

## Module: 3.2

### Problem Solving and Search

#### Motivation:

This module 3.2: will brief about Uninformed Search Methods and Informed Search Methods.

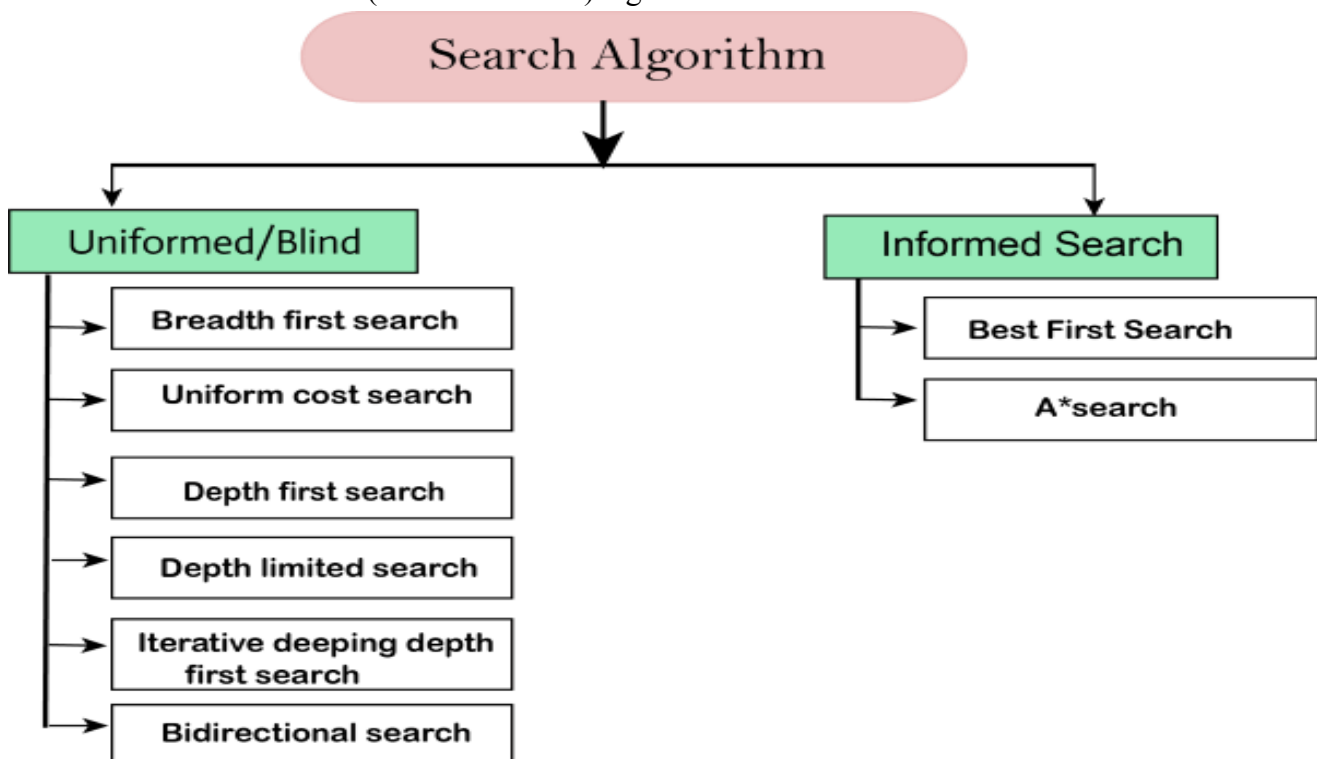
#### Syllabus:

Lecture no	Content	Duration (Hrs)	Self-Study (Hrs)
1	Uninformed Search Methods	1	2
2	Informed Search Methods	1	

#### Learning Objective:

- Learner should know about various types of uninformed and informed searching techniques.
- **Theoretical Background:**

Search algorithms are one of the most important areas of Artificial Intelligence. In Artificial Intelligence, Search techniques are universal problem-solving methods. **Problem-solving agents** in AI mostly used these search strategies or algorithms to solve a specific problem. There are many approaches to traverse the search tree generated during problem solving to achieve desired goal. Based on the search problems we can classify the search algorithms into uninformed (Blind search) search and informed search (Heuristic search) algorithms.



**Uninformed/Blind Search:** The uninformed search does not contain any domain knowledge such as closeness, the location of the goal. It operates in a brute-force way as it only includes information about how to traverse the tree and how to identify leaf and goal nodes. Uninformed search applies a way in which search tree is searched without any information about the search space like initial state operators and test for the goal, so it is also called blind search. It examines each node of the tree until it achieves the goal node.

**It can be divided into five main types:**

- Breadth-first search
- Uniform cost search
- Depth-first search
- Iterative deepening depth-first search
- Bidirectional Search

**Informed Search :** Informed search algorithms use domain knowledge. In an informed search, problem information is available which can guide the search. Informed search strategies can find a solution more efficiently than an uninformed search strategy. Informed search is also called a Heuristic search.

A heuristic is a way which might not always be guaranteed for best solutions but guaranteed to find a good solution in reasonable time.

Informed search can solve much complex problem which could not be solved in another way.

An example of informed search algorithms is a traveling salesman problem.

1. Greedy Search
2. A\* Search

- **Key Definitions:**

A search strategy is defined by picking the order of node expansion. Strategies are evaluated along the following dimensions:

- Completeness: does it always find a solution if one exists?
- Time complexity: time taken to find solution
- Space complexity: maximum number of nodes in memory
- Optimality: does it always find a least-cost solution?

Time and space complexity are measured in terms of

- $b$ : maximum branching factor (state expanded to yield new states) of the search tree
- $d$ : depth of the least-cost solution
- $m$ : maximum depth of the state space (may be  $\infty$ )

**Course Content:****Lecture : 1****Uninformed Search Methods**

**Based on the search problems we can classify the search algorithms into uninformed (Blind search) search and informed search (Heuristic search) algorithms.**

**1. Breadth-first Search:**

- Breadth-first search is the most common search strategy for traversing a tree or graph. This algorithm searches breadthwise in a tree or graph, so it is called breadth-first search.
- BFS algorithm starts searching from the root node of the tree and expands all successor node at the current level before moving to nodes of next level.
- The breadth-first search algorithm is an example of a general-graph search algorithm.
- Breadth-first search implemented using FIFO queue data structure.

**Advantages:**

- BFS will provide a solution if any solution exists.
- If there are more than one solutions for a given problem, then BFS will provide the minimal solution which requires the least number of steps.

