Mansoura University
Faculty of Computers and Information
Department of Computer Science
First Semester: 2020-2021

[CS324P] Artificial Intelligence - 1 : Solving Problems By Searching

Grade: Third Year (Computer Science)

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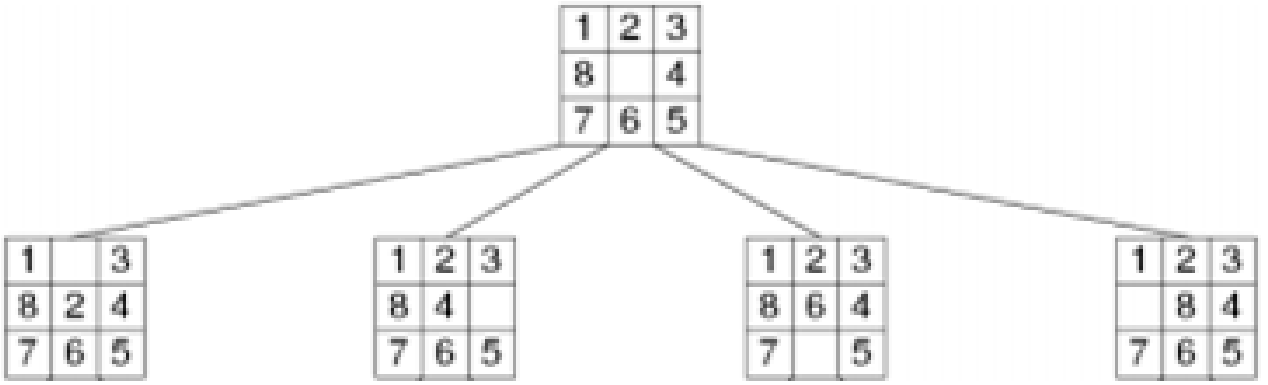
Contents

Blind Search



- **States:** locations of tiles
- **Initial State:** any random arrangement
- **Successor function:** move blank **left**, **right**, **up**, **down**
- **Goal test:** Ordered arrangement
- **Path cost:** 1 per move

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

Search Strategy

- Strategies are evaluated along the following properties:

Completeness

Guaranteed to find a solution when there is one?

Optimality

Finds the optimal solution?

Time

How long does it take to find a solution?

Space

How much memory is needed to perform the search?

- **b:** maximum branching factor of the search tree
- **d:** depth of the least-cost (optimum) solution
- **m:** maximum depth of the state space

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

Uninformed (blind) Search

- Uninformed search strategies use only the information available in the problem definition

- Uninformed search algorithms:

1. Breadth-first search (BFS)
2. Uniform-cost search (UCS)
3. Depth-first search (DFS)
4. Depth-limited search (DLS)
5. Iterative deepening search (IDS)
6. Bidirectional search(BS)

Blind Search

1. Breadth-first search (BFS)

- Expand shallowest unexpanded node
- Nodes are stored in FIFO queue (new successors go at end)

Queue: [A]

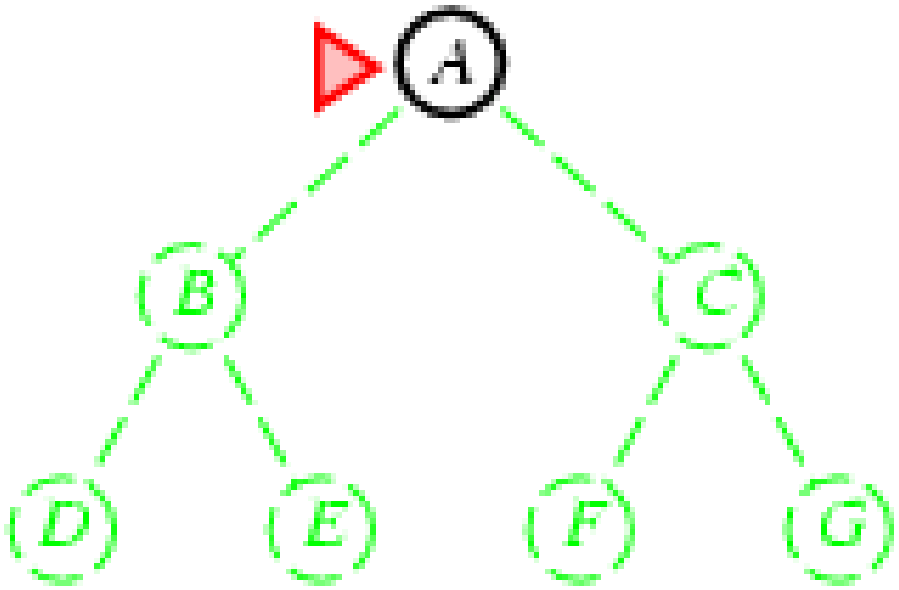


Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

Blind Search

1. Breadth-first search (BFS)

- Expand shallowest unexpanded node
- Nodes are stored in FIFO queue (new successors go at end)

Queue: [B, C]

