Artificial Intelligence

3.4: Solving Problem by Searching

Today’s Topic

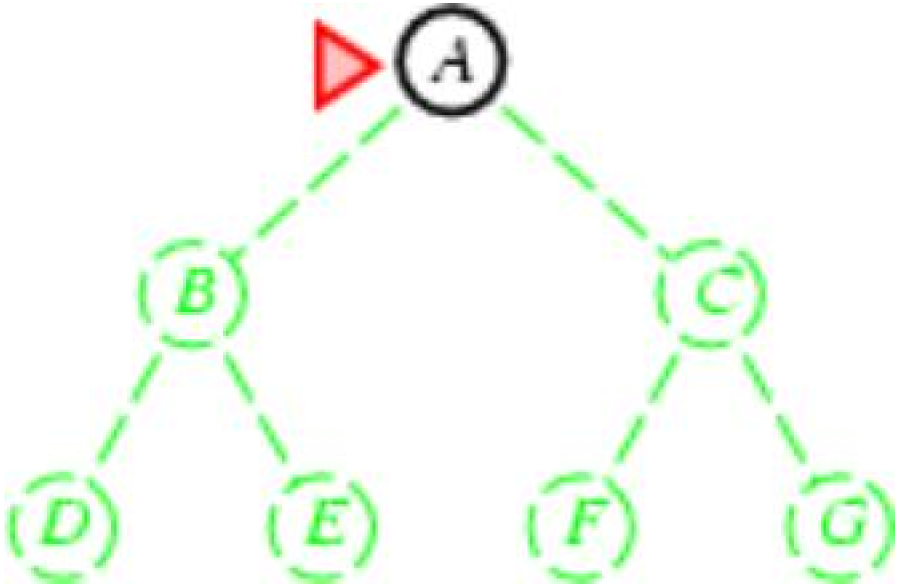
- Uninformed Search Strategies
  - BFS,DFS,UCS
  - DPL, ID

Uninformed search strategies

- Uninformed search strategies use only the information available in the problem definition
  - Breadth-first search
  - Uniform-cost search
  - Depth-first search
  - Depth-limited search
  - Iterative deepening search

Breadth-first search

- Expand shallowest unexpanded node
- Implementation:
  - – QUEUE : FIFO Implementation



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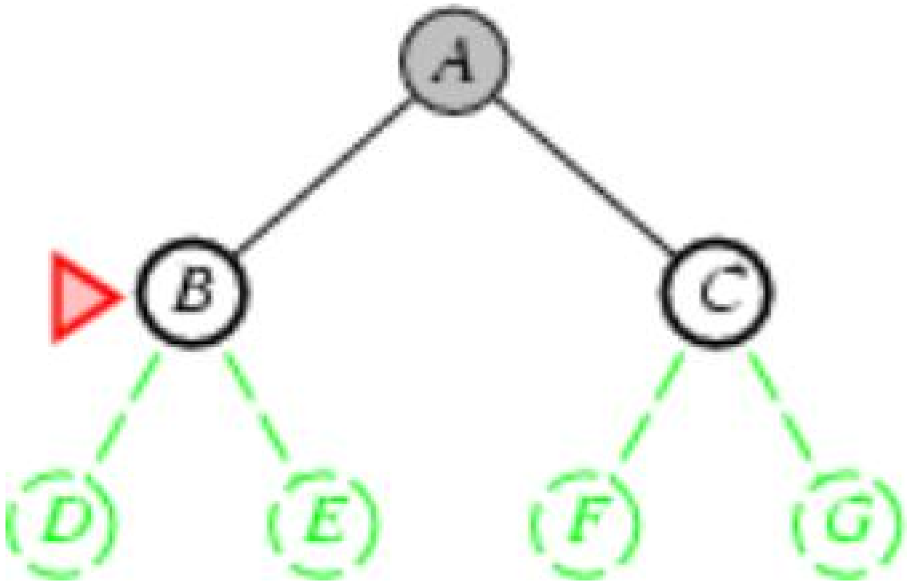

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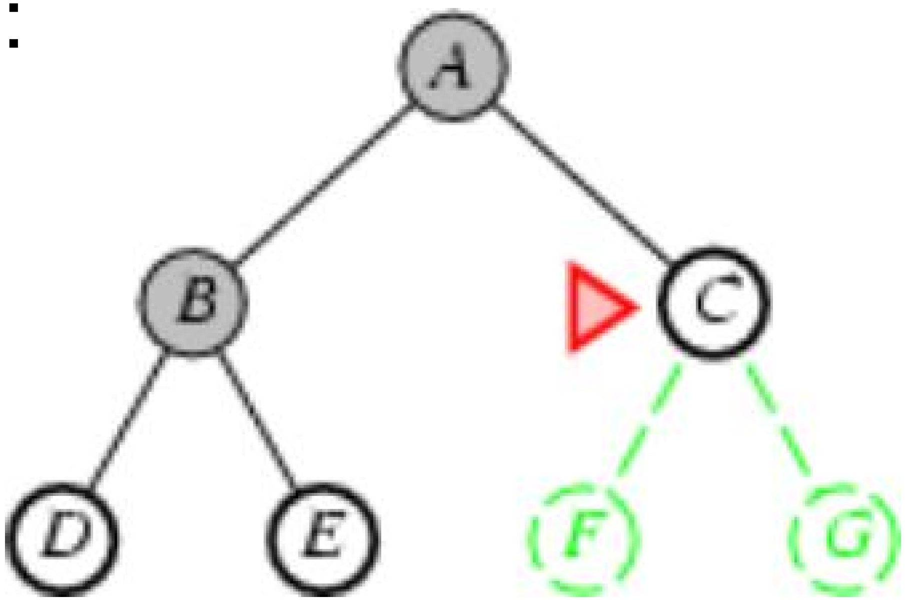

