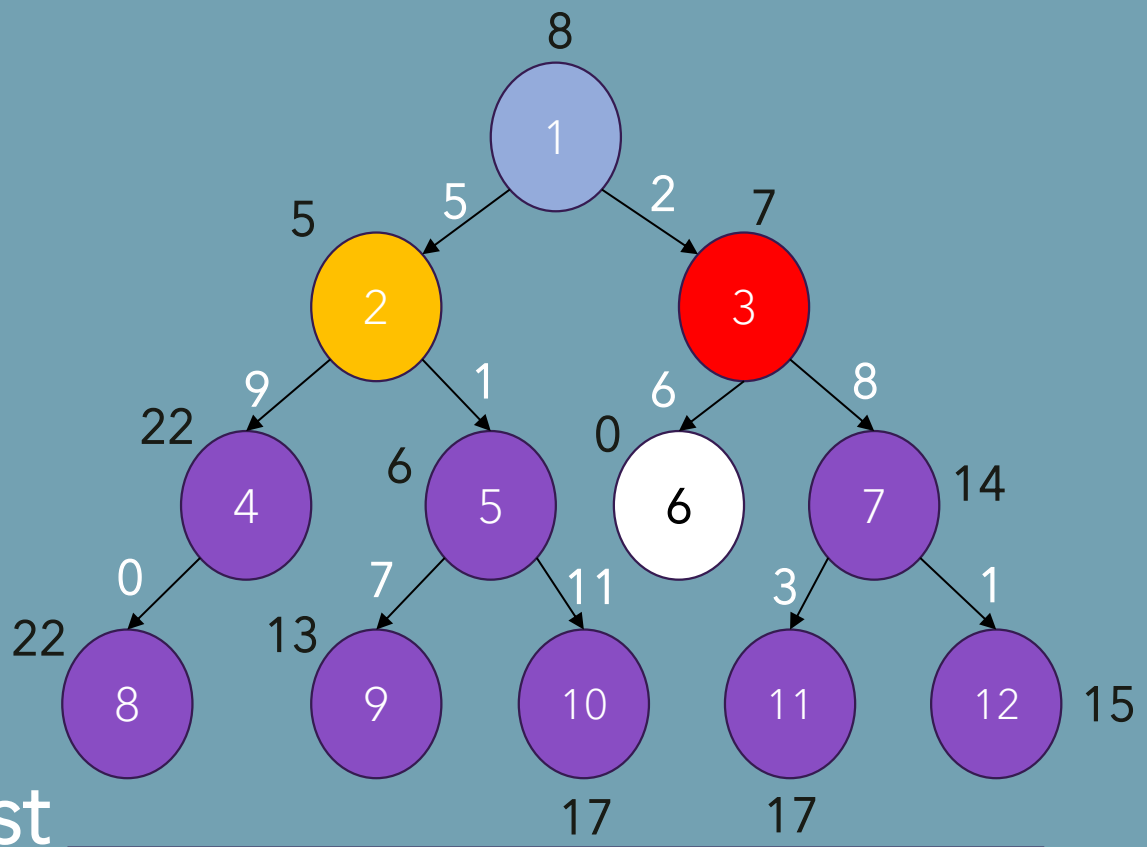


List

Insert → 2 (10), 3 (9) → Remove

A* (A-STAR) ALGORITHM

Goal: 6



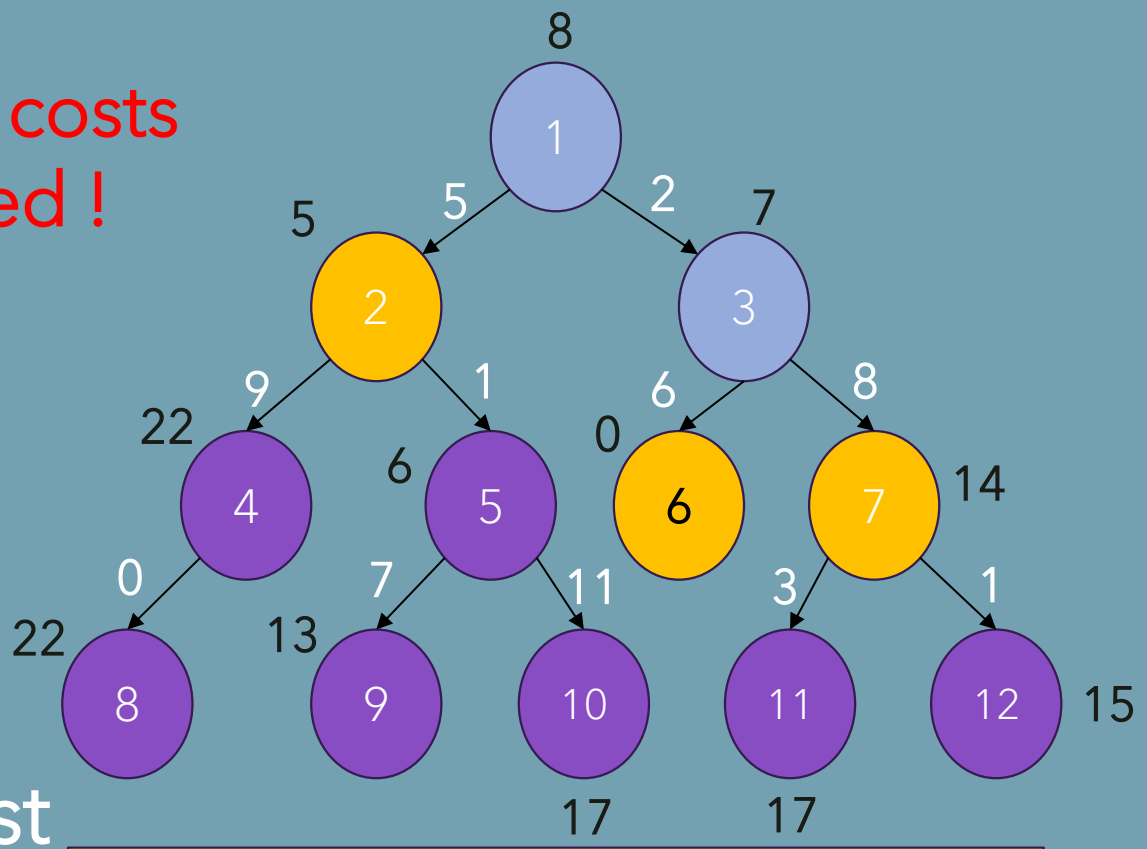
List

Insert → 2 (10) → Remove

A* (A-STAR) ALGORITHM

Goal: 6

Only actual path costs are accumulated !