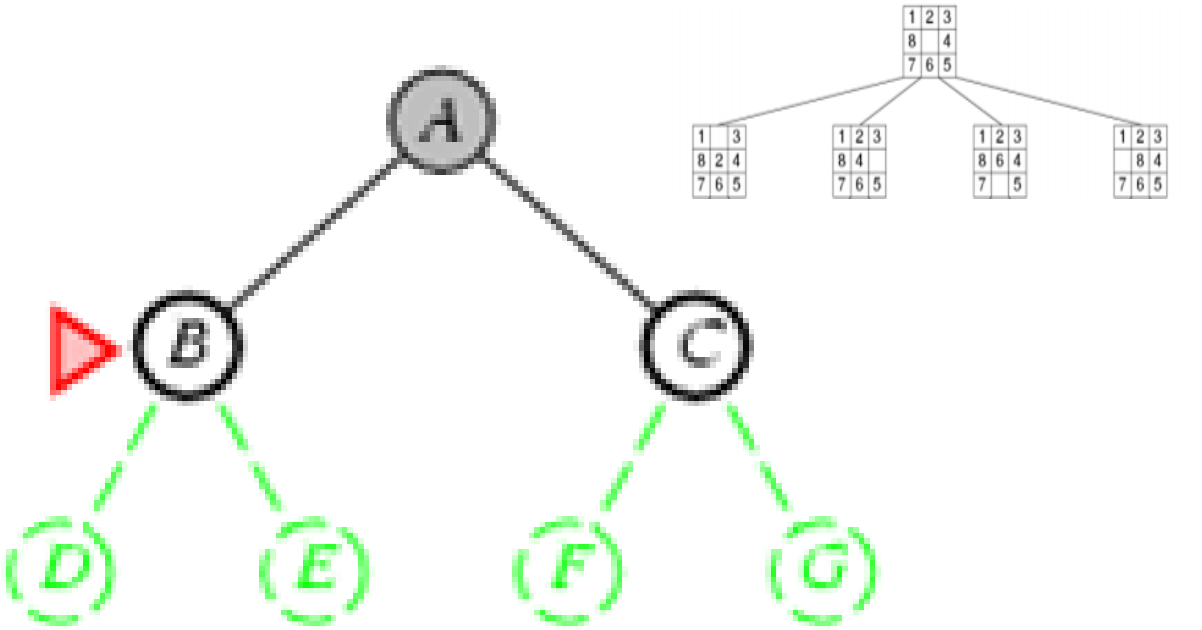


Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

Blind Search

1. Breadth-first search (BFS)

- Expand shallowest unexpanded node
- Nodes are stored in FIFO queue (new successors go at end)

Queue: [C, D, E]

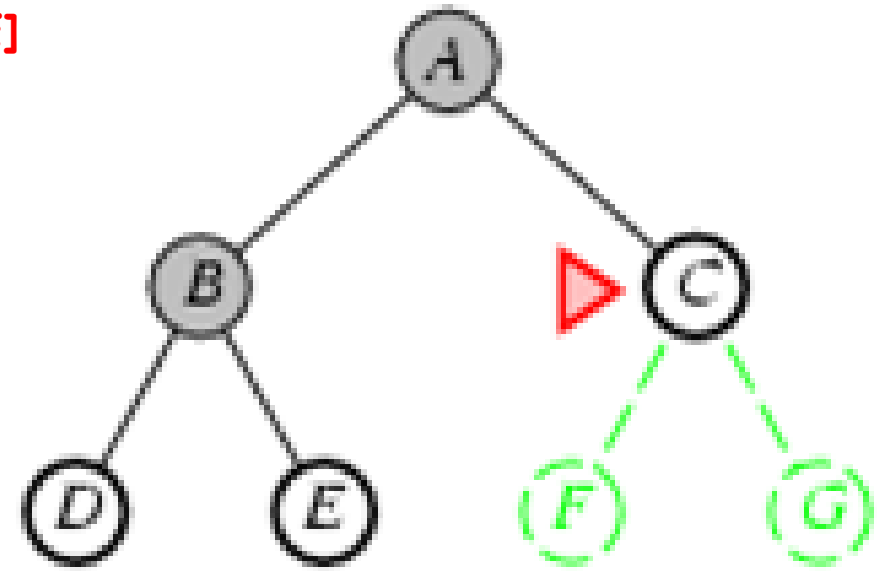


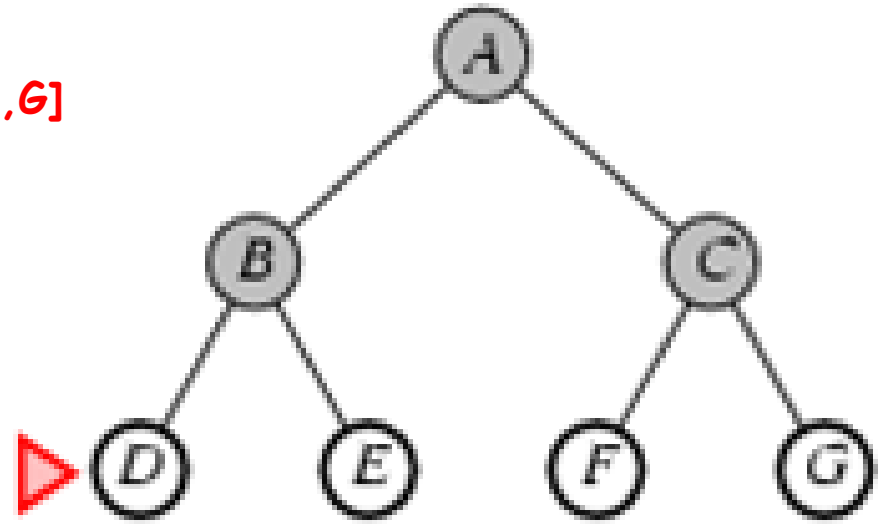
Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

Blind Search

1. Breadth-first search (BFS)

- Expand shallowest unexpanded node
- Nodes are stored in FIFO queue (new successors go at end)

Queue: [D, E,F,G]



Goal is found!