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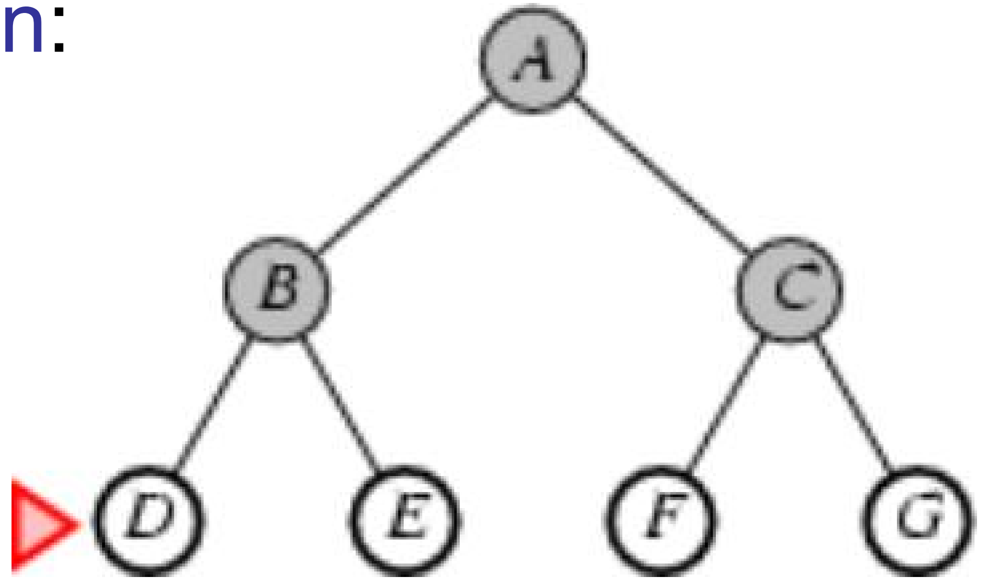


Breadth-first search

```
function BREADTH-FIRST-SEARCH(problem) returns a solution, or failure
  node ← a node with STATE = problem.INITIAL-STATE, PATH-COST = 0
  if problem.GOAL-TEST(node.STATE) then return SOLUTION(node)
  frontier ← a FIFO queue with node as the only element
  explored ← an empty set
  loop do
     if EMPTY?(frontier) then return failure
     node ← POP(frontier)  /* chooses the shallowest node in frontier */
     add node.STATE to explored
     for each action in problem.ACTIONS(node.STATE) do
        child ← CHILD-NODE(problem, node, action)
        if child.STATE is not in explored or frontier then
           if problem.GOAL-TEST(child.STATE) then return SOLUTION(child)
           frontier ← INSERT(child, frontier)
```

Figure 3.11 Breadth-first search on a graph.

Breadth-first Search: Analysis of BFS

- Time complexity: Assume a state space where every state has b successors
  - Assume solution is at depth d
  - Worst case: expand all but the last node at depth d
  - Total number of nodes generated:
    - $b + b^2 + b^3 + \ldots + b^d = O(b^d)$
- Space Complexity: Every node generated must remain in memory so it will be same as time complexity

Properties of breadth-first search

- Complete? Yes (if b is finite)
- Time? $b+b^2+b^3+\dots+b^d = O(b^d)$
- Space? $O(b^d)$ (keeps every node in memory)
- Optimal? Yes (if cost = 1 per step)
- Space is the bigger problem (more than time)

Using Breadth-first Search

- When is BFS appropriate?
  - space is not a problem
  - it's necessary to find the solution with the fewest arcs
  - although all solutions may not be shallow, at least some are

- When is BFS inappropriate?
  - space is limited
  - all solutions tend to be located deep in the tree
  - the branching factor is very large

Exponential Growth

- Exponential growth quickly makes complete state space searches unrealistic

- If the branch factor was 10, by level 5 we would need to search 100,000 nodes (i.e. 10^5)

Exponential Growth

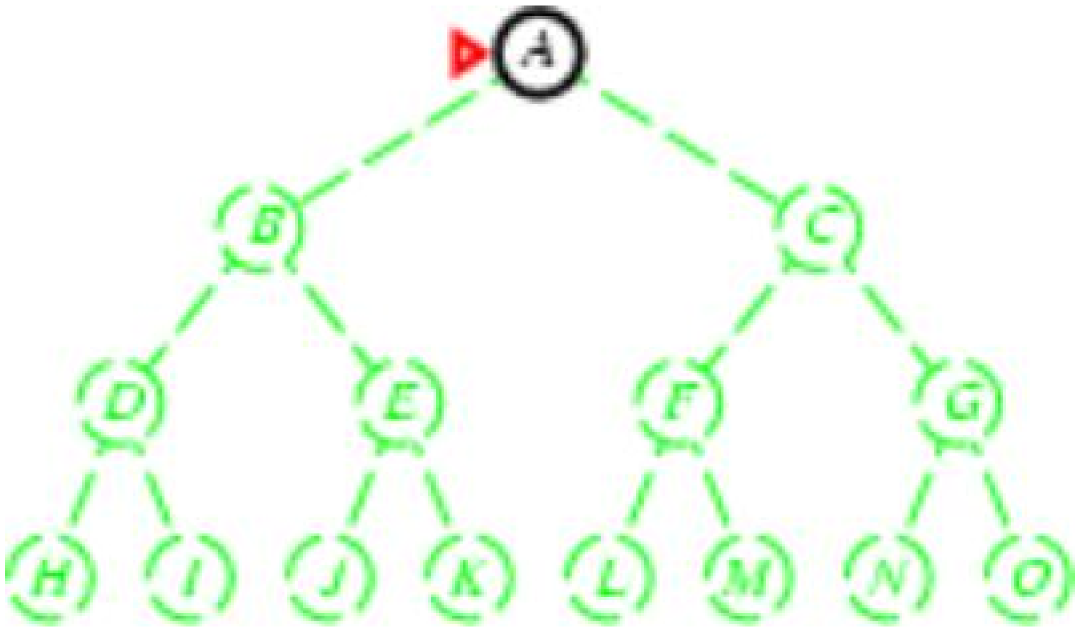
Depth	Nodes	Time	Memory
2	110	.11 milliseconds	107 kilobytes
4	11,110	11 milliseconds	10.6 megabytes
6	10^6	1.1 seconds	1 gigabyte
8	10^8	2 minutes	103 gigabytes
10	10^{10}	3 hours	10 terabytes
12	10^{12}	13 days	1 petabyte
14	10^{14}	3.5 years	99 petabytes
16	10^{16}	350 years	10 exabytes

Figure 3.13 Time and memory requirements for breadth-first search. The numbers shown assume branching factor $b = 10$; 1 million nodes/second; 1000 bytes/node.