**Disadvantages:**

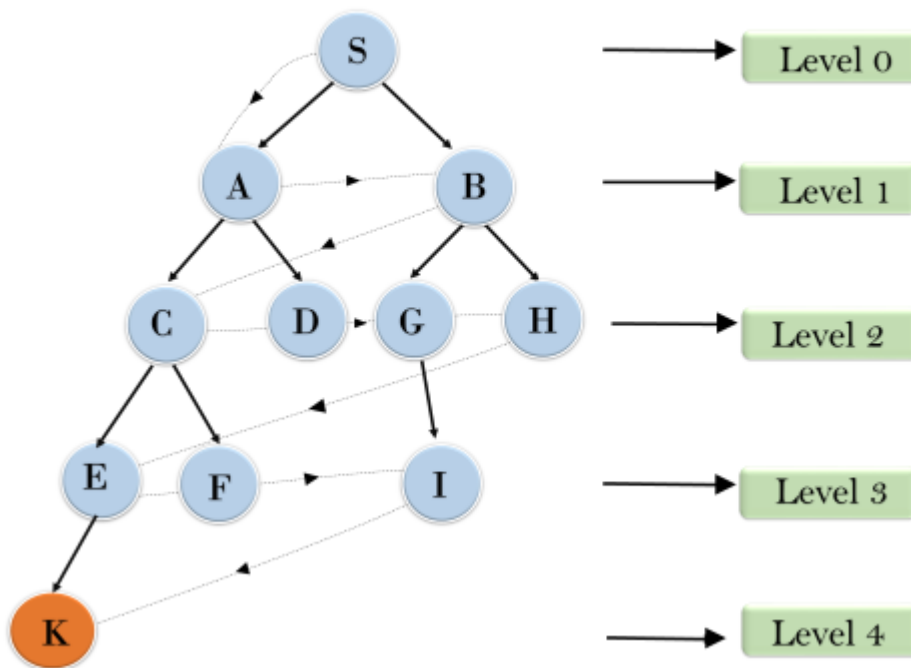
- It requires lots of memory since each level of the tree must be saved into memory to expand the next level.
- BFS needs lots of time if the solution is far away from the root node.

**Example:**

In the below tree structure, we have shown the traversing of the tree using BFS algorithm from the root node S to goal node K. BFS search algorithm traverse in layers, so it will follow the path which is shown by the dotted arrow, and the traversed path will be:

1. S---> A--->B---->C--->D---->G--->H--->E---->F---->I---->K

## Breadth First Search



**Time Complexity:** Time Complexity of BFS algorithm can be obtained by the number of nodes traversed in BFS until the shallowest Node. Where the  $d$  = depth of shallowest solution and  $b$  is a node at every state.

$$T(b) = 1 + b^1 + b^2 + \dots + b^d = O(b^d)$$

**Space Complexity:** Space complexity of BFS algorithm is given by the Memory size of frontier which is  $O(b^d)$ .

**Completeness:** BFS is complete, which means if the shallowest goal node is at some finite depth, then BFS will find a solution.

**Optimality:** BFS is optimal if path cost is a non-decreasing function of the depth of the node.

## 2. Depth-first Search

- Depth-first search is a recursive algorithm for traversing a tree or graph data structure.
- It is called the depth-first search because it starts from the root node and follows each path to its greatest depth node before moving to the next path.
- DFS uses a stack data structure for its implementation.
- The process of the DFS algorithm is similar to the BFS algorithm.

Note: Backtracking is an algorithm technique for finding all possible solutions using recursion.

**Advantage:**

- DFS requires very less memory as it only needs to store a stack of the nodes on the path from root node to the current node.
- It takes less time to reach to the goal node than BFS algorithm (if it traverses in the right path).

**Disadvantage:**

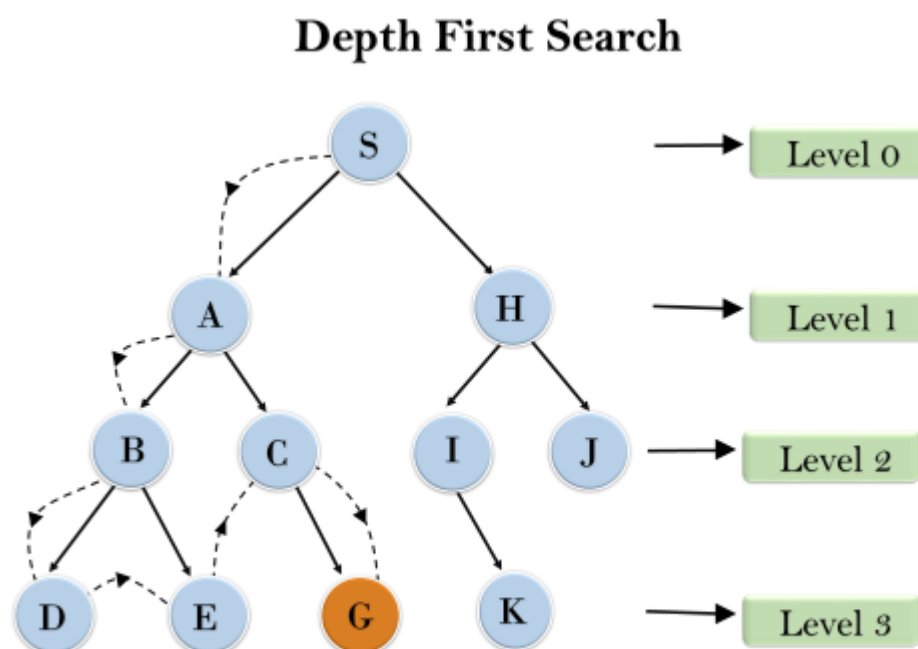
- There is the possibility that many states keep re-occurring, and there is no guarantee of finding the solution.
- DFS algorithm goes for deep down searching and sometime it may go to the infinite loop.

**Example:**

In the below search tree, we have shown the flow of depth-first search, and it will follow the order as:

Root node--->Left node ----> right node.

It will start searching from root node S, and traverse A, then B, then D and E, after traversing E, it will backtrack the tree as E has no other successor and still goal node is not found. After backtracking it will traverse node C and then G, and here it will terminate as it found goal node.



**Completeness:** DFS search algorithm is complete within finite state space as it will expand every node within a limited search tree.

**Time Complexity:** Time complexity of DFS will be equivalent to the node traversed by the algorithm. It is given by:

$$T(n) = 1 + n^2 + n^3 + \dots + n^m = O(n^m)$$

**Where,  $m$  = maximum depth of any node and this can be much larger than  $d$  (Shallowest solution depth)**

**Space Complexity:** DFS algorithm needs to store only single path from the root node, hence space complexity of DFS is equivalent to the size of the fringe set, which is  **$O(bm)$** .

**Optimal:** DFS search algorithm is non-optimal, as it may generate a large number of steps or high cost to reach to the goal node.

### *3. Depth-Limited Search Algorithm:*

A depth-limited search algorithm is similar to depth-first search with a predetermined limit. Depth-limited search can solve the drawback of the infinite path in the Depth-first search. In this algorithm, the node at the depth limit will treat as it has no successor nodes further.

Depth-limited search can be terminated with two Conditions of failure:

- Standard failure value: It indicates that problem does not have any solution.
- Cutoff failure value: It defines no solution for the problem within a given depth limit.