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

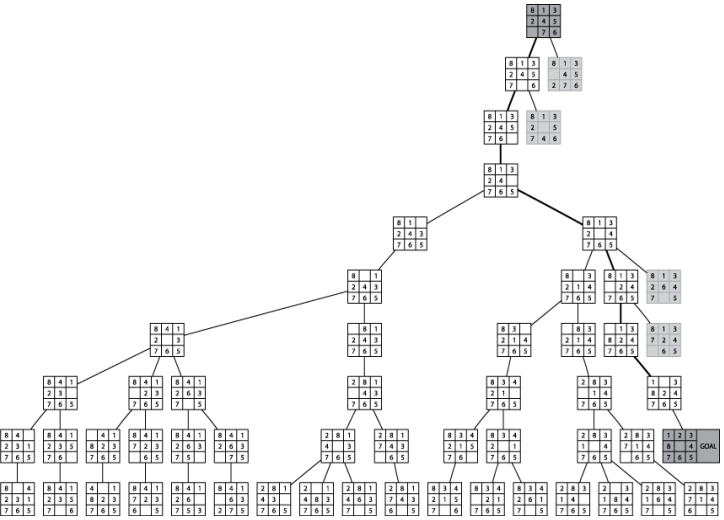
Blind Search

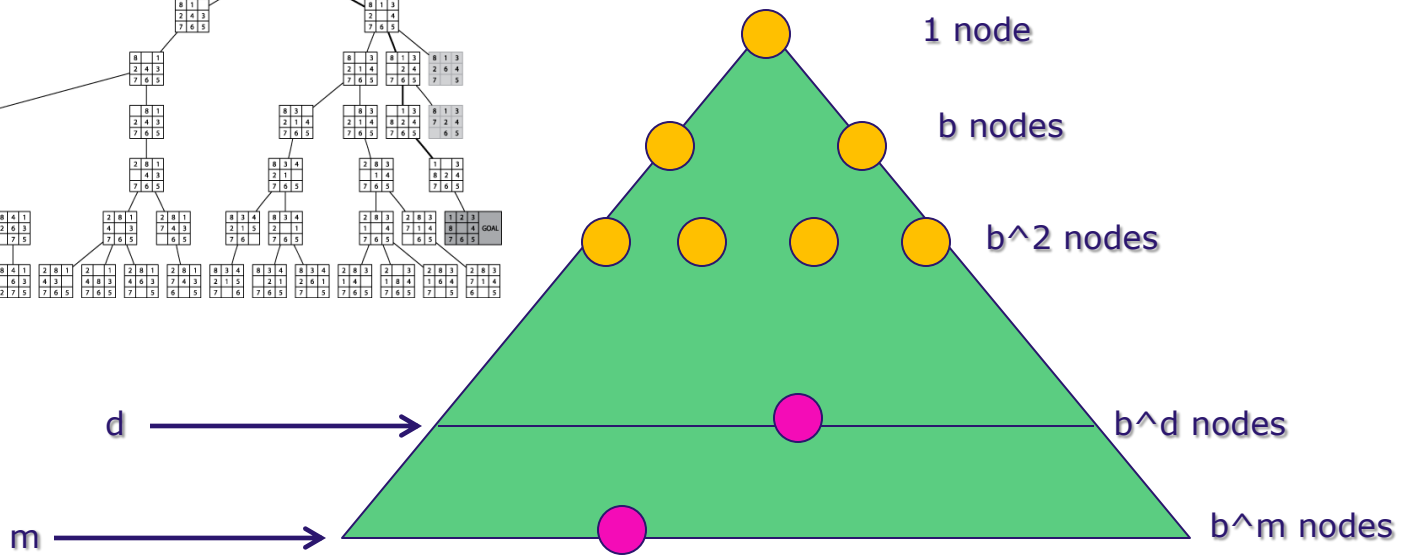
```
function BREADTH-FIRST-SEARCH(problem) returns a solution, or failure
  node ← a node with STATE = problem.INITIAL-STATE, PATH-COST = 0
  if problem.GOAL-TEST(node.STATE) then return SOLUTION(node)
  frontier ← a FIFO queue with node as the only element
  explored ← an empty set
  loop do
    if 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.

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