Time and memory requirements for breadth-first search, assuming a branching factor of 10, 100 bytes per node and searching 1000 nodes/second

Depth-first search

- Expand deepest unexpanded node in the current fringe
- LIFO-Stack
- Implementation:



Depth-first search

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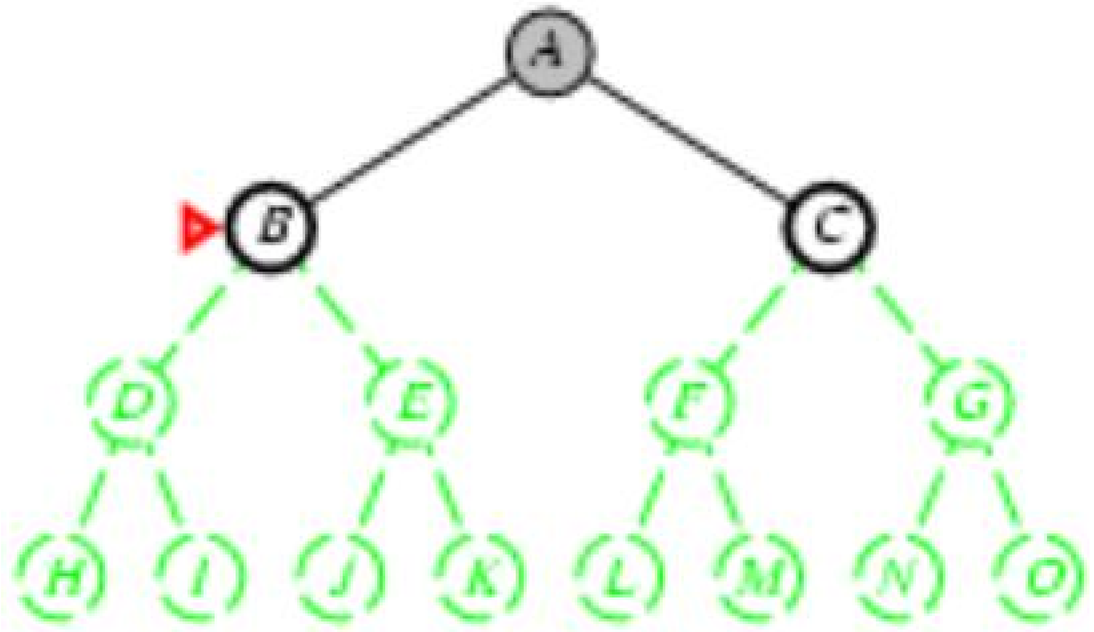

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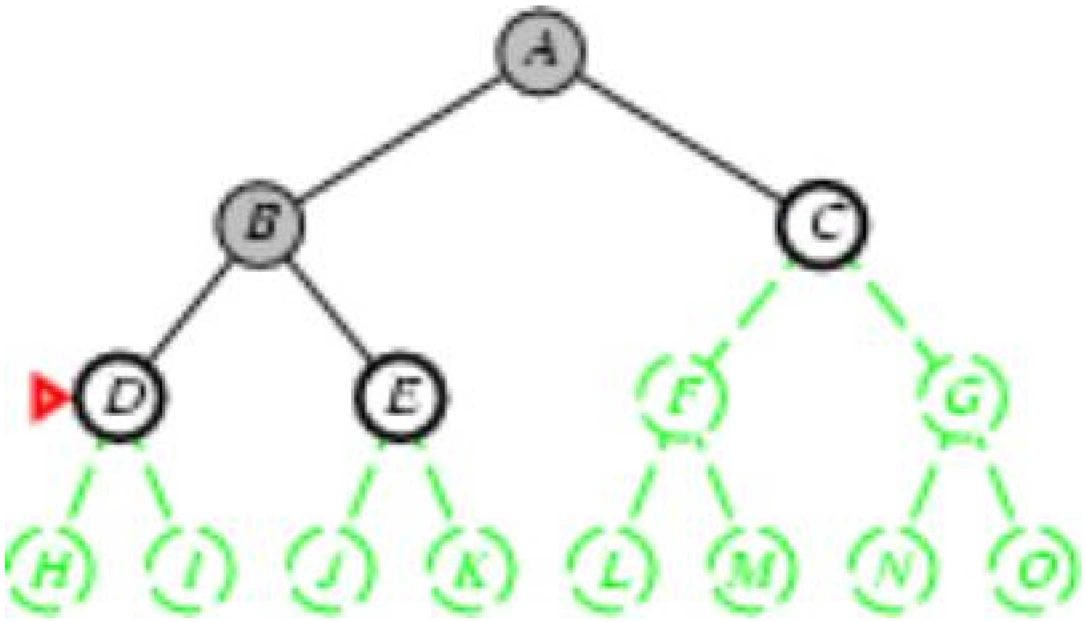

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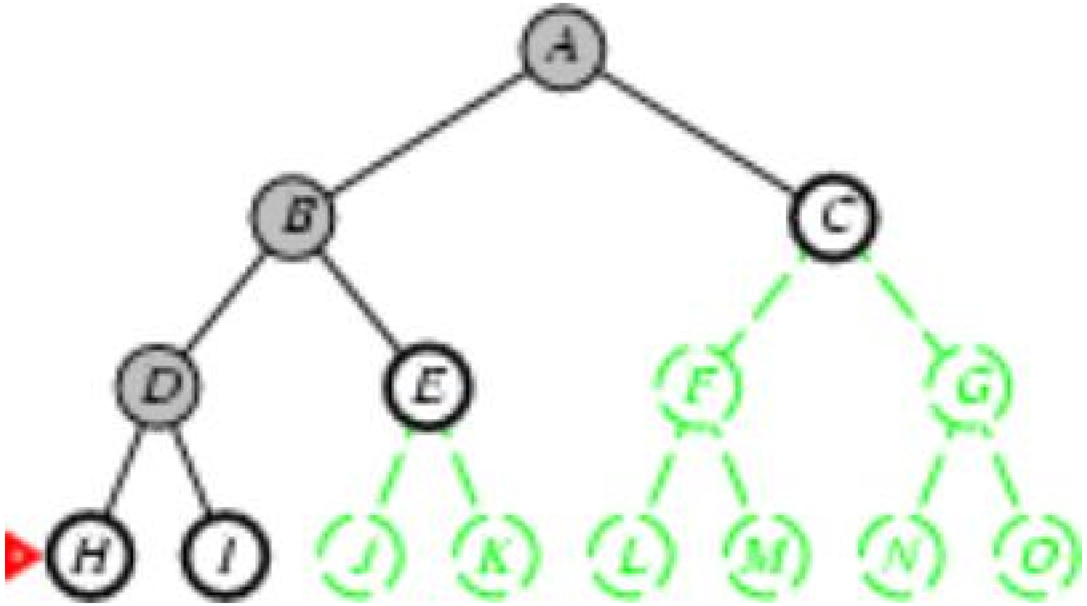