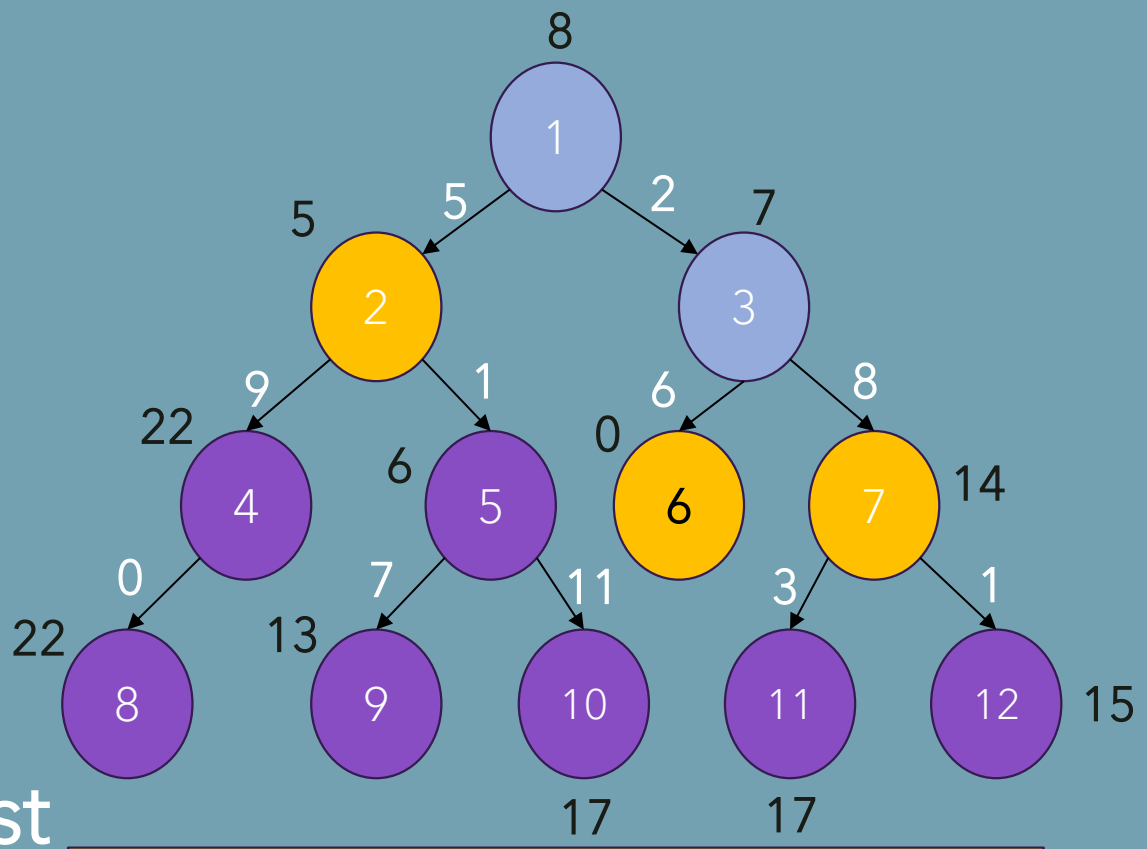


List

Insert → 7(2+8+14), 6 (2+6+0), 2 (10) → Remove

A* (A-STAR) ALGORITHM

Goal: 6

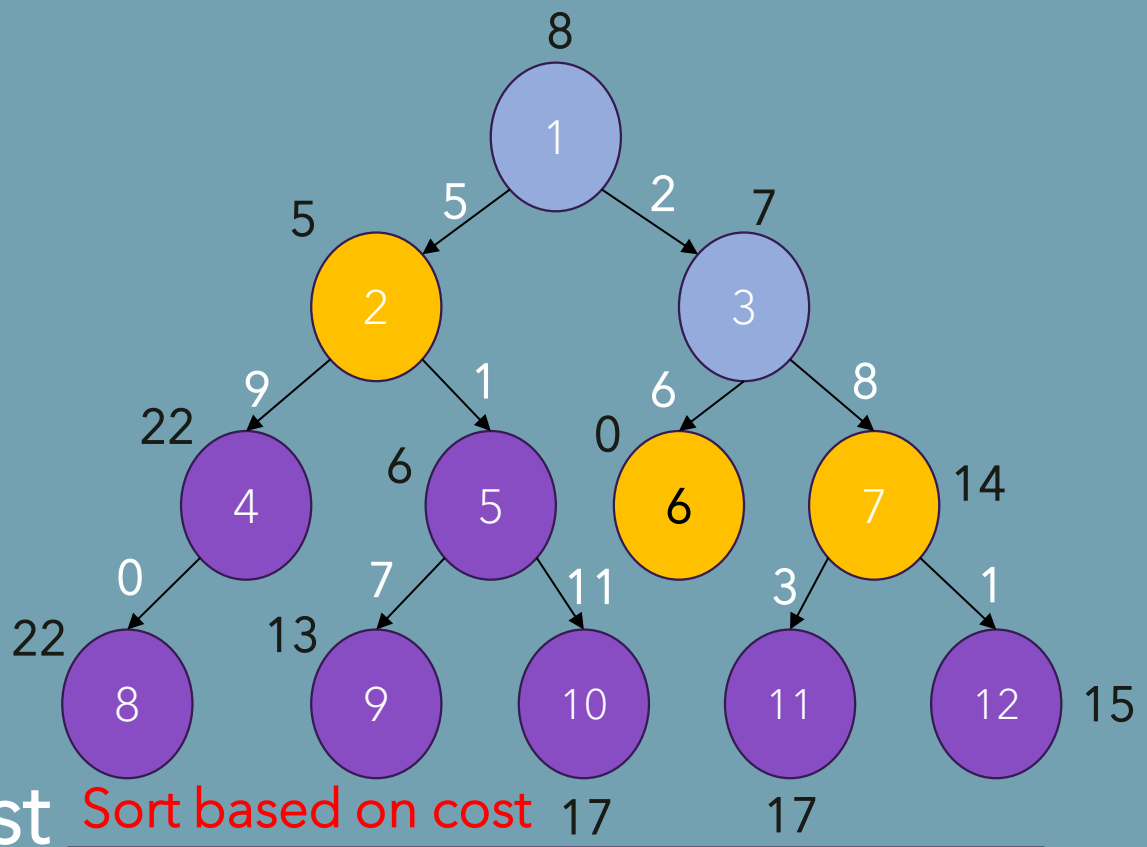


List

Insert → 7(24), 6 (8), 2 (10) → Remove

A* (A-STAR) ALGORITHM

Goal: 6

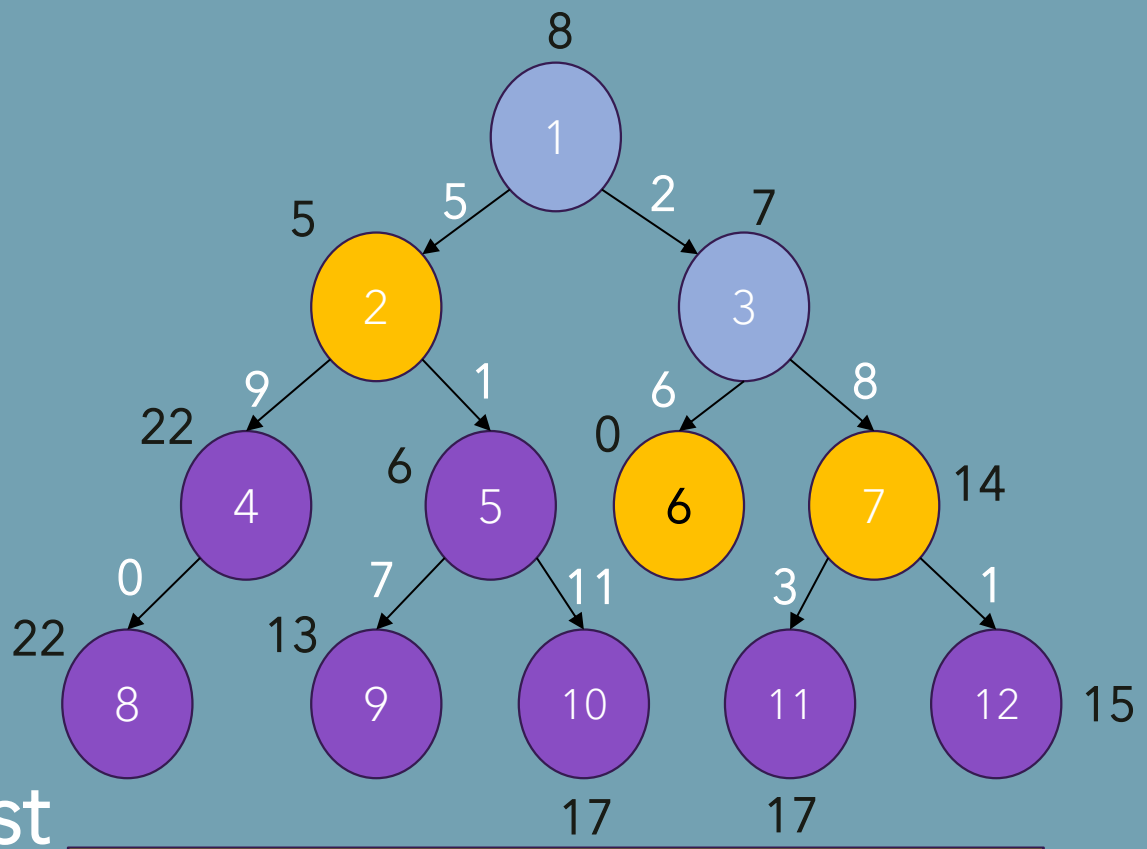


List Sort based on cost

Insert → 7(24), 6 (8), 2 (10) → Remove