BFS





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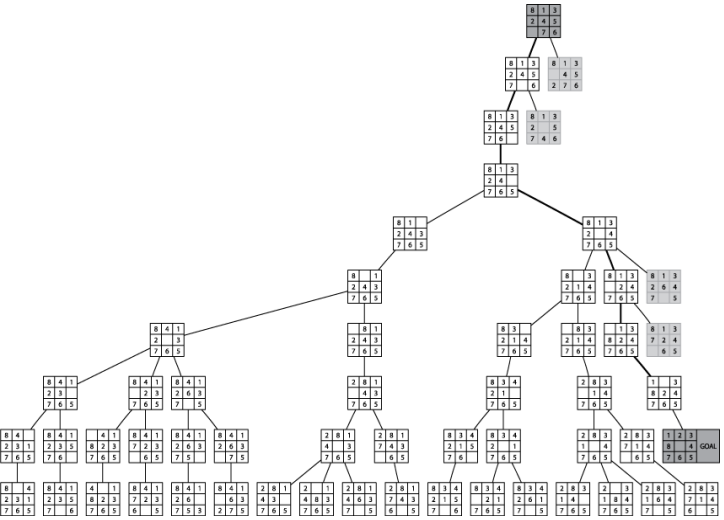
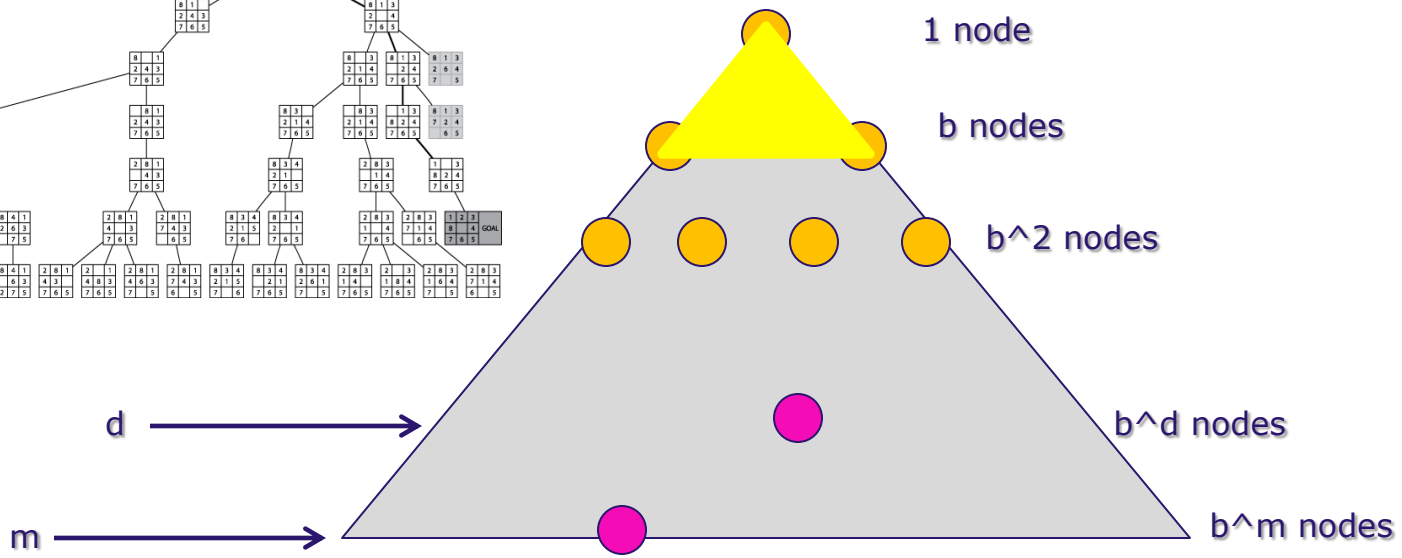
BFS





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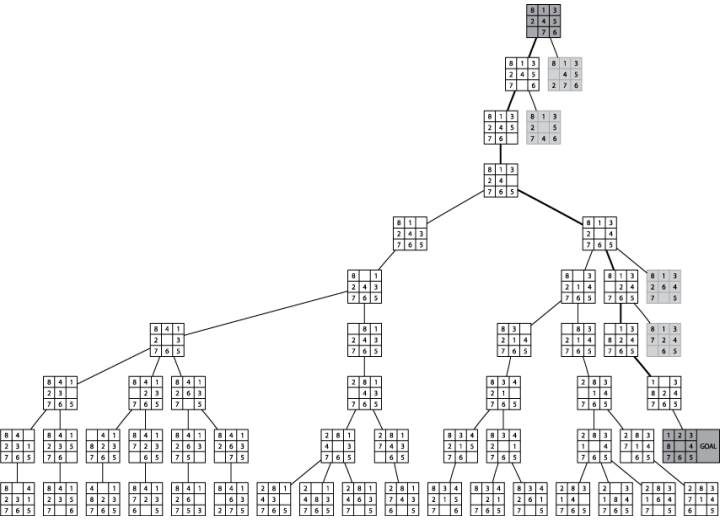
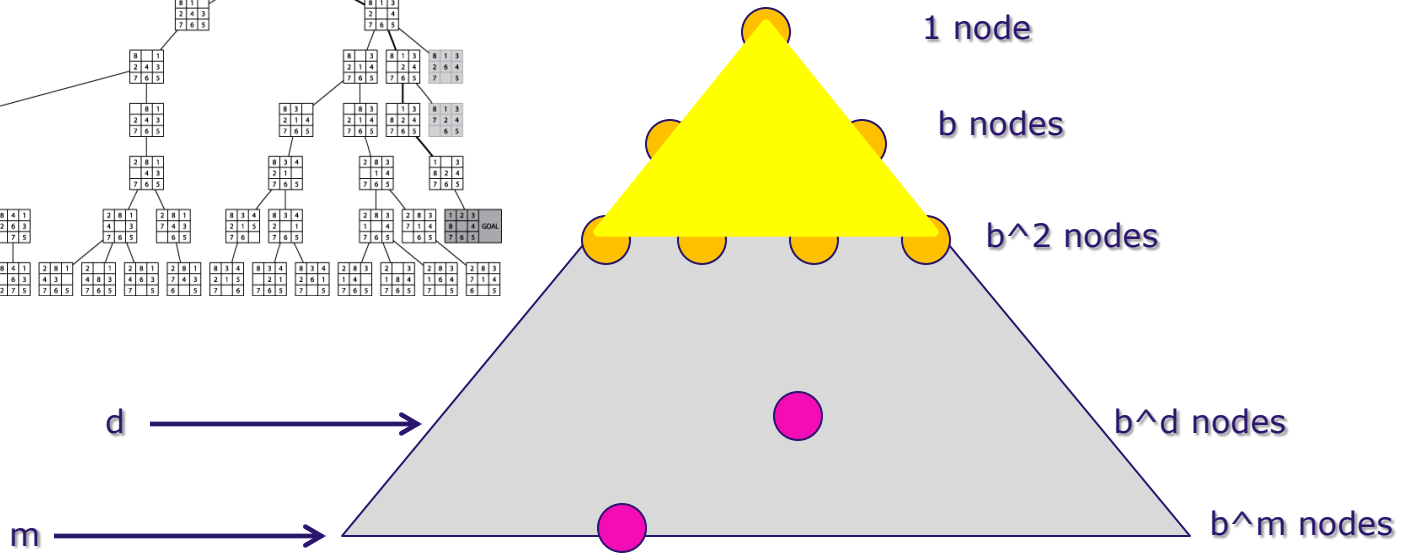
BFS





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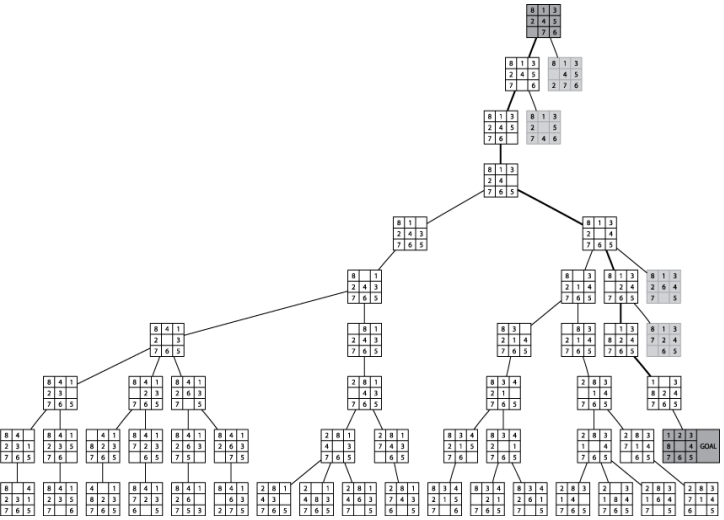
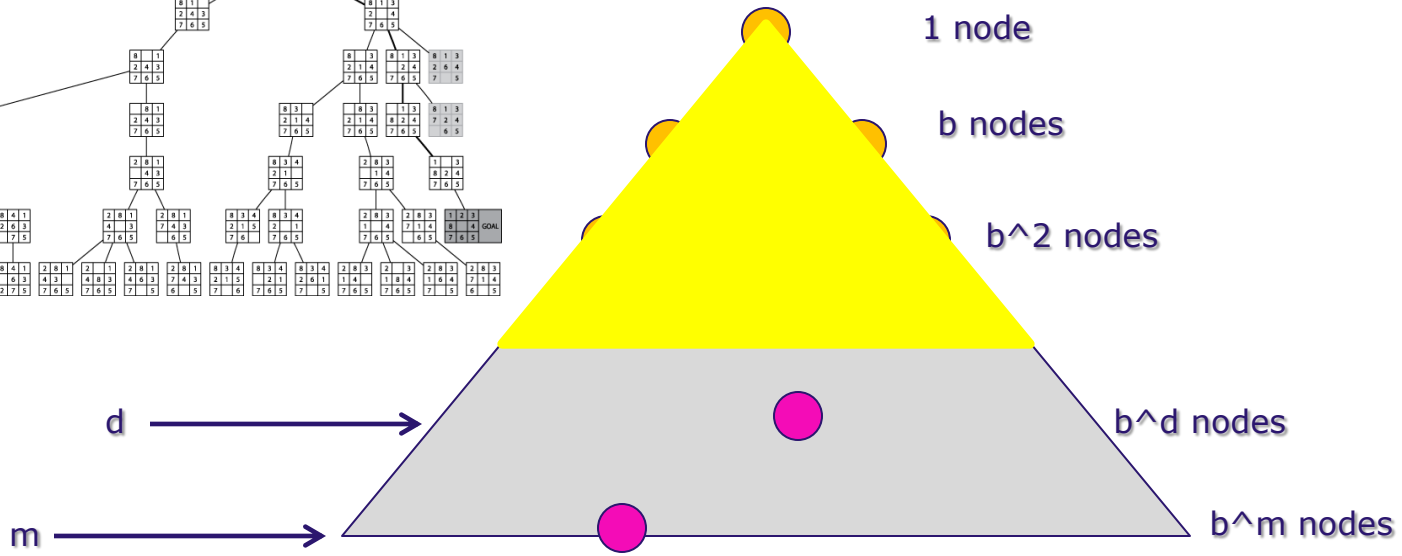
BFS





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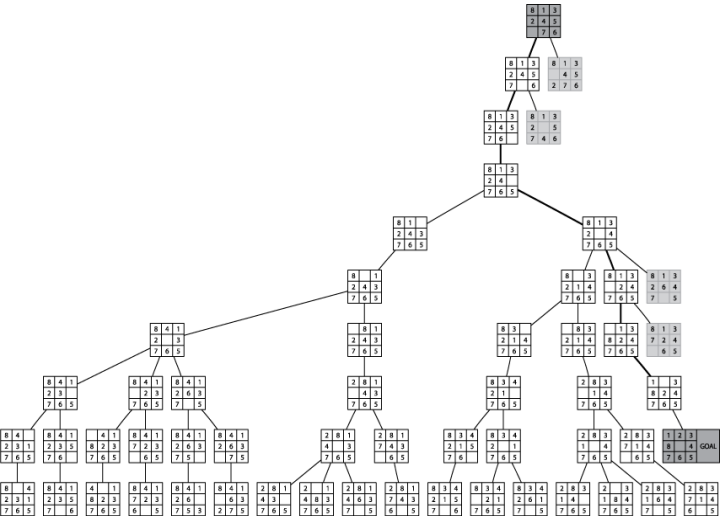
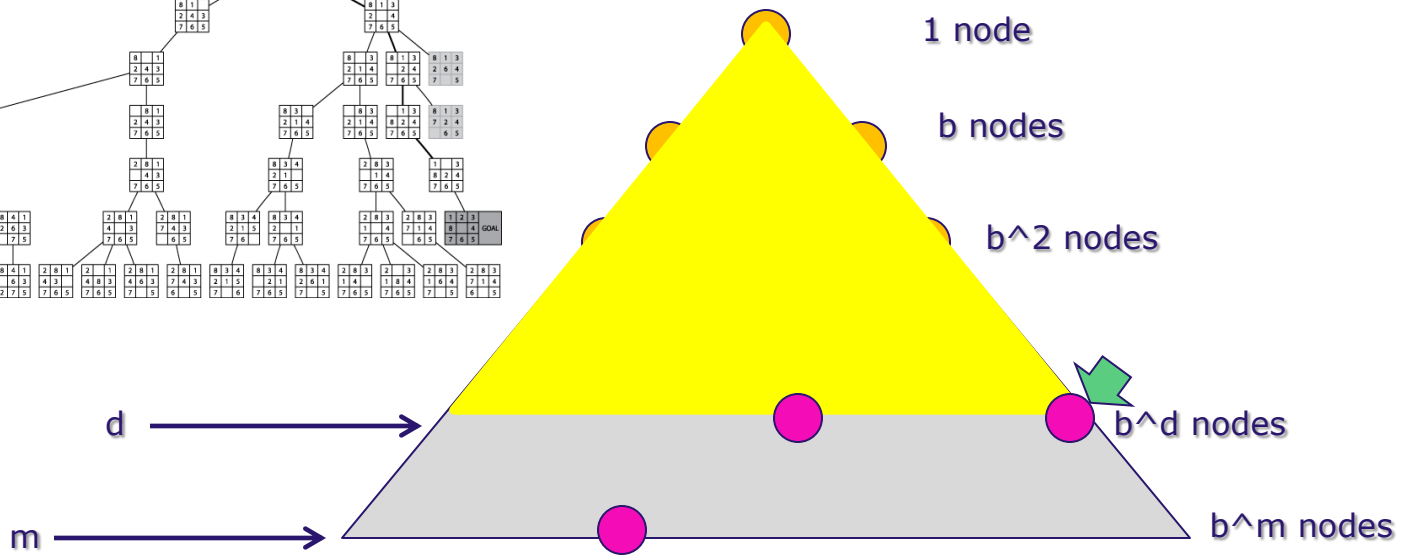