**Depth-limited search** avoids the pitfalls of depth-first search by imposing a cutoff on the maximum depth of a path. This cutoff can be implemented with a special depth-limited search algorithm, or by using the general search algorithm with operators that keep track of the depth. For example, on the map of Romania, there are 20 cities, so we know that if there is a solution, then it must be of length 19 at the longest. We can implement the depth cutoff using operators of the form "If you are in city A and have travelled a path of less than 19 steps, then generate a new state in city B with a path length that is one greater." With this new operator set, we are guaranteed to find the solution if it exists, but we are still not guaranteed to find the shortest solution first: depth-limited search is complete but not optimal. If we choose a depth limit that is too small, then depth-limited search is not even complete. The time and space complexity of depth-limited search is similar to depth-first search. It takes  $O(b^l)$  time and  $O(bl)$  space, where  $l$  is the depth limit.

**Depth-limited search**

= depth-first search with depth limit  $l$ ,  
i.e., nodes at depth  $l$  have no successors

**Recursive implementation:**

```

function DEPTH-LIMITED-SEARCH( $problem, limit$ ) returns soln/fail/cutoff
  RECURSIVE-DLS(MAKE-NODE(INITIAL-STATE[ $problem$ ]),  $problem, limit$ )
function RECURSIVE-DLS( $node, problem, limit$ ) returns soln/fail/cutoff
  cutoff-occurred?  $\leftarrow$  false
  if GOAL-TEST[ $problem$ ](STATE[ $node$ ]) then return SOLUTION( $node$ )
  else if DEPTH[ $node$ ] = limit then return cutoff
  else for each successor in EXPAND( $node, problem$ ) do
    result  $\leftarrow$  RECURSIVE-DLS(successor,  $problem, limit$ )
    if result = cutoff then cutoff-occurred?  $\leftarrow$  true
    else if result  $\neq$  failure then return result
  if cutoff-occurred? then return cutoff else return failure
  
```

### Advantages:

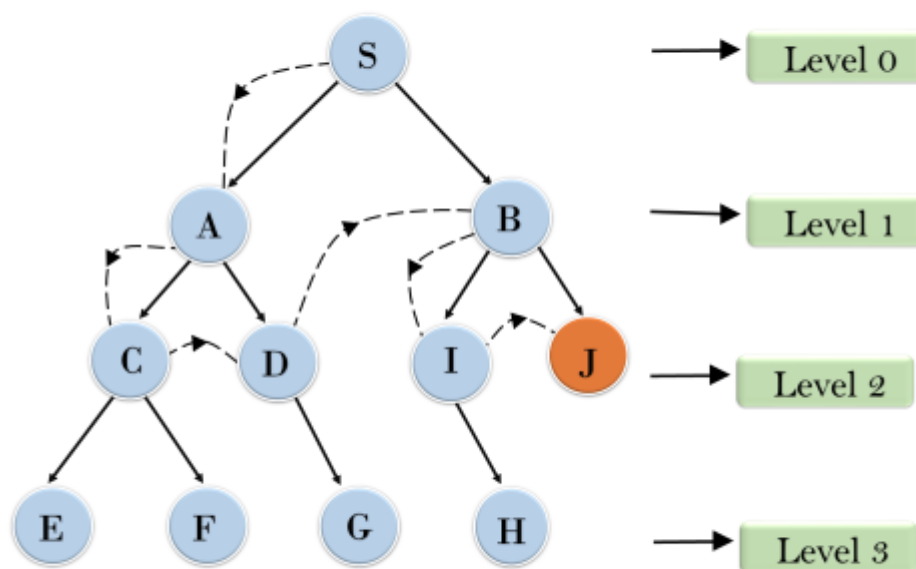
Depth-limited search is Memory efficient.

### Disadvantages:

- Depth-limited search also has a disadvantage of incompleteness.
- It may not be optimal if the problem has more than one solution.

### Example:

#### Depth Limited Search



**Completeness:** DLS search algorithm is complete if the solution is above the depth-limit.

**Time Complexity:** Time complexity of DLS algorithm is  $O(b^l)$ .

**Space Complexity:** Space complexity of DLS algorithm is  $O(b \times l)$ .

**Optimal:** Depth-limited search can be viewed as a special case of DFS, and it is also not optimal even if  $\ell > d$ .

#### 4. Uniform-cost Search Algorithm:

Uniform-cost search is a searching algorithm used for traversing a weighted tree or graph. This algorithm comes into play when a different cost is available for each edge. The primary goal of the uniform-cost search is to find a path to the goal node which has the lowest cumulative cost. Uniform-cost search expands nodes according to their path costs from the root node. It can be used to solve any graph/tree where the optimal cost is in demand. A uniform-cost search algorithm is implemented by the priority queue. It gives maximum priority to the lowest cumulative cost. Uniform cost search is equivalent to BFS algorithm if the path cost of all edges is the same.

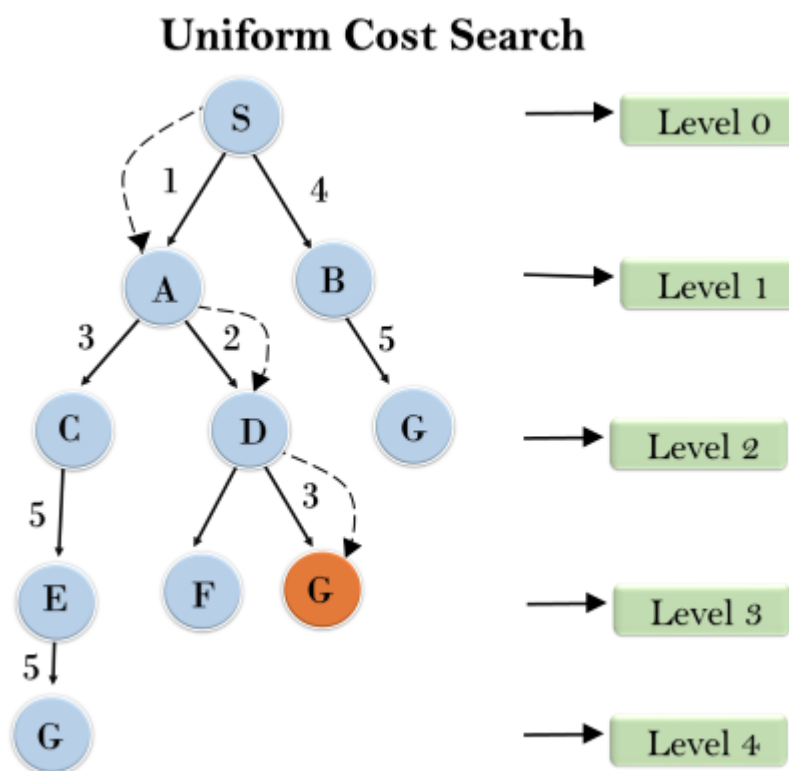
##### Advantages:

- Uniform cost search is optimal because at every state the path with the least cost is chosen.

##### Disadvantages:

- It does not care about the number of steps involve in searching and only concerned about path cost. Due to which this algorithm may be stuck in an infinite loop.

Example:



##### Completeness:

Uniform-cost search is complete, such as if there is a solution, UCS will find it.

##### Time Complexity:



Let  $C^*$  is **Cost of the optimal solution**, and  $\epsilon$  is each step to get closer to the goal node. Then the number of steps is  $= C^*/\epsilon + 1$ . Here we have taken  $+1$ , as we start from state 0 and end to  $C^*/\epsilon$ .