A* (A-STAR) ALGORITHM

Goal: 6

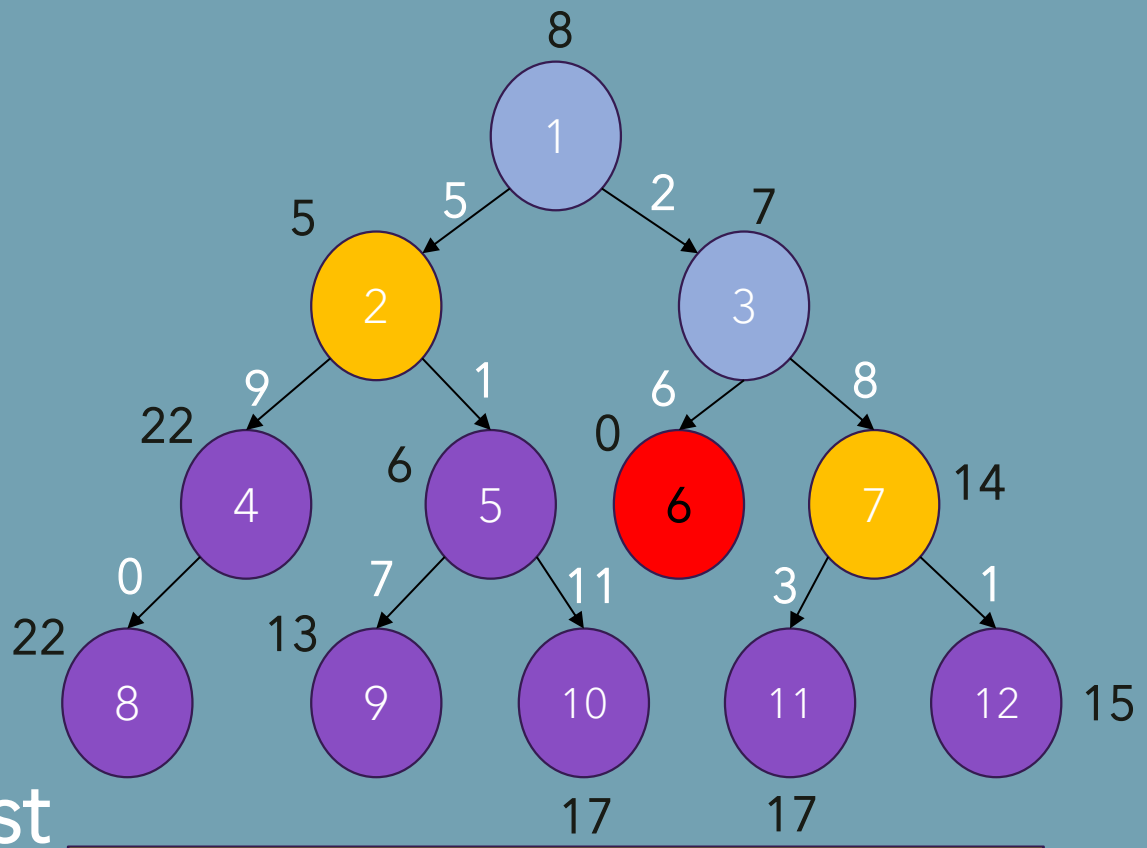


List

Insert → 7(24), 2 (10), 6 (8) → Remove

A* (A-STAR) ALGORITHM

Goal: 6

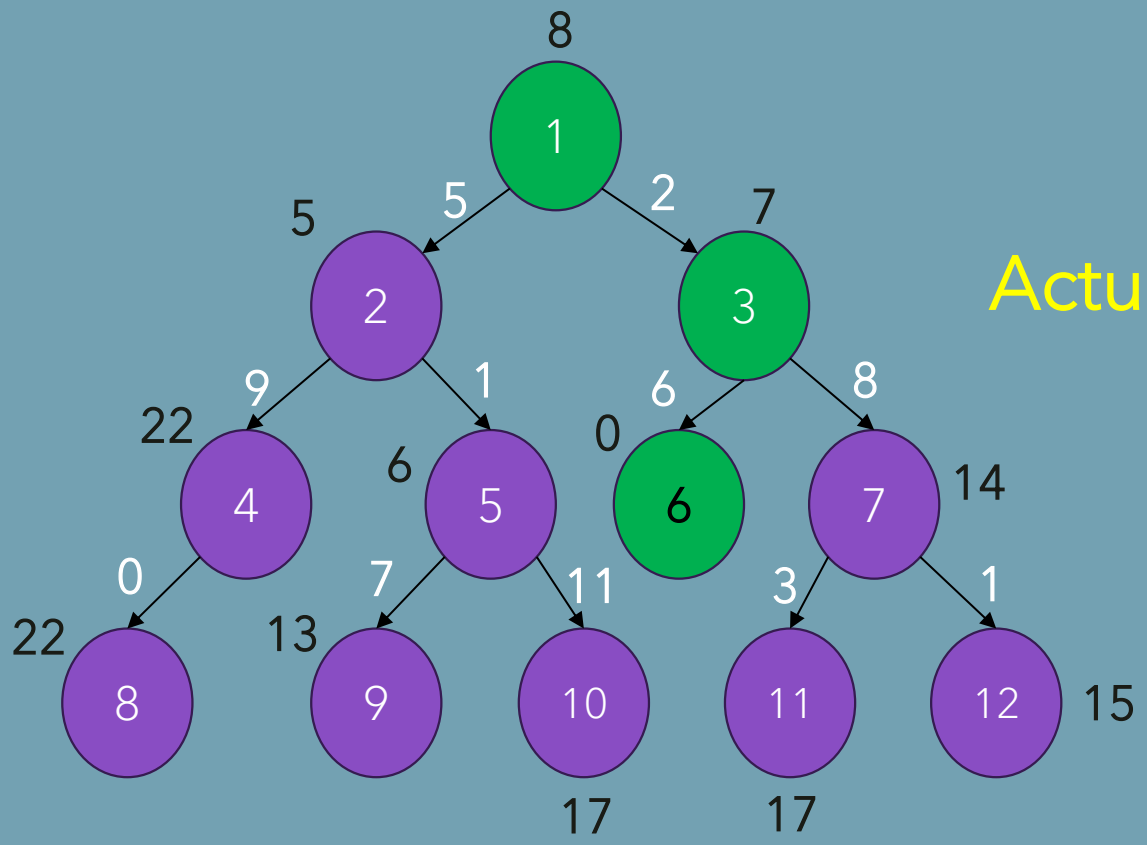


List

Insert → 7(24), 2 (10) → Remove

A* (A-STAR) ALGORITHM

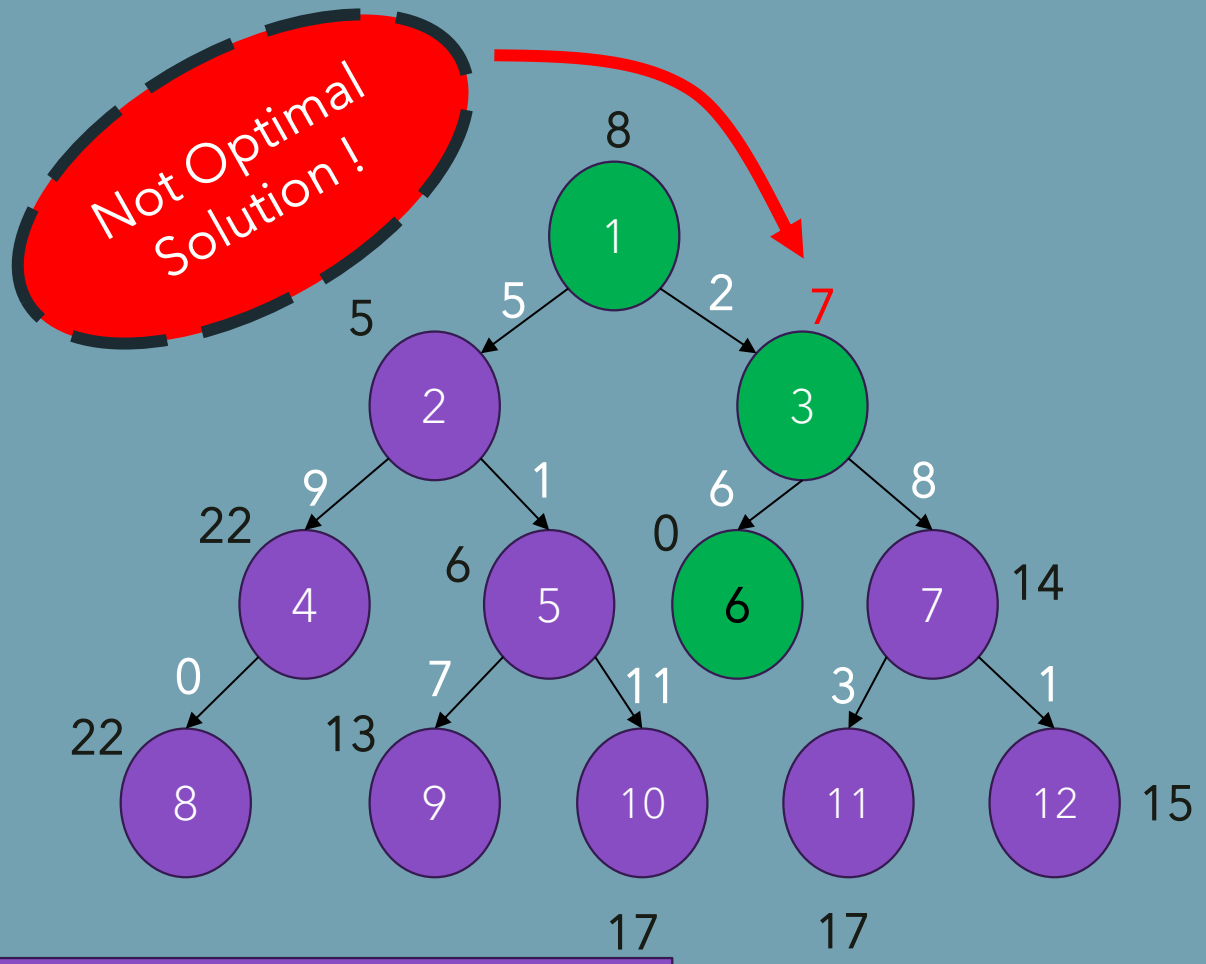
Goal: 6



Actual solution cost = 8

Solution: [1, 3, 6] – Visited: [1, 3, 6]

ANALYZE THE OPTIMALITY OF THE SOLUTION



Proving that it is optimal, it should be both admissible and consistent

Solution: [1, 3, 6]

Admissibility

Each h(n) on the solution path <= actual total cost

h(1) <= g(1 to 6) → 8 <= 8 – Correct

h(3) <= g(3 to 6) → 7 <= 6 – Incorrect

The solution is inadmissible, an OVERESTIMATING for h(3)