BFS

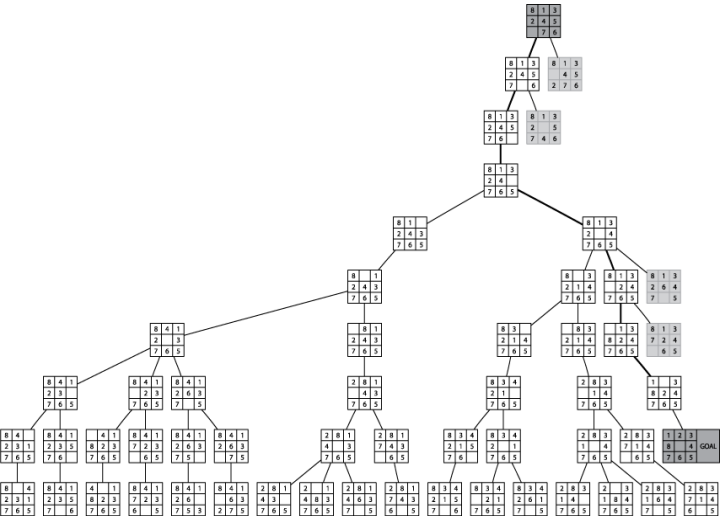


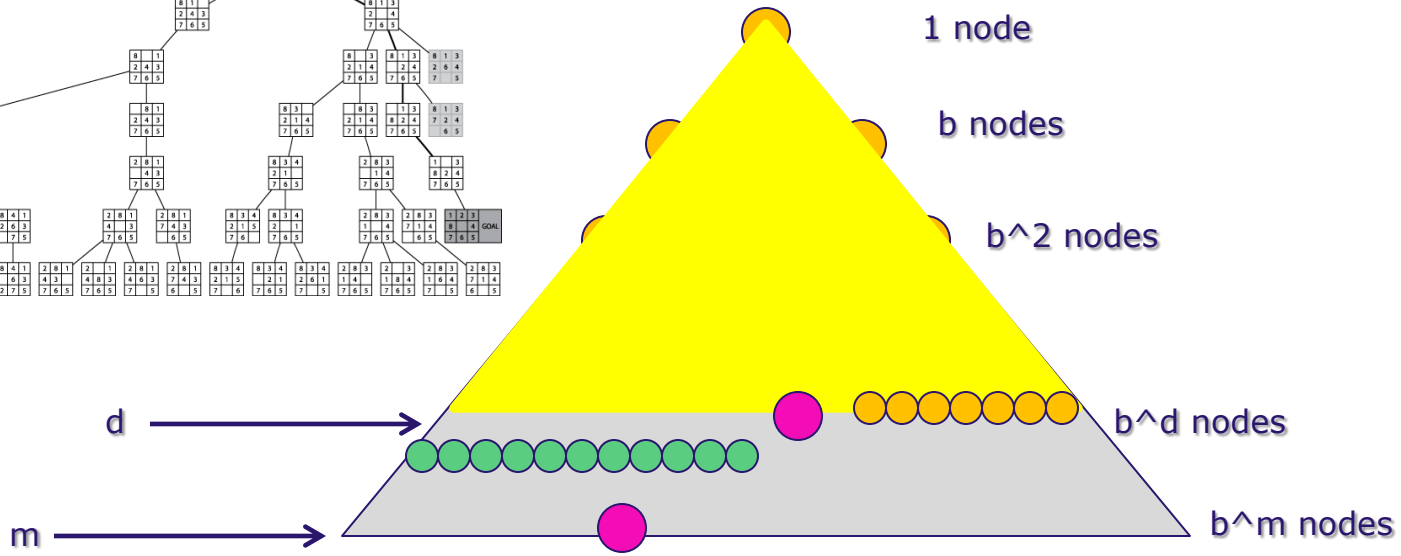


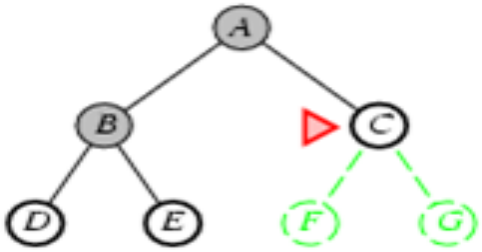
Time? $O(b^d)$

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

BFS







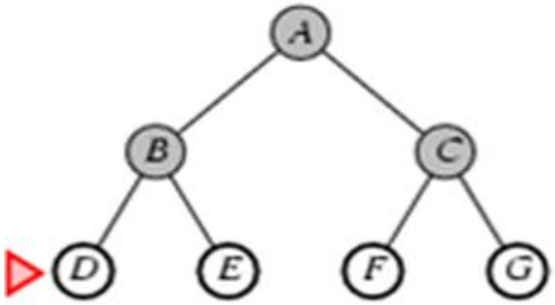
Space?

$O(b^d)$

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

Blind Search, evaluation

1. Breadth-first search (BFS)



- Complete? Yes (if **b** is finite)
- Time? $O(b^d)$
- Space? $O(b^d)$
- Optimal? Yes (if all trans. have same cost)

Space is the main problem