Hence, the worst-case time complexity of Uniform-cost search is  $O(b^{1 + \lceil C^*/\epsilon \rceil})$ .

### Space Complexity:

The same logic is for space complexity so, the worst-case space complexity of Uniform-cost search is  $O(b^{1 + \lceil C^*/\epsilon \rceil})$ .

### Optimal:

Uniform-cost search is always optimal as it only selects a path with the lowest path cost.

## 5. Iterative deepening depth-first Search:

The iterative deepening algorithm is a combination of DFS and BFS algorithms. This search algorithm finds out the best depth limit and does it by gradually increasing the limit until a goal is found.

This algorithm performs depth-first search up to a certain "depth limit", and it keeps increasing the depth limit after each iteration until the goal node is found.

This Search algorithm combines the benefits of Breadth-first search's fast search and depth-first search's memory efficiency.

The iterative search algorithm is useful uninformed search when search space is large, and depth of goal node is unknown.

**Depth First Iterative deepening search:** The hard part about depth-limited search is picking a good limit. We picked 19 as an "obvious" depth limit for the Romania problem, but in fact if we studied the map carefully, we would discover that any city can be reached from any other city in at most 9 steps. This number, known as the **diameter** of the state space, gives us a better depth limit, which leads to a more efficient depth-limited search. However, for most problems, we will not know a good depth limit until we have solved the problem. **DFID search** is a strategy that sidesteps the issue of choosing the best depth limit by trying all possible depth limits: first depth 0, then depth 1, then depth 2, and so on. In effect, iterative deepening combines the benefits of depth-first and breadth-first search. It is optimal and complete, like breadth-first search, but has only the modest memory requirements of depth-first search. The order of expansion of states is similar to breadth-first, except that some states are expanded multiple times. Iterative deepening search may seem wasteful, because so many states are expanded multiple times. For most problems, however, the overhead of this multiple expansion is actually rather small. Intuitively, the reason is that in an exponential search tree, almost all of the nodes are in the bottom level, so it does not matter much that the upper levels are expanded multiple times.

Number of nodes generated in a **depth-limited search** to depth  $d$  with branching factor  $b$ :

$$N_{DLS} = b^0 + b^1 + b^2 + \dots + b^{d-2} + b^{d-1} + b^d$$

Number of nodes generated in an **iterative deepening search** to depth  $d$  with branching factor  $b$ :

$$N_{IDS} = (d+1)b^0 + d b^1 + (d-1)b^2 + \dots + 3b^{d-2} + 2b^{d-1} + 1b^d$$

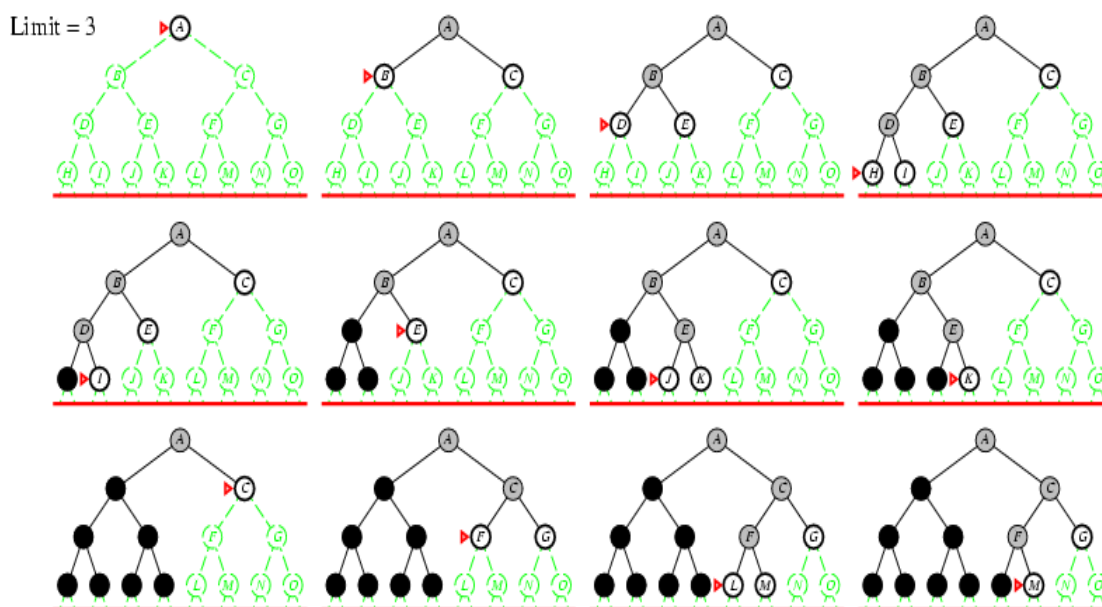
For  $b = 10, d = 5$ ,

$$N_{DLS} = 1 + 10 + 100 + 1,000 + 10,000 + 100,000 = 111,111$$

$$N_{IDS} = 6 + 50 + 400 + 3,000 + 20,000 + 100,000 = 123,456$$

$$\text{Overhead} = (123,456 - 111,111) / 111,111 = 11\%$$

In an iterative deepening search, the nodes on the bottom level are expanded once, those on the next to bottom level are expanded twice, and so on, up to the root of the search tree, which is expanded  $d + 1$  times. All together, an iterative deepening search from depth 1 all the way down to depth  $d$  expands only about 11 % more nodes than a single breadth-first or depth-limited search to depth  $d$ , when  $b = 10$ . The higher the branching factor, the lower the overhead of repeatedly expanded states, but even when the branching factor is 2, iterative deepening search only takes about twice as long as a complete breadth-first search. This means that the time complexity of iterative deepening is still  $O(b^d)$ , and the space complexity is  $O(bd)$ . *In general, iterative deepening is the preferred search method when there is a large search space and the depth of the solution is not known.*



```

function ITERATIVE-DEEPENING-SEARCH(proWem) returns a solution sequence
inputs: problem, a problem
for depth  $\leftarrow$  0 to  $\infty$  do
  if DEPTH-LIMITED-SEARCH(proWem, depth) succeeds then return its result
end
return failure

```

### Advantages:

- It combines the benefits of BFS and DFS search algorithm in terms of fast search and memory efficiency.