Consistency

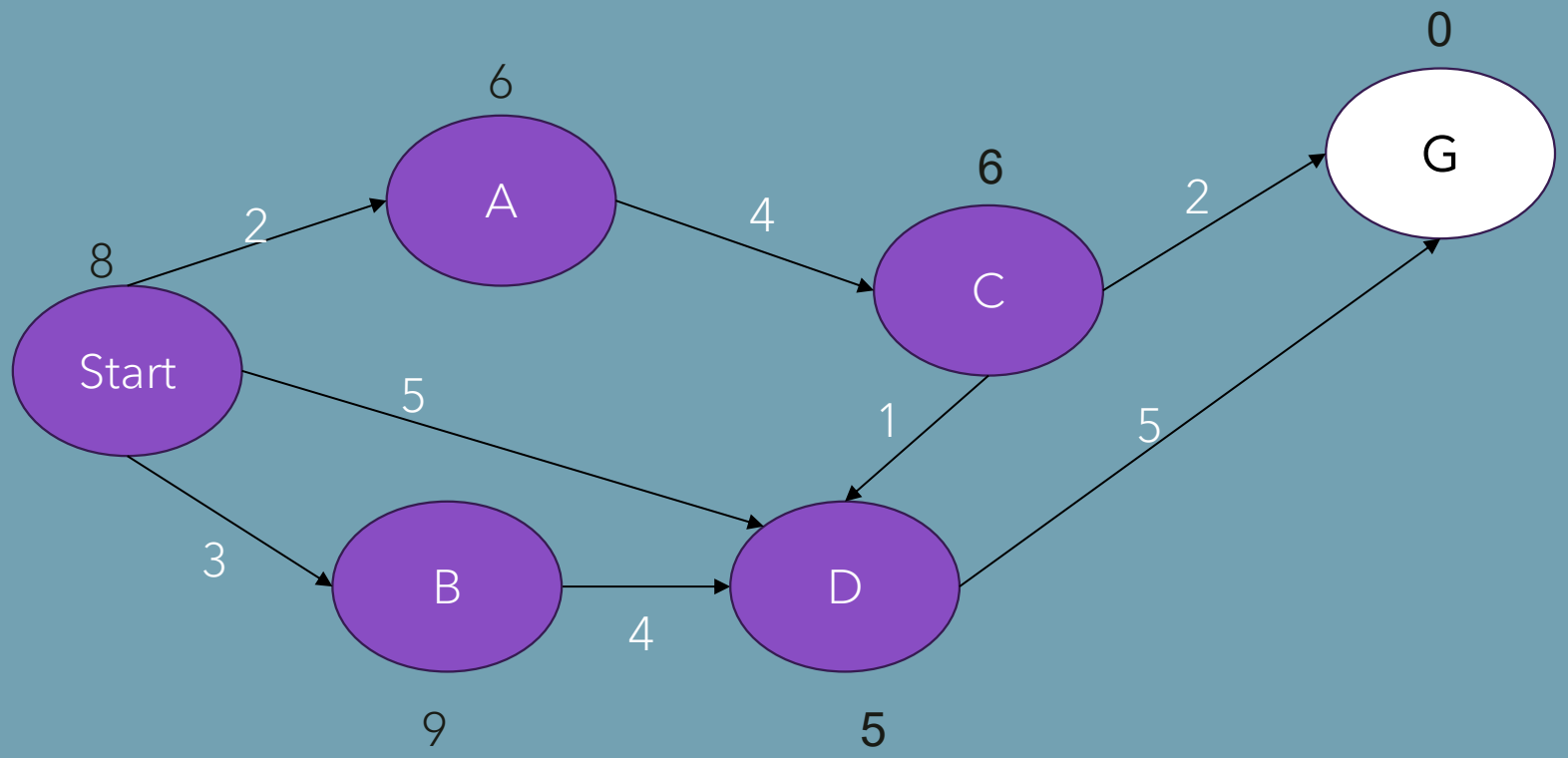
Each h(n) on the solution path <= g(n, n+1) + h(n+1)

h(1) <= g(1 to 3) + h(3) → 8 <= 9 – Correct

h(3) <= g(3 to 6) + h(6) → 7 <= 6 – Incorrect

The solution is inconsistent, an OVERESTIMATING for h(3)

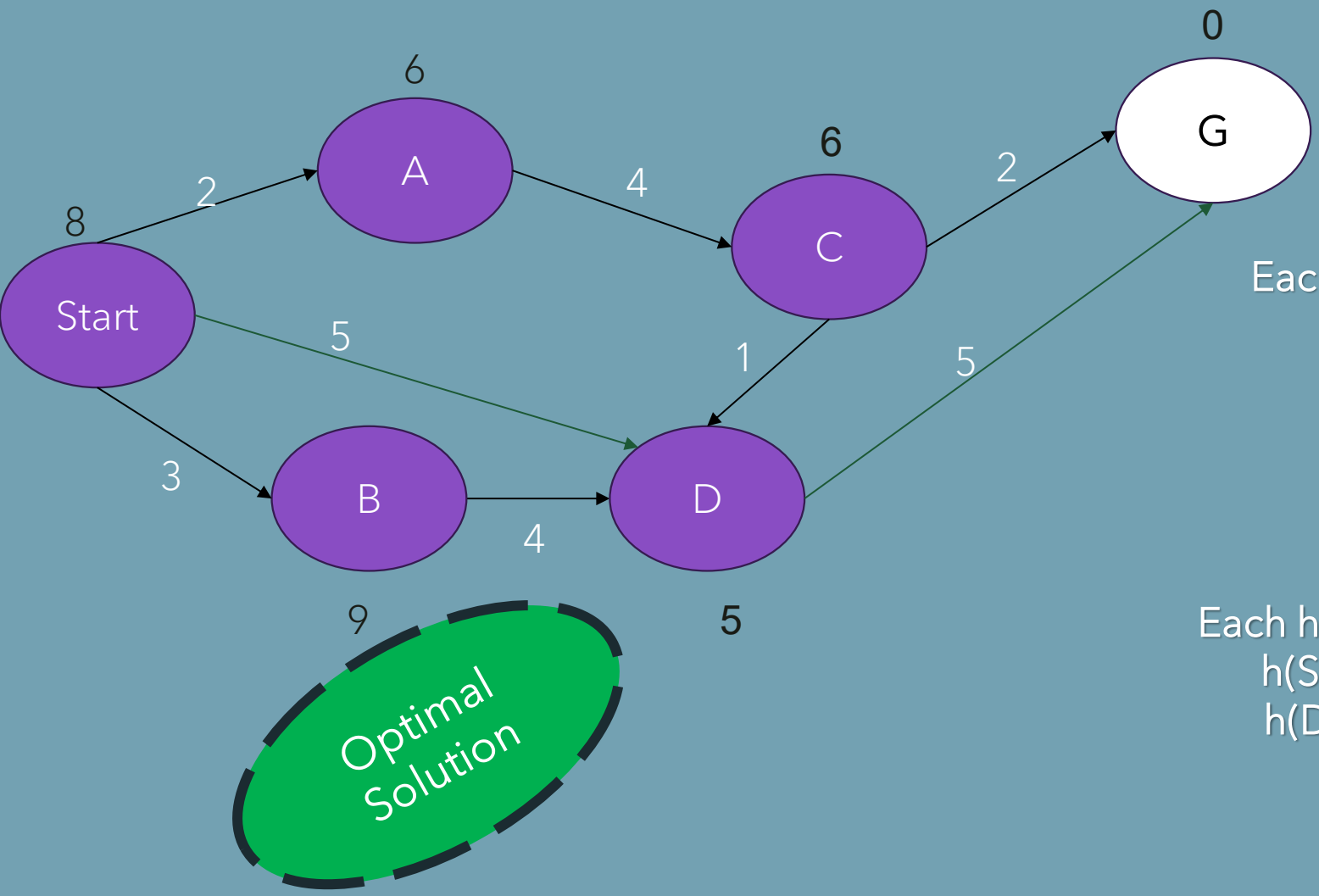
A* (A-STAR) ALGORITHM (GRAPH)



Current	FIFO FRONT < - - - - - - > REAR
	[S (8)]
[S (8)]	[S, A (8)], [S, D (10)], [S, B (12)]
[S, A (8)]	[S, D (10)], [S, A, C (12)], [S, B (12)]
[S, D, (10)]	[S, D, G (10)], [S, A, C (12)], [S, B (12)]
[S, D, G (10)]	

In graphs, if two elements got the same cost, then sort alphabetically only for unified answer for all students !