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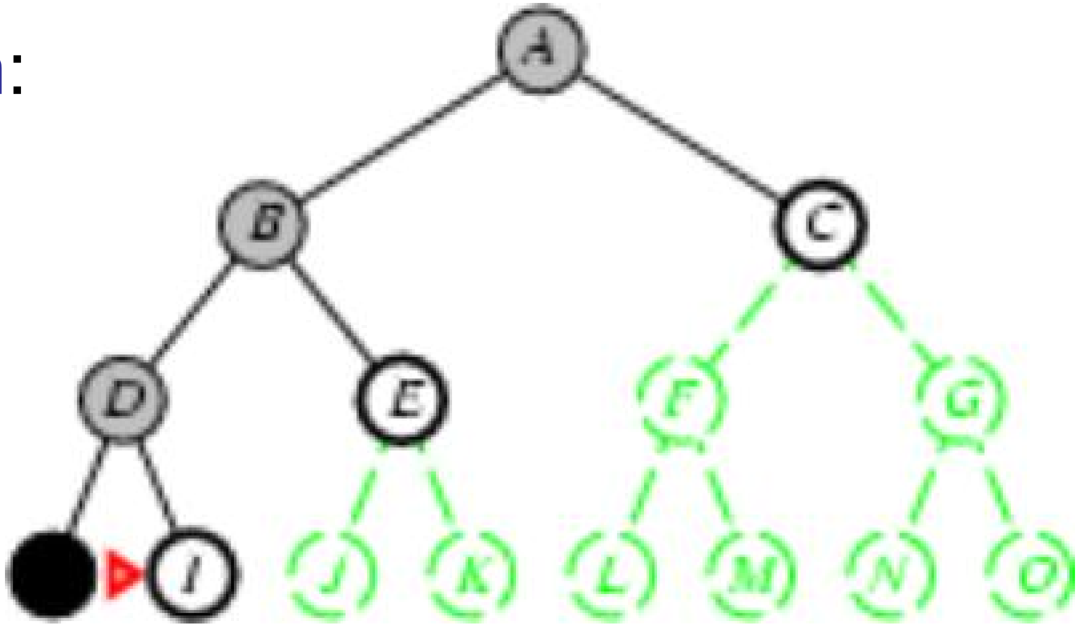
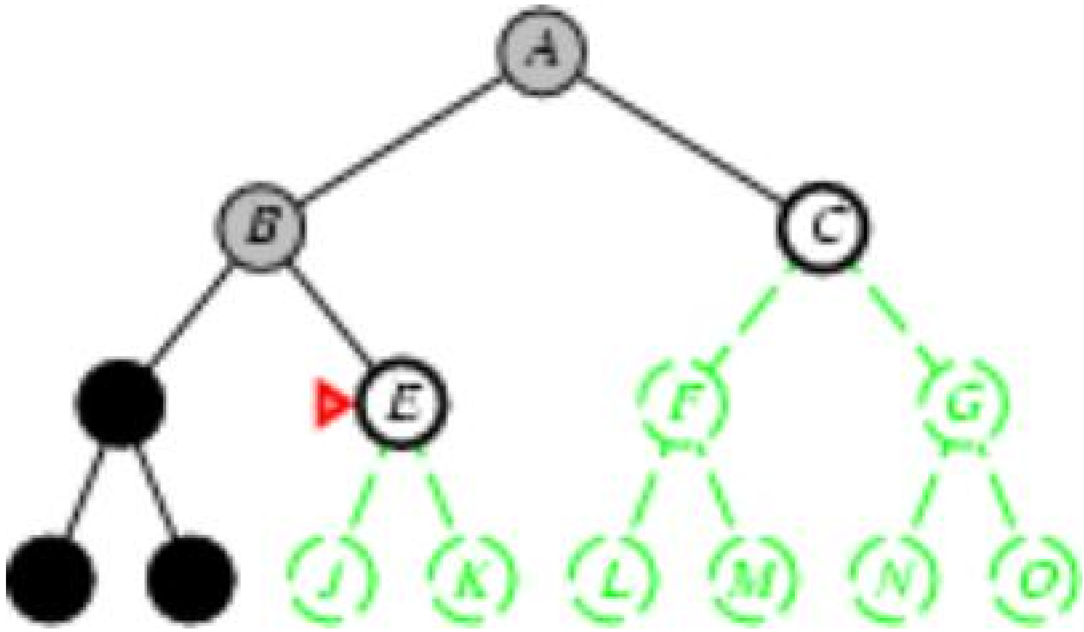


Depth-first search

- Expand deepest unexpanded node
- Implementation:
  - *fringe* = LIFO queue, i.e., put successors at front



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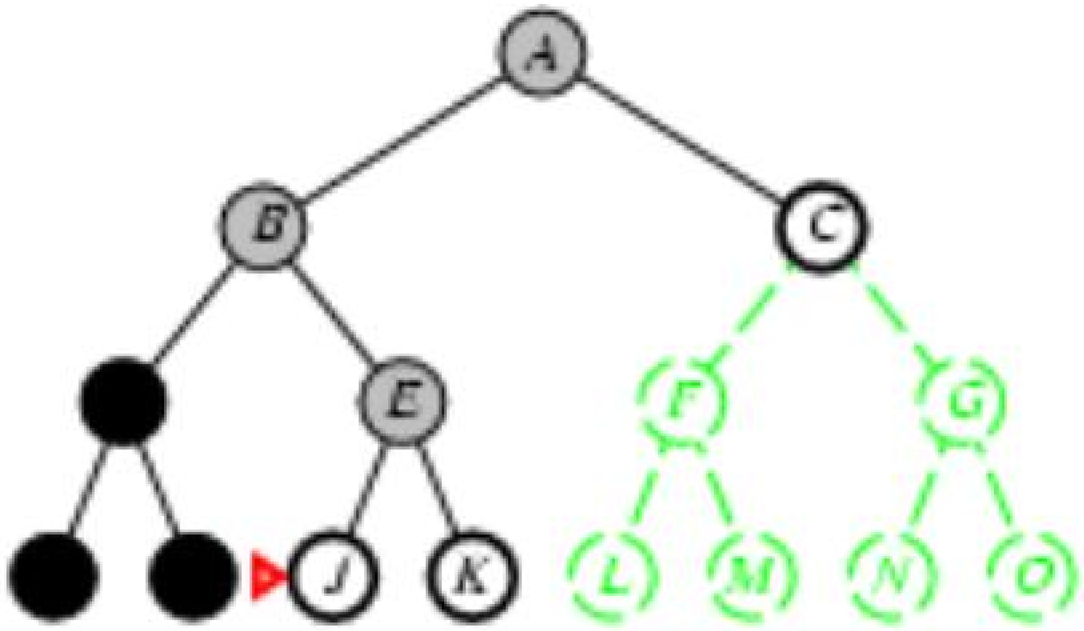