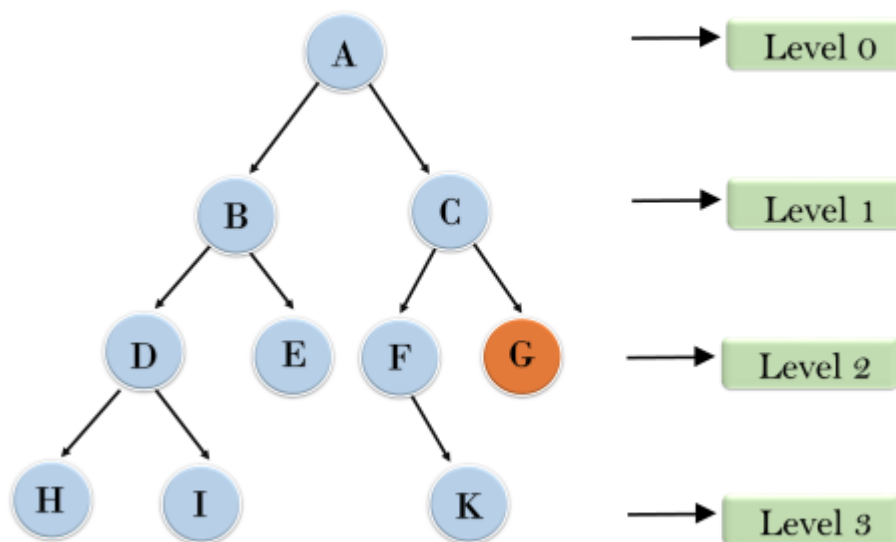
### Disadvantages:

- The main drawback of IDDFS is that it repeats all the work of the previous phase.

### Example:

Following tree structure is showing the iterative deepening depth-first search. IDDFS algorithm performs various iterations until it does not find the goal node. The iteration performed by the algorithm is given as:

### Iterative deepening depth first search



1'st Iteration-----> A

2'nd Iteration-----> A, B, C

3'rd Iteration----->A, B, D, E, C, F, G

4'th Iteration----->A, B, D, H, I, E, C, F, K, G

In the fourth iteration, the algorithm will find the goal node.

#### Completeness:

This algorithm is complete if the branching factor is finite.

#### Time Complexity:

Let's suppose  $b$  is the branching factor and depth is  $d$  then the worst-case time complexity is  $O(b^d)$ .

#### Space Complexity:

The space complexity of IDDFS will be  $O(bd)$ .

#### Optimal:

IDDFS algorithm is optimal if path cost is a non-decreasing function of the depth of the node.

#### 6. Bidirectional Search Algorithm:

**Bidirectional search algorithm** runs two simultaneous searches, one from initial state called as forward-search and other from goal node called as backward-search, to find the goal node. Bidirectional search replaces one single search graph with two small subgraphs in which one starts the search from an initial vertex and other starts from goal vertex. The search stops when these two graphs intersect each other.

Bidirectional search can use search techniques such as BFS, DFS, DLS, etc.

**Advantages:**

- Bidirectional search is fast.
- Bidirectional search requires less memory

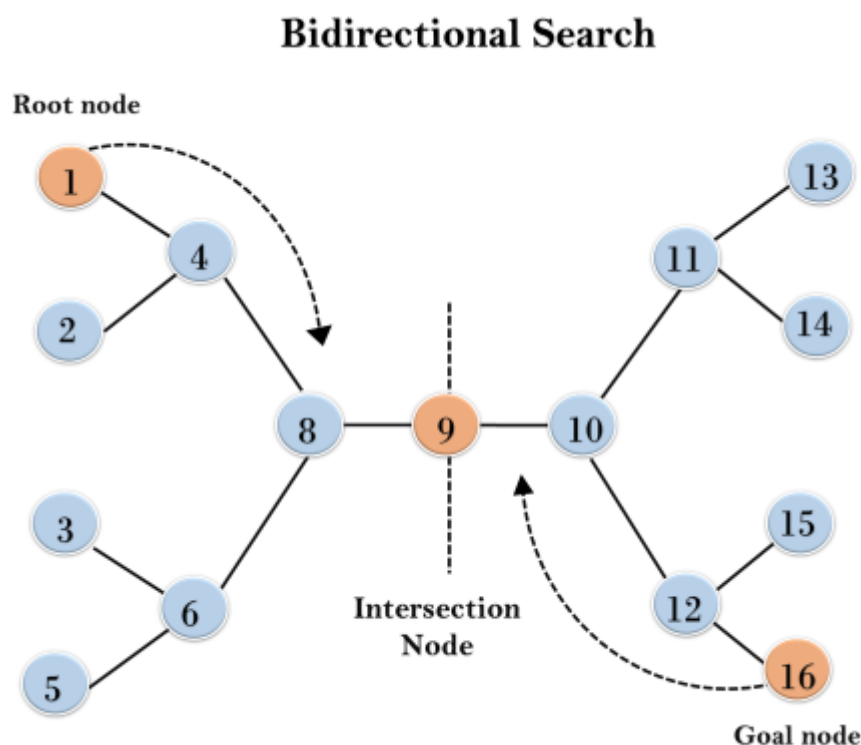
**Disadvantages:**

- Implementation of the bidirectional search tree is difficult.
- **In bidirectional search, one should know the goal state in advance.**

**Example:**

In the below search tree, bidirectional search algorithm is applied. This algorithm divides one graph/tree into two sub-graphs. It starts traversing from node 1 in the forward direction and starts from goal node 16 in the backward direction.

The algorithm terminates at node 9 where two searches meet.



**Completeness:** Bidirectional Search is complete if we use BFS in both searches.

**Time Complexity:** Time complexity of bidirectional search using BFS is  $O(b^d)$ .

**Space Complexity:** Space complexity of bidirectional search is  $O(b^d)$ .

**Optimal:** Bidirectional search is Optimal.

*Let's check the take away from this lecture*

### Exercise/FA through activity

**Debate Activity on primitive uninformed searches / advanced uninformed searches.**

**Learning from this lecture:** Learners will be able to understand various types Uninformed Search Methods with their performance measure.

## Lecture : 2

So far we have talked about the uninformed search algorithms which looked through search space for all possible solutions of the problem without having any additional knowledge about search space. But informed search algorithm contains an array of knowledge such as how far we are from the goal, path cost, how to reach to goal node, etc. This knowledge help agents to explore less to the search space and find more efficiently the goal node.

The informed search algorithm is more useful for large search space. Informed search algorithm uses the idea of heuristic, so it is also called Heuristic search.

**Heuristics function:** Heuristic is a function which is used in Informed Search, and it finds the most promising path. It takes the current state of the agent as its input and produces the estimation of how close agent is from the goal. The heuristic method, however, might not always give the best solution, but it guaranteed to find a good solution in reasonable time. Heuristic function estimates how close a state is to the goal. It is represented by  $h(n)$ , and it calculates the cost of an optimal path between the pair of states. The value of the heuristic function is always positive.

**Admissibility of the heuristic function is given as:**

1.  $h(n) \leq h^*(n)$

**Here  $h(n)$  is heuristic cost, and  $h^*(n)$  is the estimated cost. Hence heuristic cost should be less than or equal to the estimated cost.**

### Pure Heuristic Search:

Pure heuristic search is the simplest form of heuristic search algorithms. It expands nodes based on their heuristic value  $h(n)$ . It maintains two lists, OPEN and CLOSED list. In the CLOSED list, it

places those nodes which have already expanded and in the OPEN list, it places nodes which have yet not been expanded.

On each iteration, each node  $n$  with the lowest heuristic value is expanded and generates all its successors and  $n$  is placed to the closed list. The algorithm continues until a goal state is found.