ANALYZE THE OPTIMALITY OF THE SOLUTION



Solution: [S, D, G (10)]

Admissibility

Each h(n) on the solution path <= actual total cost

h(S) <= g(S to G) → 8 <= 10 – Correct

h(D) <= g(D to G) → 5 <= 5 – Correct

The solution is admissible

Consistency

Each h(n) on the solution path <= g(n, n+1) + h(n+1)

h(S) <= g(S to D) + h(D) → 8 <= 10 – Correct

h(D) <= g(D to G) + h(G) → 5 <= 5 – Correct

The solution is consistent

BEST-FIRST VS. GREEDY VS A-STAR

Best-First

Current	FIFO FRONT < - - - - - - > REAR
	[S (8)]
[S (8)]	[S,D (5)], [S,A (6)], [S,B (9)]
[S,D (5)]	[S,D, G (0)], [S, A (6)], [S, B (9)]
[S, D, G (0)]	No. of steps = 3 Actual cost = 10

Greedy

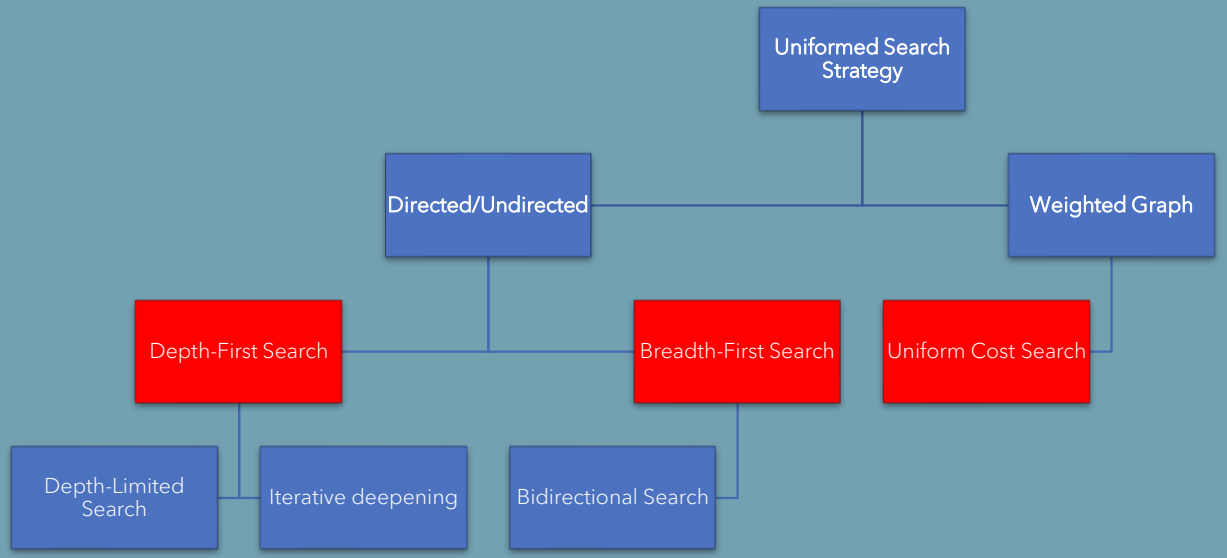
Current	FIFO FRONT < - - - - - - > REAR
	[S (8)]
[S (8)]	[S,D (5)], [S,A (6)], [S,B (9)]
[S,D (5)]	[S, D, G (0)]
[S, D, G (0)]	No. of steps = 3 Actual cost = 10

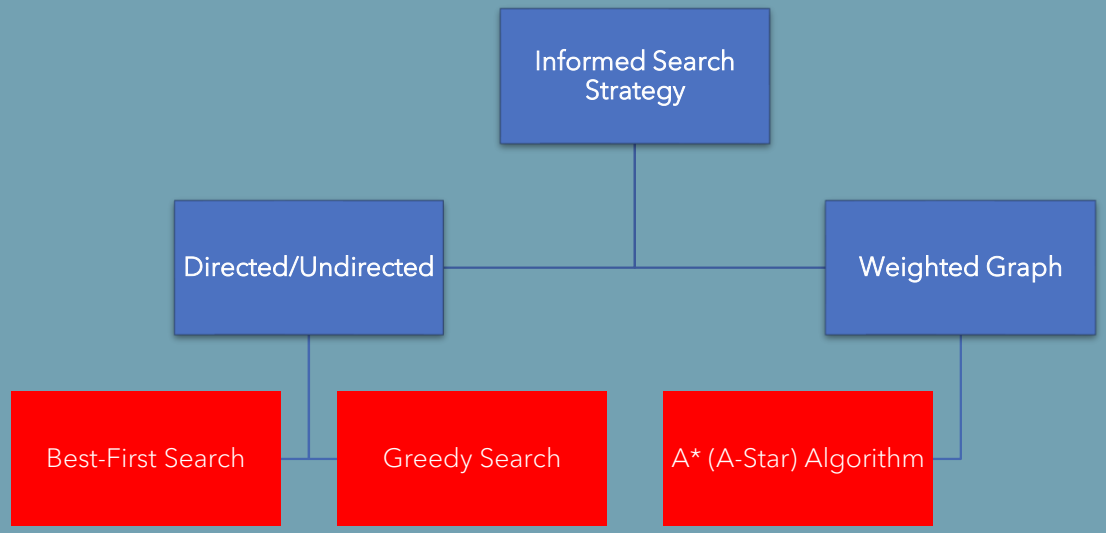
A-Star

Current	FIFO FRONT < - - - - - - > REAR
	[S (8)]
[S (8)]	[S, A (8)], [S, D (10)], [S, B (12)]
[S, A (8)]	[S, D (10)], [S, A, C (12)], [S, B (12)]
[S, D, (10)]	[S, D, G (10)], [S, A, C (12)], [S, B (12)]
[S, D, G (10)]	No. of steps = 4 Actual cost = 10

Guaranteed Optimality

END OF BASIC STRATEGIES





IMPLEMENTATION

GRAPH CLASS (ADJACENCY LIST REP.)

```python
# Make a Graph class
class Graph:
    def __init__(self, root=None, weighted=None, directed=None, h_flag=None, root_h_val=None):
        # Adjacency list representation
        if root:
            self.__graph = {root: []}
        else:
            self.__graph = {"root": []}

        self.__h_flag = h_flag
        if h_flag == True:
            self.__h_flag = h_flag
            if root_h_val:
                self.__h_map = {list(self.__graph.keys())[0]: root_h_val}
            else:
                raise Exception("There should be an heuristic value for the root")
        elif self.__h_flag != None:
            raise Exception("h_flag parameter should be True or None")

        self.__weighted = weighted
        if weighted == True:
            self.__weighted = weighted
        elif self.__weighted != None:
            raise Exception("weighted parameter should be True or None")

        self.__directed = directed
        if directed == True:
            self.__directed = directed
        elif self.__directed != None:
            raise Exception("directed parameter should be True or None")

        print(f"Graph is created with root name: {list(self.__graph.keys())[0]}")
```