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

BFS

Image Credit: CS188 Artificial Intelligence (Spring 2013) by Prof. Pieter Abbeel, UC Berkeley

UCS

Image Credit: CS188 Artificial Intelligence (Spring 2013) by Prof. Pieter Abbeel, UC Berkeley

Blind Search

2. Uniform-cost search (UCS)

- Expand least-cost unexpanded node
- Nodes are stored in Ordered queue (order by cost)

Consider this state space for a given problem :

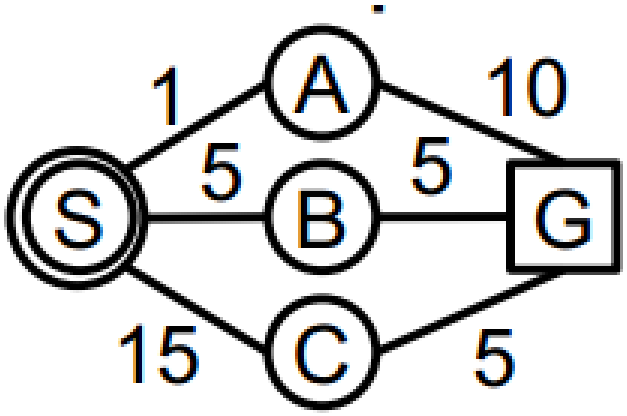
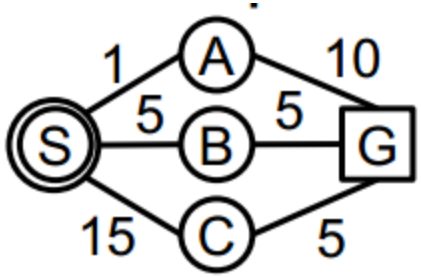


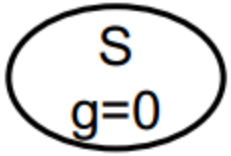
Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