In the informed search we will discuss two main algorithms which are given below:

- **Best First Search Algorithm(Greedy search)**
- **A\* Search Algorithm**

### **1.) Best-first Search Algorithm (Greedy Search):**

Greedy best-first search algorithm always selects the path which appears best at that moment. It is the combination of depth-first search and breadth-first search algorithms. It uses the heuristic function and search. Best-first search allows us to take the advantages of both algorithms. With the help of best-first search, at each step, we can choose the most promising node. In the best first search algorithm, we expand the node which is closest to the goal node and the closest cost is estimated by heuristic function, i.e.

1.  $f(n) = h(n)$ .

Where,  $h(n)$  = estimated cost from node  $n$  to the goal.

The greedy best first algorithm is implemented by the priority queue.

Best first search algorithm:

- **Step 1:** Place the starting node into the OPEN list.
- **Step 2:** If the OPEN list is empty, Stop and return failure.
- **Step 3:** Remove the node  $n$ , from the OPEN list which has the lowest value of  $h(n)$ , and places it in the CLOSED list.
- **Step 4:** Expand the node  $n$ , and generate the successors of node  $n$ .
- **Step 5:** Check each successor of node  $n$ , and find whether any node is a goal node or not. If any successor node is goal node, then return success and terminate the search, else proceed to Step 6.
- **Step 6:** For each successor node, algorithm checks for evaluation function  $f(n)$ , and then check if the node has been in either OPEN or CLOSED list. If the node has not been in both list, then add it to the OPEN list.
- **Step 7:** Return to Step 2.

Advantages:

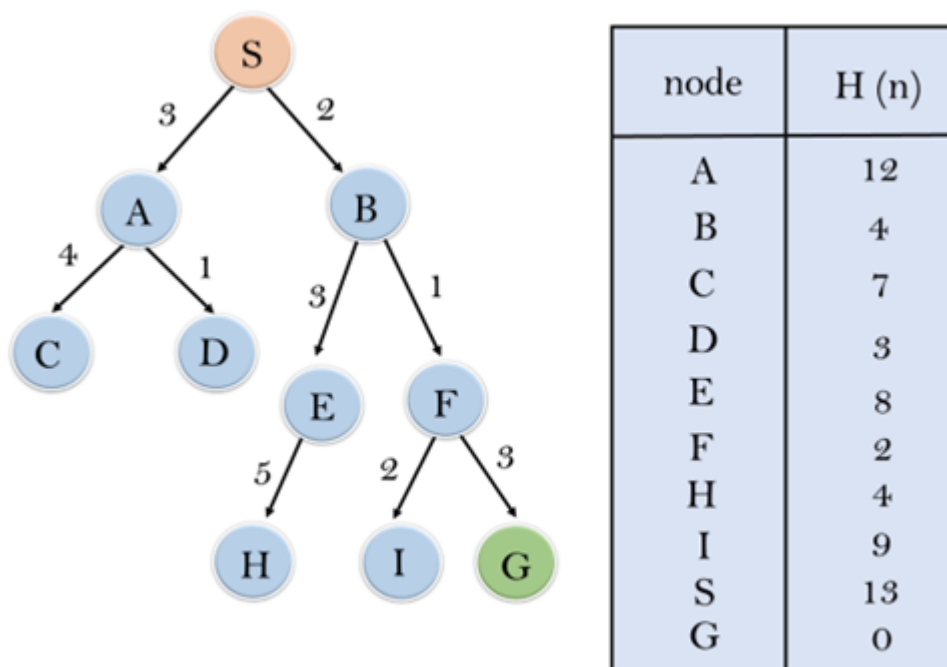
- Best first search can switch between BFS and DFS by gaining the advantages of both the algorithms.
- This algorithm is more efficient than BFS and DFS algorithms.

Disadvantages:

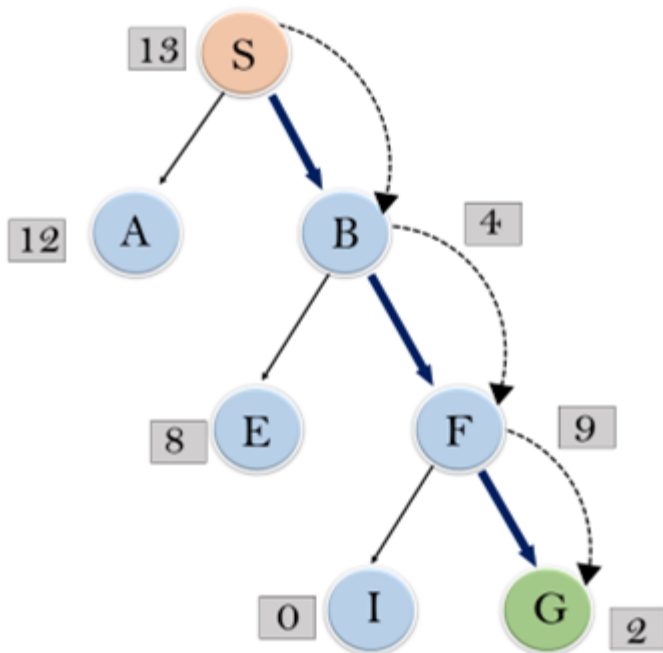
- It can behave as an unguided depth-first search in the worst case scenario.
- It can get stuck in a loop as DFS.
- This algorithm is not optimal.

Example:

Consider the below search problem, and we will traverse it using greedy best-first search. At each iteration, each node is expanded using evaluation function  $f(n)=h(n)$ , which is given in the below table.



In this search example, we are using two lists which are **OPEN** and **CLOSED** Lists. Following are the iteration for traversing the above example.



**Expand the nodes of S and put in the CLOSED list**

**Initialization:** Open [A, B], Closed [S]

**Iteration 1:** Open [A], Closed [S, B]

**Iteration 2:** Open [E, F, A], Closed [S, B]  
: Open [E, A], Closed [S, B, F]

**Iteration 3:** Open [I, G, E, A], Closed [S, B, F]  
: Open [I, E, A], Closed [S, B, F, G]

Hence the final solution path will be: **S----> B----->F----> G**

**Time Complexity:** The worst case time complexity of Greedy best first search is  $O(b^m)$ .

**Space Complexity:** The worst case space complexity of Greedy best first search is  $O(b^m)$ . Where,  $m$  is the maximum depth of the search space.

**Complete:** Greedy best-first search is also incomplete, even if the given state space is finite.

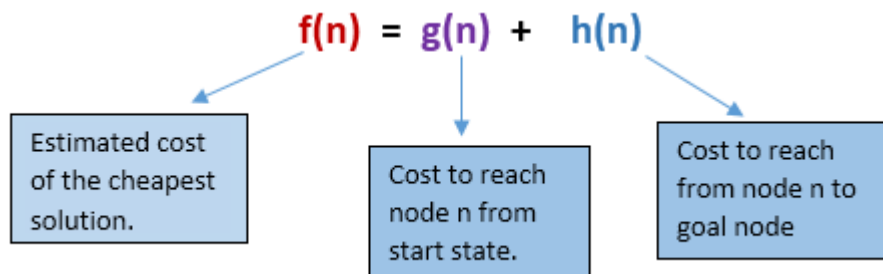
**Optimal:** Greedy best first search algorithm is not optimal.