GRAPH CLASS (ADD VERTICES METHOD)

```
def add_vertex(self, vertex, h_val=None):
    if vertex not in self.__graph.keys():
        self.__graph[vertex] = []
        print("Vertex is added successfully !")
        if self.__h_flag:
            if h_val is not None:
                self.__h_map[vertex] = h_val
            else:
                raise Exception("There should be an heuristic value for the vertex")
    else:
        print("This vertex does exist in the graph already !")
```

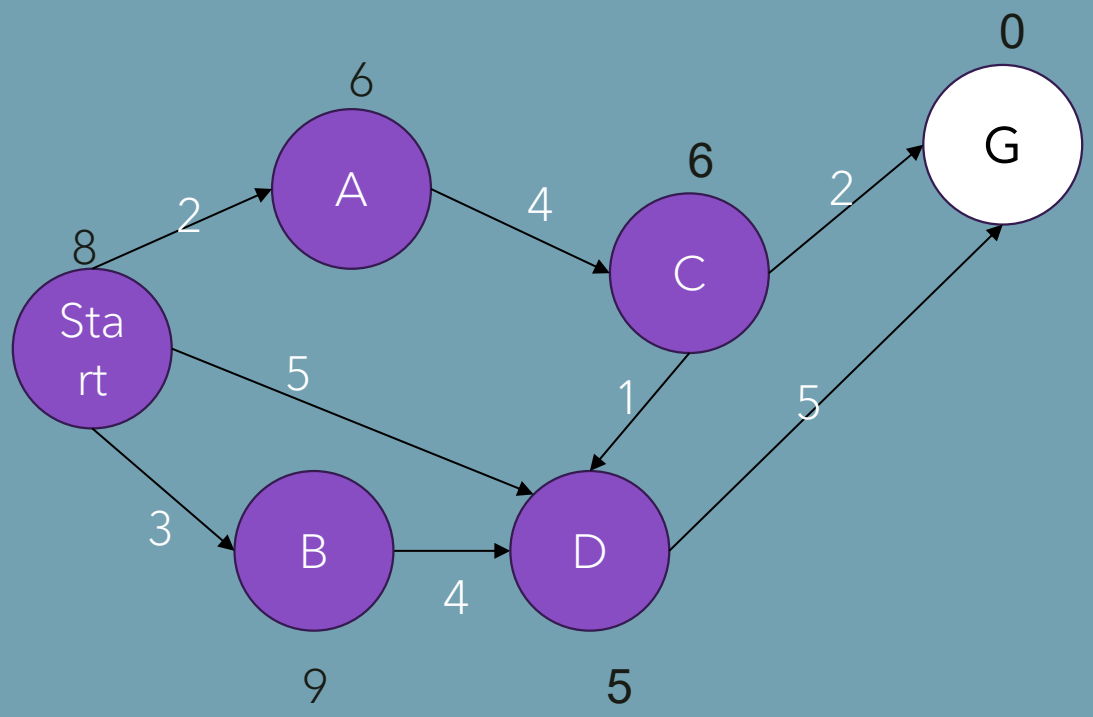
GRAPH CLASS (ADD EDGES METHOD)

```
def add_edge(self, vertex_1, vertex_2, weight=None):
    if vertex_1 in self.__graph.keys() and vertex_2 in self.__graph.keys():
        if not self.__directed:
            if not self.__weighted:
                self.__graph[vertex_1].append(vertex_2)
                self.__graph[vertex_2].append(vertex_1)
            else:
                if weight != None:
                    self.__graph[vertex_1].append((vertex_2, weight))
                    self.__graph[vertex_2].append((vertex_1, weight))
                else:
                    raise Exception("It should be a weight for the edge")
        else:
            if not self.__weighted:
                self.__graph[vertex_1].append(vertex_2)
            else:
                if weight != None:
                    self.__graph[vertex_1].append((vertex_2, weight))
                else:
                    raise Exception("It should be a weight for the edge")
    else:
        raise Exception("It should be both vertices exist in the graph !")

    print(f"Edge added between {vertex_1} and {vertex_2}")
```

GRAPH CLASS (GET GRAPH METHOD)

```
def get_graph(self):
    return self.__graph, self.__h_map
```

FORMULATE THE PROBLEM




```
my_graph = Graph("S" , directed=True, weighted=True, h_flag=True, root_h_val=8)
my_graph.add_vertex("A", 6)
my_graph.add_vertex("B", 9)
my_graph.add_vertex("C", 6)
my_graph.add_vertex("D", 5)
my_graph.add_vertex("G", 0)
my_graph.add_edge("S","B", 3)
my_graph.add_edge("S","A", 2)
my_graph.add_edge("S","D", 5)
my_graph.add_edge("A","C", 4)
my_graph.add_edge("C","G", 2)
my_graph.add_edge("C","D", 1)
my_graph.add_edge("B","D", 4)
my_graph.add_edge("D","G", 5)
print(my_graph.get_graph())
```

```
Graph is created with root name: S
Vertex is added successfully !
Vertex is added successfully !
Vertex is added successfully !
Vertex is added successfully !
Vertex is added successfully !
Edge added between S and B
Edge added between S and A
Edge added between S and D
Edge added between A and C
Edge added between C and G
Edge added between C and D
Edge added between B and D
Edge added between D and G
({'S': [('B', 3), ('A', 2), ('D', 5)], 'A': [('C', 4)], 'B': [('D', 4)], 'C': [('G', 2), ('D', 1)], 'D': [('G', 5)], 'G': []}, {'S': 8, 'A': 6, 'B': 9,
'C': 6, 'D': 5, 'G': 0})
```

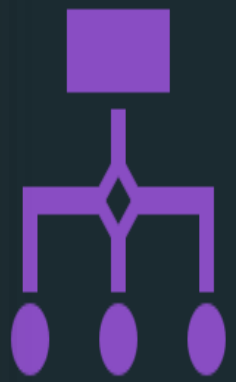
GRAPH CLASS (A-STAR METHOD)

```python
def A_star(self, goal, start=None):
    if self.__h_flag is None or self.__weighted is None:
        raise Exception("A-Star Algorithm only works with Graphs with Heuristic values and Weighted Graphs !")

    if start != None:
        lst = [[(start, 0)]]
    else:
        lst = [[("root", 0)]]

    visited = []
    while lst:
        # Sort all elements alphabetically to get a unified answer !
        # Sorting based on f(n) = total cost + heuristic cost and alphabetical order to follow "FIFO + Priority" principle
        lst.sort(key=self.__total_cost)
        # basic search
        current_path = lst.pop(0) # FIFO
        current_node = current_path[-1][0]

        if current_node in visited:
            continue
        visited.append(current_node)

        if current_node == goal:
            if self.__check_optimality(current_path):
                print("A-Star Solution is Optimal")
            else:
                print("A-Star Solution is Not Optimal")
            return list(map(lambda x: x[0], current_path)), visited, sum(list(map(lambda x: x[1], current_path)))
        else:
            adjacent_nodes = self.__graph[current_node]
            for node, cost in adjacent_nodes:
                new_path = current_path.copy()
                new_path.append((node, cost))
                lst.append(new_path)

    raise Exception("Search Failed !")
```

```python
def __total_cost(self, path):
    total_cost = 0
    for node, cost in path:
        total_cost += cost
    total_cost += self.__h_map[path[-1][0]]
    return total_cost, path[-1][0]
```