Blind Search

2. Uniform-cost search (UCS), example

- Expand least-cost unexpanded node
- Nodes are stored in Ordered queue (order by cost)





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Blind Search

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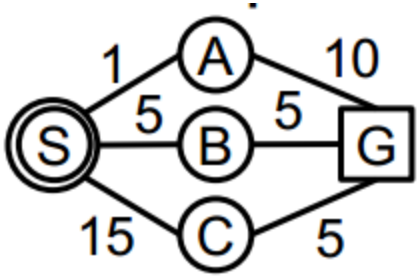

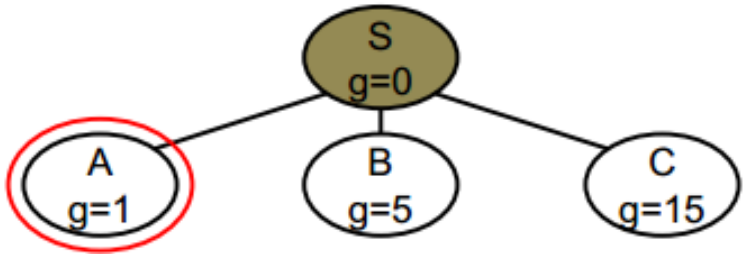

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Blind Search

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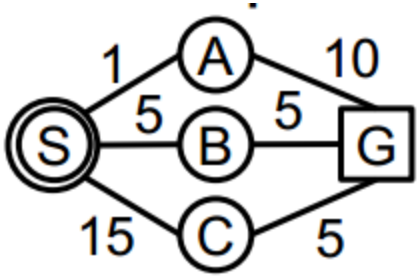

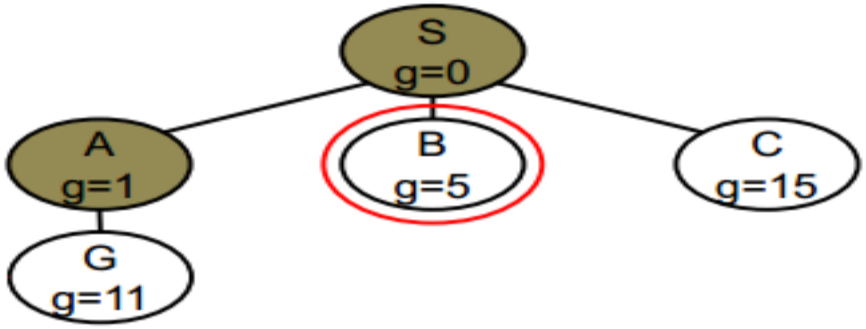