2.) A\* Search Algorithm:

A\* search is the most commonly known form of best-first search. It uses heuristic function  $h(n)$ , and cost to reach the node  $n$  from the start state  $g(n)$ . It has combined features of UCS and greedy best-first search, by which it solve the problem efficiently. A\* search algorithm finds the shortest path through the search space using the heuristic function. This search algorithm expands less search tree and provides optimal result faster. A\* algorithm is similar to UCS except that it uses  $g(n)+h(n)$  instead of  $g(n)$ .



In A\* search algorithm, we use search heuristic as well as the cost to reach the node. Hence we can combine both costs as following, and this sum is called as a **fitness number**.



At each point in the search space, only those node is expanded which have the lowest value of  $f(n)$ , and the algorithm terminates when the goal node is found.

Algorithm of A\* search:

**Step1:** Place the starting node in the OPEN list.

**Step 2:** Check if the OPEN list is empty or not, if the list is empty then return failure and stops.

**Step 3:** Select the node from the OPEN list which has the smallest value of evaluation function ( $g+h$ ), if node  $n$  is goal node then return success and stop, otherwise

**Step 4:** Expand node  $n$  and generate all of its successors, and put  $n$  into the closed list. For each successor  $n'$ , check whether  $n'$  is already in the OPEN or CLOSED list, if not then compute evaluation function for  $n'$  and place into Open list.

**Step 5:** Else if node  $n'$  is already in OPEN and CLOSED, then it should be attached to the back pointer which reflects the lowest  $g(n')$  value.

**Step 6:** Return to **Step 2**.

Idea: use an evaluation function  $f(n)$  for each node  
estimate of "desirability"

Expand most desirable unexpanded node

Implementation:

Order the nodes in fringe in decreasing order of desirability

Special cases:

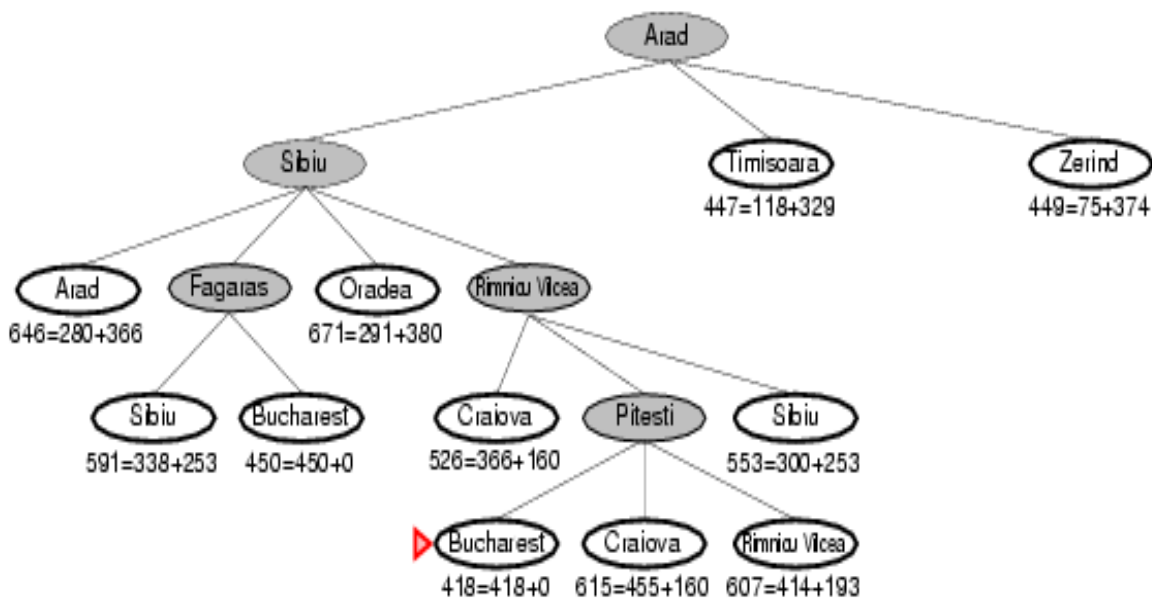
greedy best-first search

A\* search

**A\* search(Minimizing the total path cost):** Greedy search minimizes the estimated cost to the goal,  $h(n)$ , and thereby cuts the search cost considerably. Unfortunately, it is neither optimal nor complete. Uniform-cost search, on the other hand, minimizes the cost of the path so far,  $g(n)$ ; it is optimal and complete, but can be very inefficient. It would be nice if we could combine these two strategies to get the advantages of both. Fortunately, we can do exactly that, combining the two evaluation functions simply by summing them:

$$f(n) = g(n) + h(n).$$

Since  $g(n)$  gives the path cost from the start node to node  $n$ , and  $h(n)$  is the estimated cost of the cheapest path from  $n$  to the goal, we have  $f(n)$  = estimated cost of the cheapest solution through  $n$ .



The restriction is to choose an  $h$  function that *never overestimates* the cost to reach the goal. Such an  $h$  is called an **admissible heuristic**. Best-first search using  $f$  as the evaluation function and an admissible  $h$  function is known as **A\* search**

**function** A\*-SEARCH( $problem$ ) **returns** a solution or failure

**return** BEST-FIRST-SEARCH( $problem, g + h$ )

#### PERFORMANCE EVOLUTION OF A\* ALGORITHM

- ▶ A\* algorithm is Complete algorithm i.e. if there exists a solution then it will return solution
- ▶ Time Complexity: Exponential with path length
- ▶ Space Complexity: it keeps all generated nodes in memory, so memory is problem
- ▶ It is Optimal Algorithm

#### Advantages:

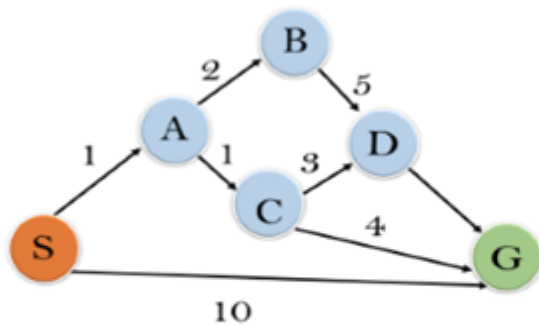
- A\* search algorithm is the best algorithm than other search algorithms.
- A\* search algorithm is optimal and complete.
- This algorithm can solve very complex problems.

#### Disadvantages:

- It does not always produce the shortest path as it mostly based on heuristics and approximation.
- A\* search algorithm has some complexity issues.
- The main drawback of A\* is memory requirement as it keeps all generated nodes in the memory, so it is not practical for various large-scale problems.