Next Slide

BASIC SEARCH



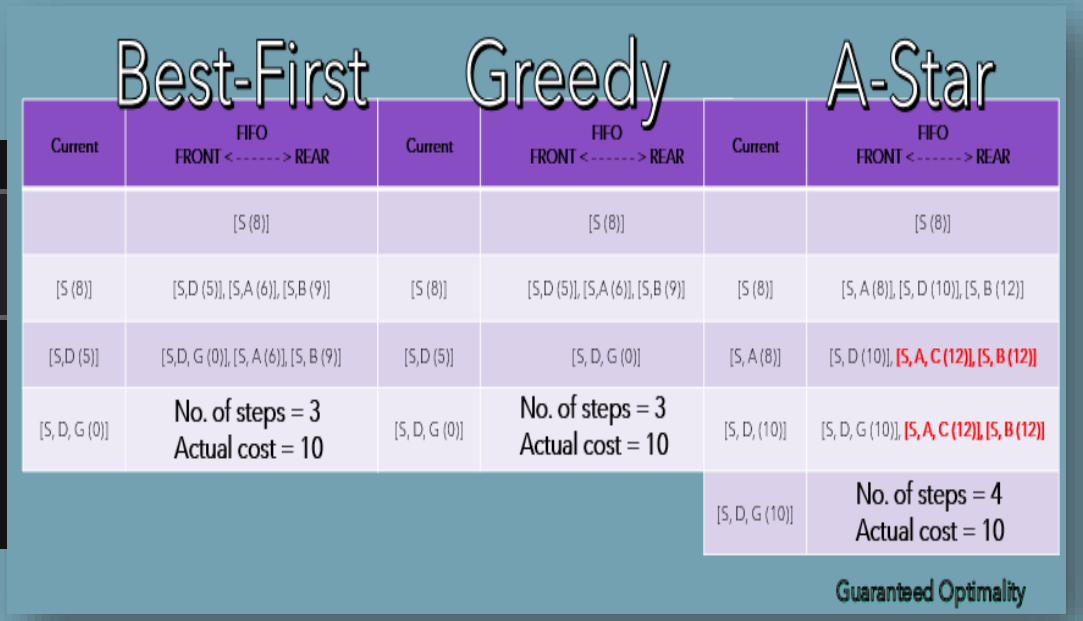
1. Initialize an **empty list** and put the **initial state** in it
2. Take the first state in the **list as the current if it is not visited yet otherwise skip it**, and remove it from the list
3. **Check if the current is the goal state**, if it is, then terminate the search and **return the solution path**
4. Otherwise, expand the current of its successors, **and add them into the list using a queuing function**
5. Repeat from (2) to (4)
6. If the current becomes empty, then there is no solution and **return "fail"**

GRAPH CLASS (CHECK OPTIMALITY METHOD)

```
def __check_optimality(self, path):
    # admissibility: h(n) <= g(n to goal)
    for idx in range(len(path) - 1):
        total_cost = sum([node[1] for node in path[idx:len(path)]])
        if self.__h_map[path[idx][0]] > total_cost:
            return False

    # consistency: h(n) <= g(n to n+1) + h(n+1)
    for idx in range(len(path) - 1):
        if self.__h_map[path[idx][0]] > self.__h_map[path[idx + 1][0]] + path[idx + 1][1]:
            return False

    return True
```

TESTING

```
[3]: print(my_graph.A_star("G", start="S"))

     A-Star Solution is Optimal
     (['S', 'D', 'G'], ['S', 'A', 'D', 'G'], 10)
```



Best-First

Current	FIFO FRONT <------> REAR
	[S (8)]
[S (8)]	[S,D (5)], [S,A (6)], [S,B (9)]
[S,D (5)]	[S,D, G (0)], [S, A (6)], [S, B (9)]
[S, D, G (0)]	No. of steps = 3 Actual cost = 10

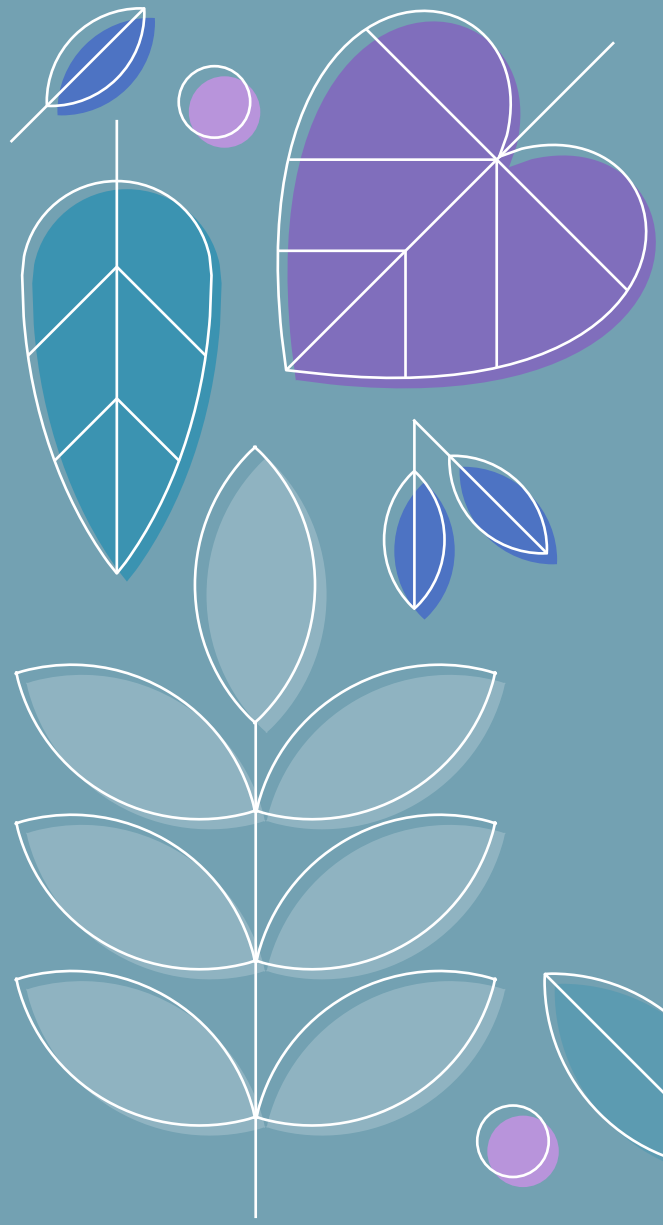
Greedy

Current	FIFO FRONT <------> REAR
	[S (8)]
[S (8)]	[S,D (5)], [S,A (6)], [S,B (9)]
[S,D (5)]	[S, D, G (0)]
[S, D, G (0)]	No. of steps = 3 Actual cost = 10

A-Star

Current	FIFO FRONT <------> REAR
	[S (8)]
[S (8)]	[S, A (8)], [S, D (10)], [S, B (12)]
[S, A (8)]	[S, D (10)], [S, A, C (12)], [S, B (12)]
[S, D, (10)]	[S, D, G (10)], [S, A, C (12)], [S, B (12)]
[S, D, G (10)]	No. of steps = 4 Actual cost = 10

Guaranteed Optimality



NEXT LAB: ADVERSARIAL SEARCH PART (1)

Thank you