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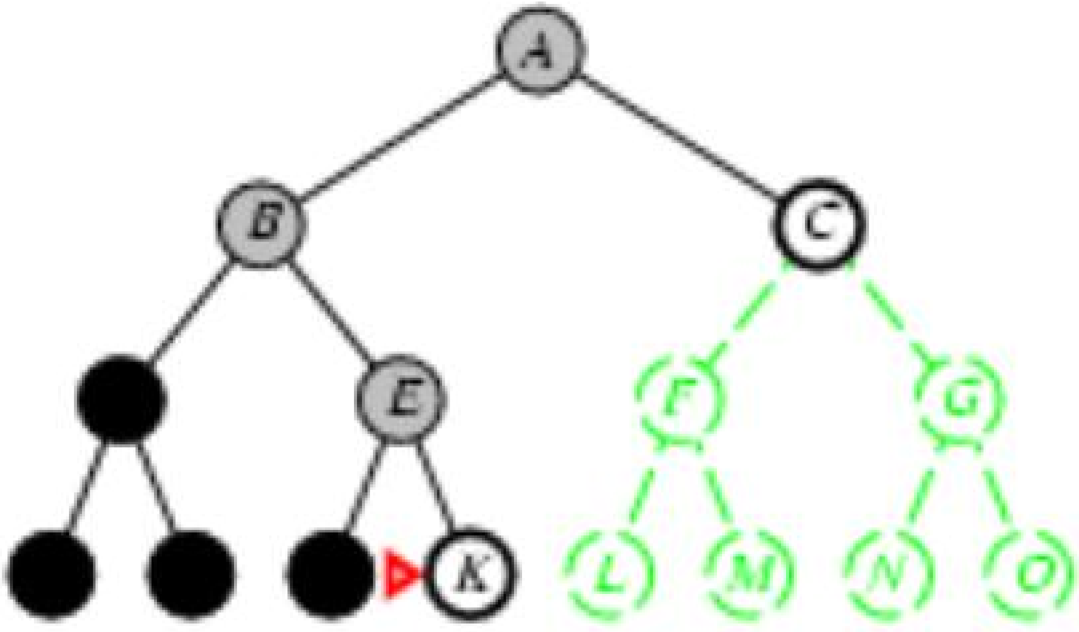

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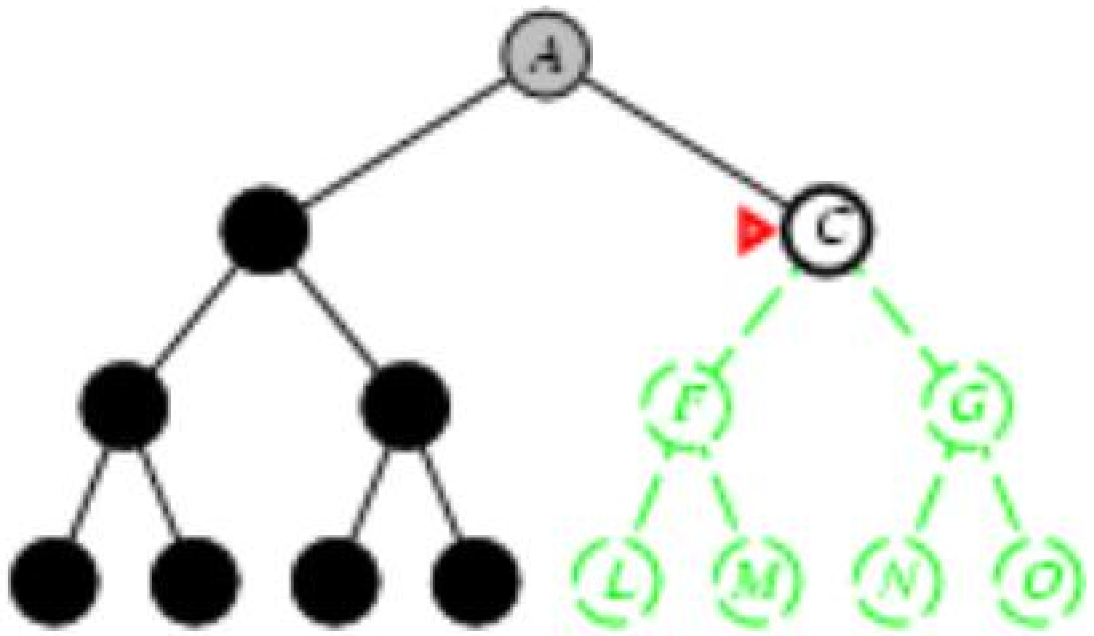

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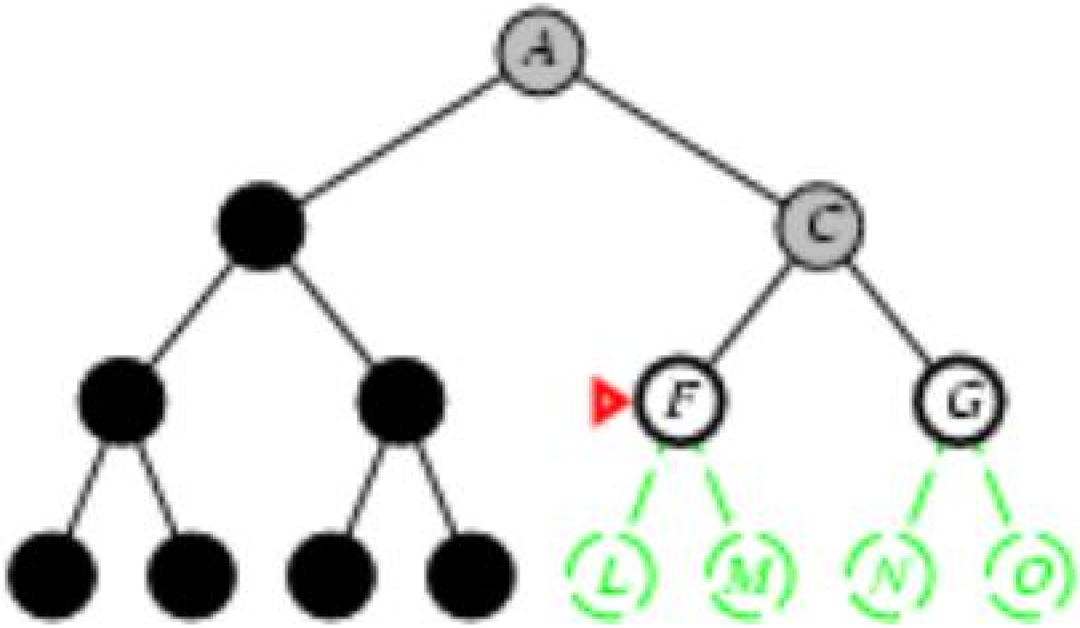