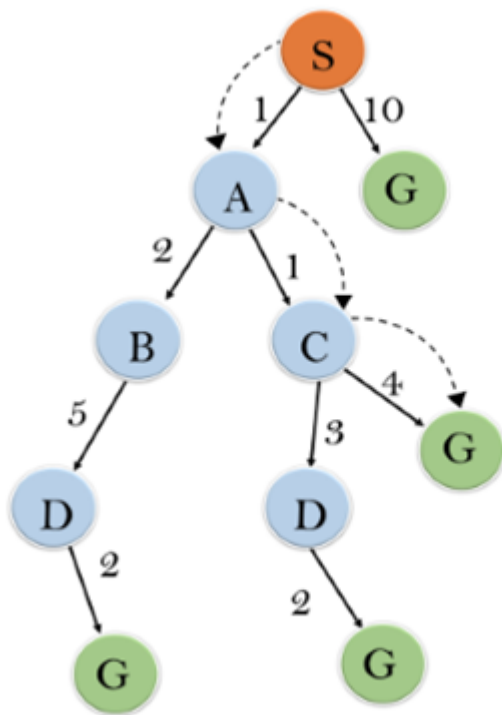
#### Example:

In this example, we will traverse the given graph using the A\* algorithm. The heuristic value of all states is given in the below table so we will calculate the  $f(n)$  of each state using the formula  $f(n) = g(n) + h(n)$ , where  $g(n)$  is the cost to reach any node from start state. Here we will use OPEN and CLOSED list.



State	$h(n)$
S	5
A	3
B	4
C	2
D	6
G	0

**Solution:**



**Initialization:**  $\{(S, 5)\}$

**Iteration1:**  $\{(S \rightarrow A, 4), (S \rightarrow G, 10)\}$

**Iteration2:**  $\{(S \rightarrow A \rightarrow C, 4), (S \rightarrow A \rightarrow B, 7), (S \rightarrow G, 10)\}$

**Iteration3:**  $\{(S \rightarrow A \rightarrow C \rightarrow G, 6), (S \rightarrow A \rightarrow C \rightarrow D, 11), (S \rightarrow A \rightarrow B, 7), (S \rightarrow G, 10)\}$

**Iteration 4** will give the final result, as  $S \rightarrow A \rightarrow C \rightarrow G$  it provides the optimal path with cost 6.

**Points to remember:**

- A\* algorithm returns the path which occurred first, and it does not search for all remaining paths.
- The efficiency of A\* algorithm depends on the quality of heuristic.
- A\* algorithm expands all nodes which satisfy the condition  $f(n) \leq l_i$

**Complete:** A\* algorithm is complete as long as:

- Branching factor is finite.
- Cost at every action is fixed.

**Optimal:** A\* search algorithm is optimal if it follows below two conditions:

- **Admissible:** the first condition requires for optimality is that  $h(n)$  should be an admissible heuristic for A\* tree search. An admissible heuristic is optimistic in nature.
- **Consistency:** Second required condition is consistency for only A\* graph-search.

If the heuristic function is admissible, then A\* tree search will always find the least cost path.

**Time Complexity:** The time complexity of A\* search algorithm depends on heuristic function, and the number of nodes expanded is exponential to the depth of solution  $d$ . So the time complexity is  $O(b^d)$ , where  $b$  is the branching factor.

**Space Complexity:** The space complexity of A\* search algorithm is  $O(b^d)$

*Let's check the take away from this lecture*

Exercise

**Debate Activity on primitive uninformed searches / informed searches.**

**Learning from this lecture:** Learners will be able to understand various types Informed Search Methods with their performance measure.

**Conclusion**

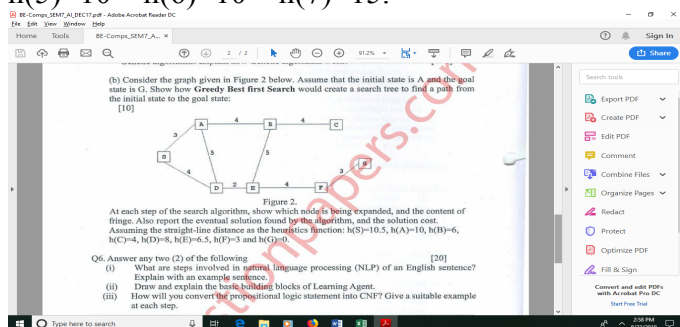
This chapter was introduction to blind search(uninformed search) and heuristic search(Informed Search).

**Short Answer Questions:**

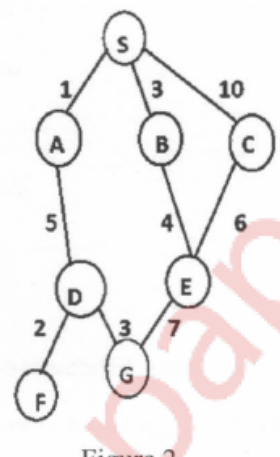
- Q.1** Prove the admissibility of  $A^*$ .
- Q.2** Give an example heuristics function for 8 puzzle problem.
- Q.3** Find the heuristic value or particular state of the block word problem.
- Q.4** Differentiate between Greedy Best First Search and  $A^*$  method.
- Q.5** Discuss for which type of applications by bidirectional search can be used.

**Long Answer Questions:**

- Q.1** Consider the graph given in Fig 1 below. Assume the initial state is S and goal state is 7. Find a path from initial state to goal state using  $A^*$  search. Also report the solution cost. The straight line distance heuristic estimates for the nodes are as follows:  $h(1)=14$   $h(2)=10$   $h(3)=8$   $h(4)=12$   $h(5)=10$   $h(6)=10$   $h(7)=15$ .



- Q.2** Invent a heuristic function for the 8-puzzle that sometimes overestimates, and show how it can lead to a suboptimal solution on a particular problem.
- Q.3** Compare different uninformed strategies with example Graph and performance measure.
- Q.4** Consider the graph below. Assume initial A and goal G. Show how  $A^*$  tree to find a path. At each step of the algorithm show which node is being expanded and content of fringe (OPEN). Report solution and cost. Assume  $h(sld)$  heuristic as  $h(S)=13$ ,  $h(A)=7$ ,  $h(B)=9$ ,  $h(C)=11$ ,  $h(D)=2$ ,  $h(E)=4$ ,  $h(F)=1$ ,  $h(G)$



- Q.5** Compare different informed strategies with example Graph and performance measure.

**References:****Books:**

	Title	Authors	Publisher	Edition	Year	Chapter No
1	Artificial Intelligence a Modern	Stuart J. Russell and Peter Norvig	McGraw Hill	3rd Edition	2009	

	Approach					
2	A First Course in Artificial Intelligence	Deepak Khemani	McGraw Hill Education (India)	1 <sup>st</sup> Edition	2013	

### Online Resources:

- [https://onlinecourses.nptel.ac.in/noc20\\_cs81/preview](https://onlinecourses.nptel.ac.in/noc20_cs81/preview)
- <https://nptel.ac.in/courses/106/102/106102220/>
- <https://www.coursera.org/learn/mind-machine-problem-solving-methods>
- [https://www.tutorialspoint.com/artificial\\_intelligence/artificial\\_intelligent\\_systems.htm](https://www.tutorialspoint.com/artificial_intelligence/artificial_intelligent_systems.htm)
- <https://www.javatpoint.com/artificial-intelligence-tutorial>
- <https://people.eecs.berkeley.edu/~russell/>
- <https://en.wikipedia.org/>