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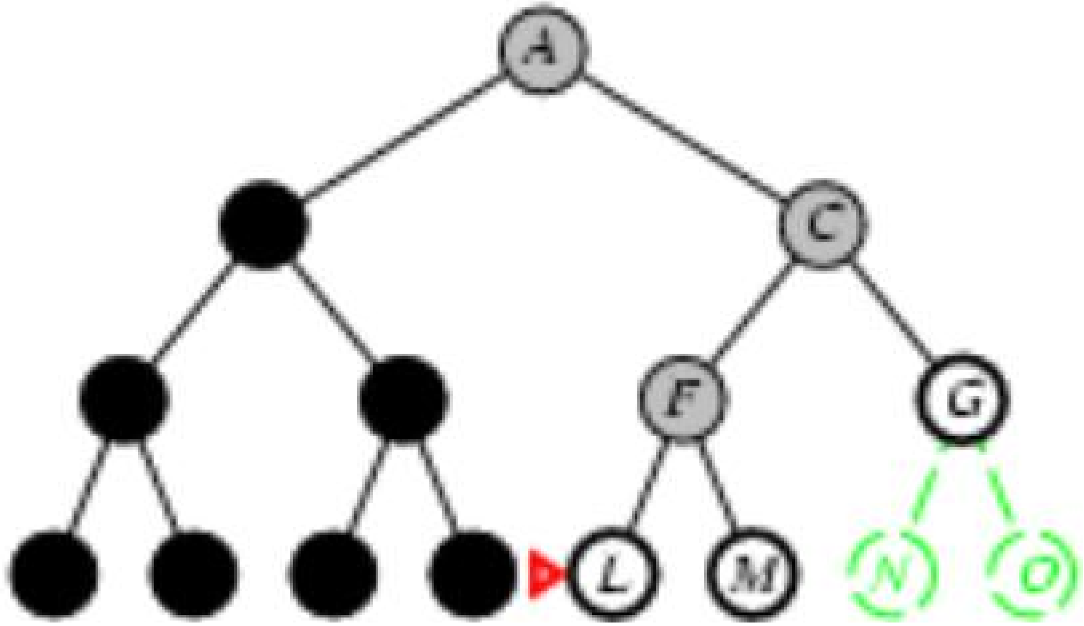

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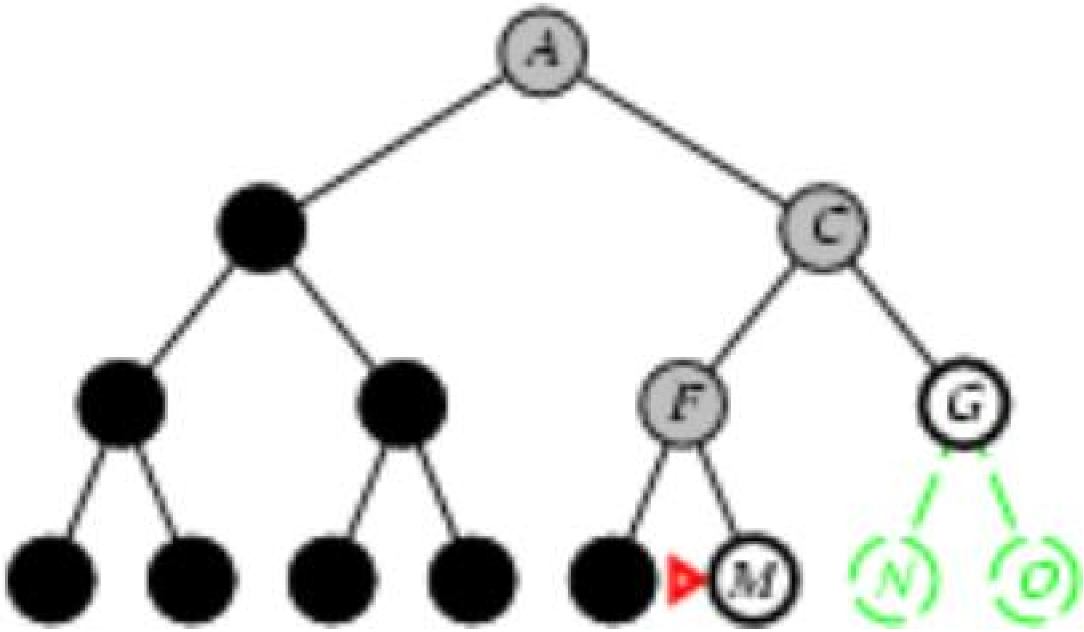


DFS: Evaluation

- DFS Graph version is complete, and **Tree Version is incomplete**
- Why?
- Time Complexity: $0(b^m)$
- If m (maximal depth) is much larger than d(depth of shallowest solution) – time is terrible
  - If there exist multiple solutions, DFS is faster than BFS

- Space Complexity: 0(bm) (in Tree Variant)
- **Non-Optimal:** it might give a solution with a higher cost

Properties of depth-first search

- Complete? No: fails in infinite-depth spaces,
- Time? $O(b^m)$: terrible if m is much larger than d

m: maximum depth of any node, d=depth of the shallowest node

- Space? $O(bm)$, i.e., linear space! (bm+1)
- Optimal? No

Depth-first Search: When it is appropriate?

Appropriate

- Space is restricted (complex state representation e.g., robotics)
- There are many solutions, perhaps with long path lengths, particularly for the case in which all paths lead to a solution

Inappropriate

- Cycles
- There are shallow solutions

Why DFS need to be studied and understood?

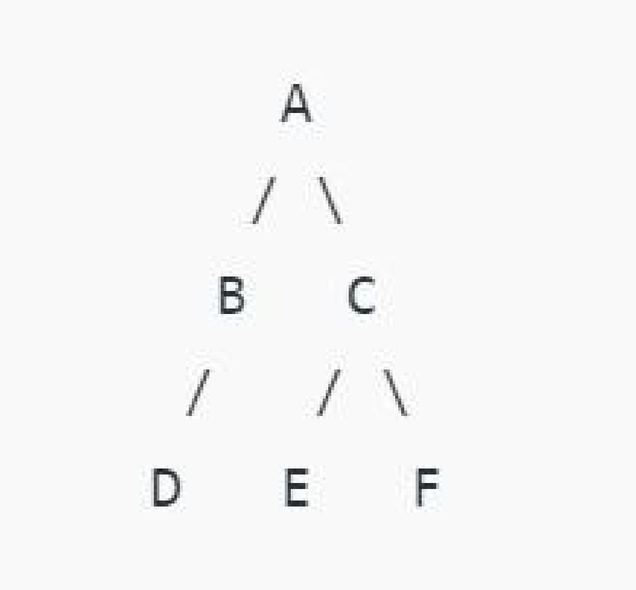
- It is simple enough to allow you to learn the basic aspects of searching (When compared with breadth first)

- It is the basis for a number of more sophisticated / useful search algorithms

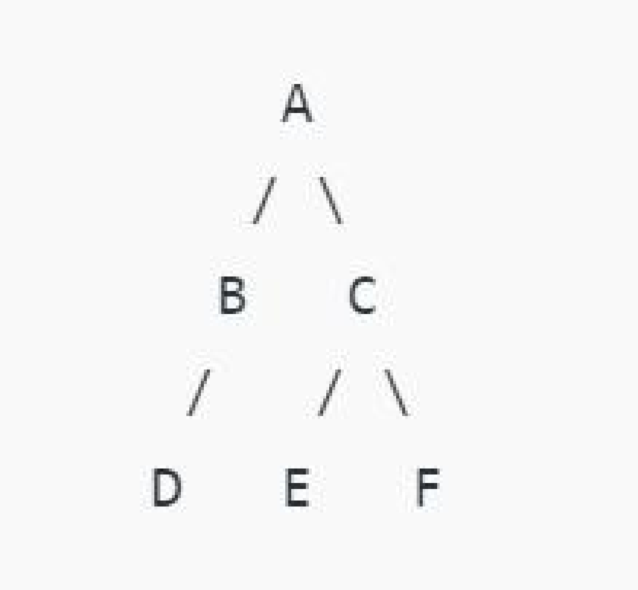
Variant of DFS: Backtracking

- Less Memory usage
- Only one successor generated at a time
- Each partially expanded node remembers which successor to generate next
- Memory : O(m) instead of O(bm)
- Example (N-queen problem, incremental approach)

BFS vs DFS

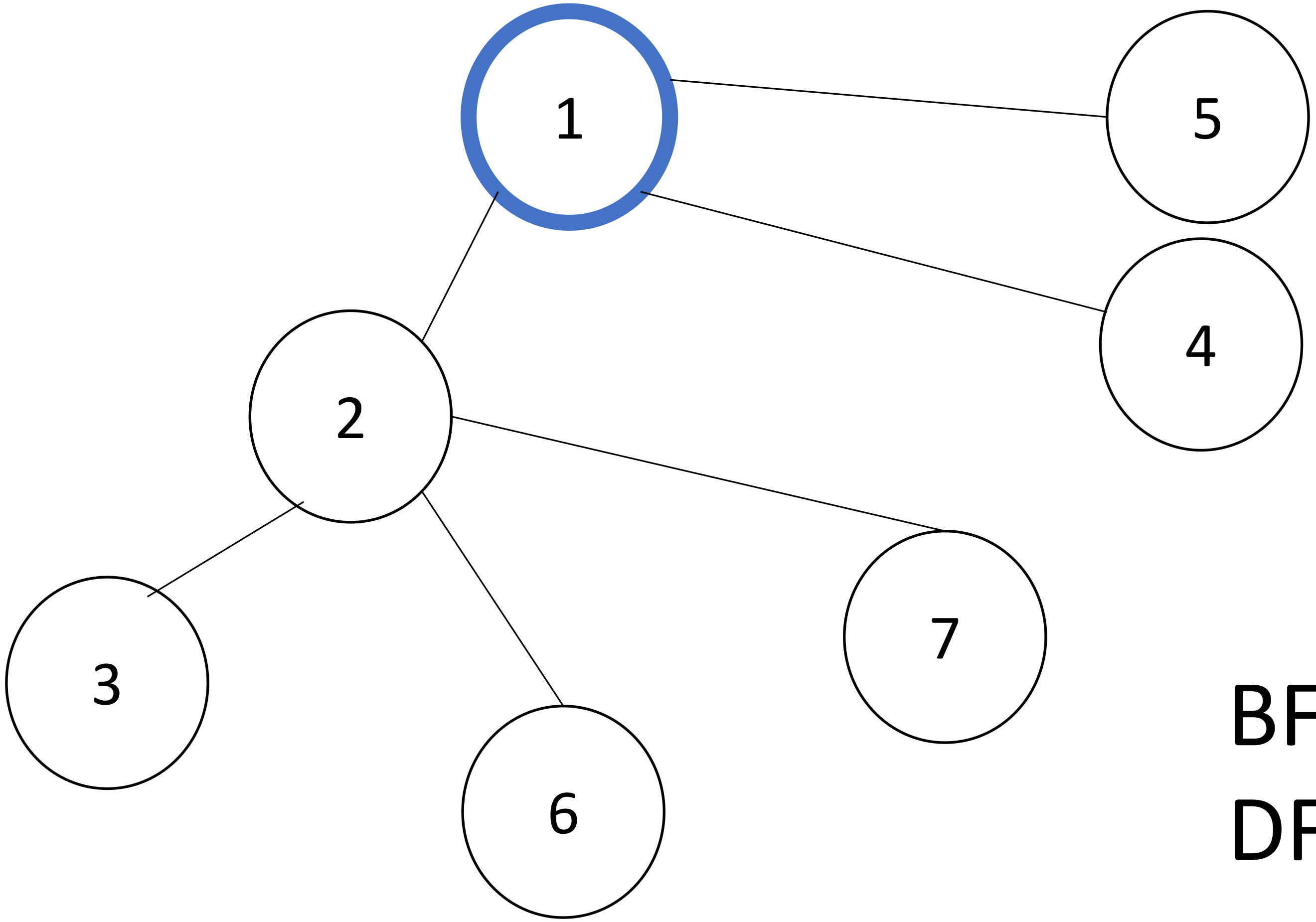


A, B, C, D, E, F



A, B, D, C, E, F

Apply BFS and DFS on following Graph



BFS:

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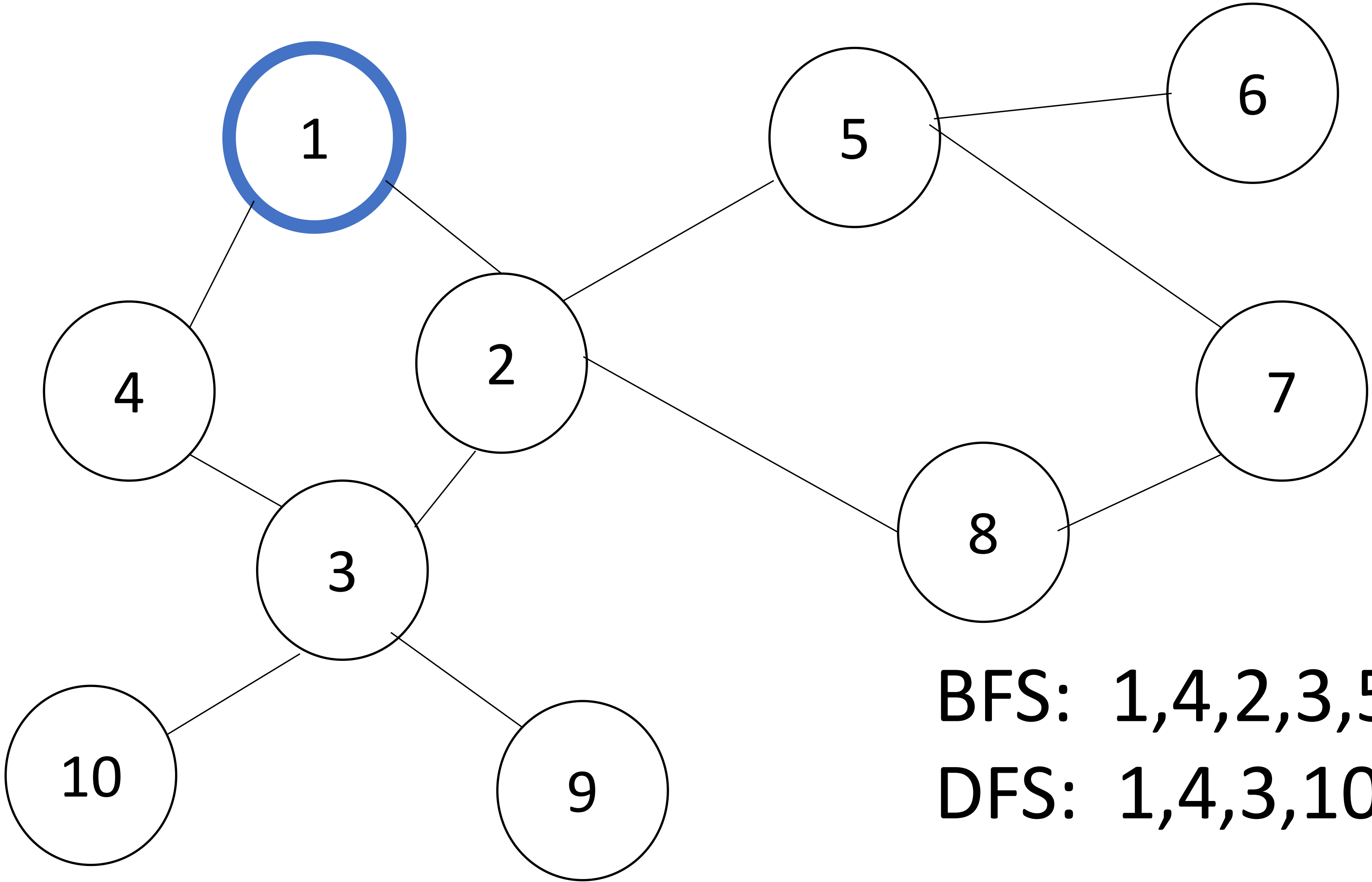
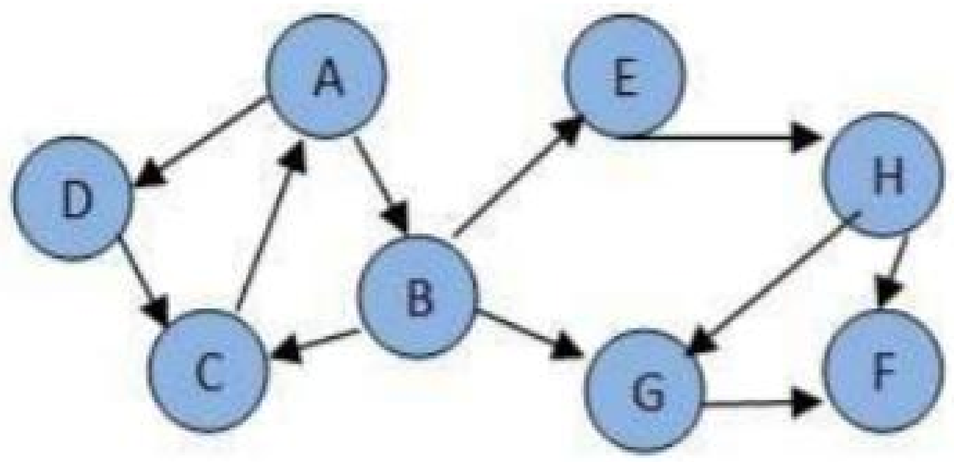


BFS: 1,4,2,3,5,8,10,9,7,6

DFS: 1,4,3,10,9,2,8,7,5,6

BFS vs DFS



A,B,D,C,E,G,H,F

A,B,C,E,H,F,G,D

Activity

- Web crawling
- Social network analysis
  - Finding similarity of two people on the social network

Activity

- Web crawling
  - BFS is more likely to find the required topic ur searching
- Social network analysis
  - Finding similarity of two people on the social network
  - DFS is more likley to do better and find similarity between two nodes, where they connect etc.
  - BFS will search all immediate child nodes and then the child of further nodes, so it might get scattered and not to detailed