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Blind Search

2. Uniform-cost search (UCS), example

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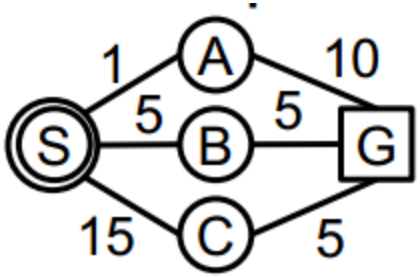

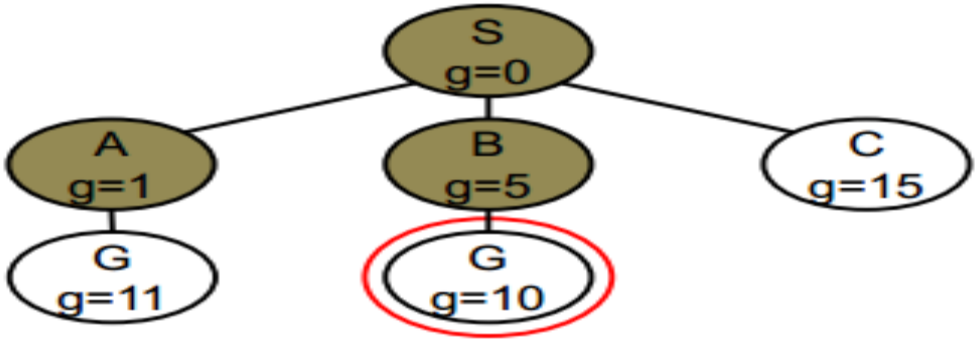

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Blind Search

2. Uniform-cost search (UCS), example

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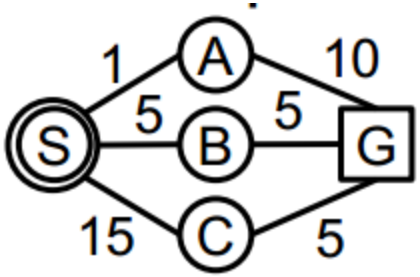
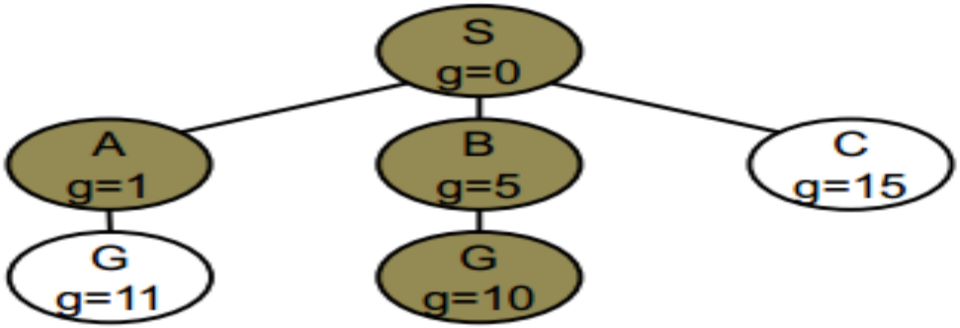
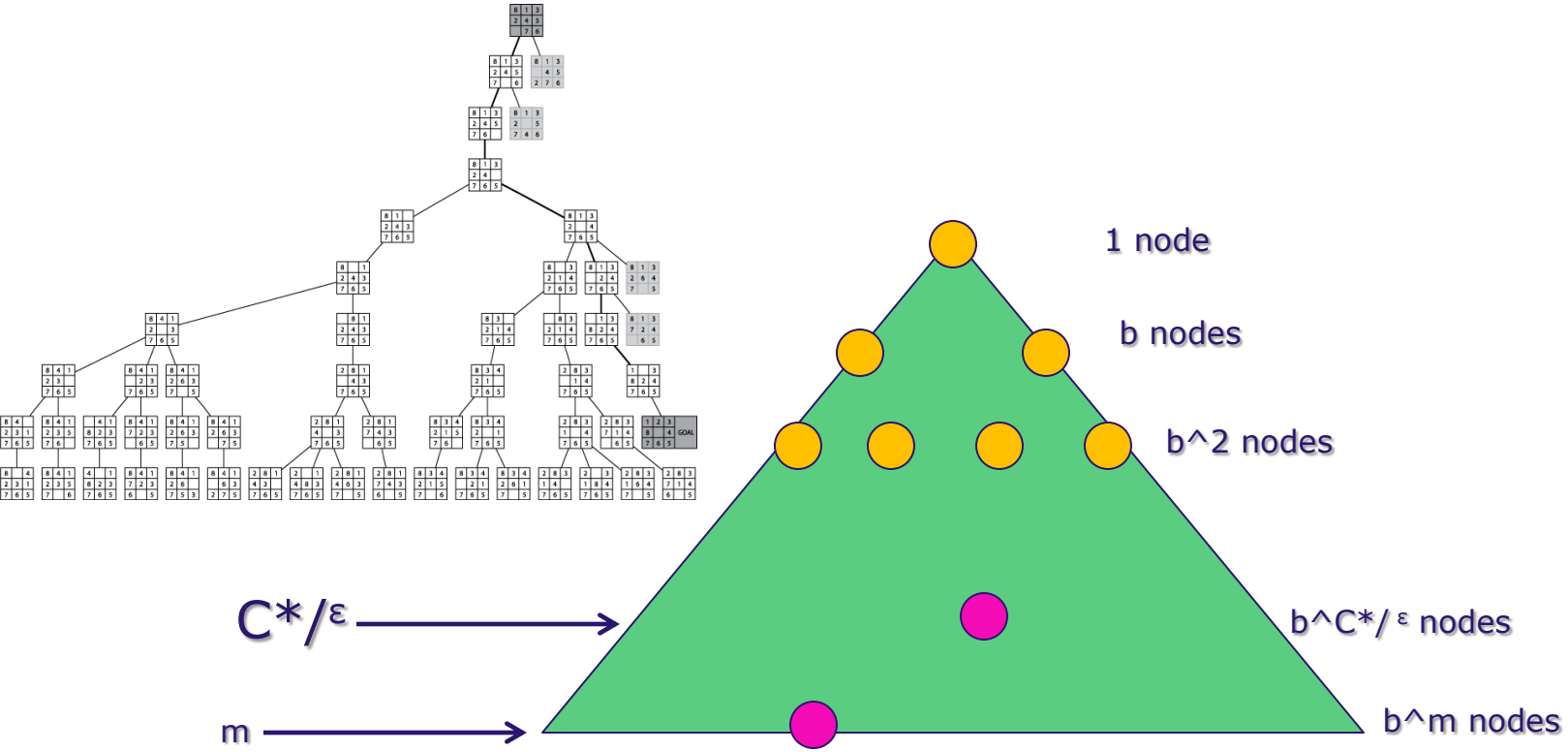




Optimum goal is found!

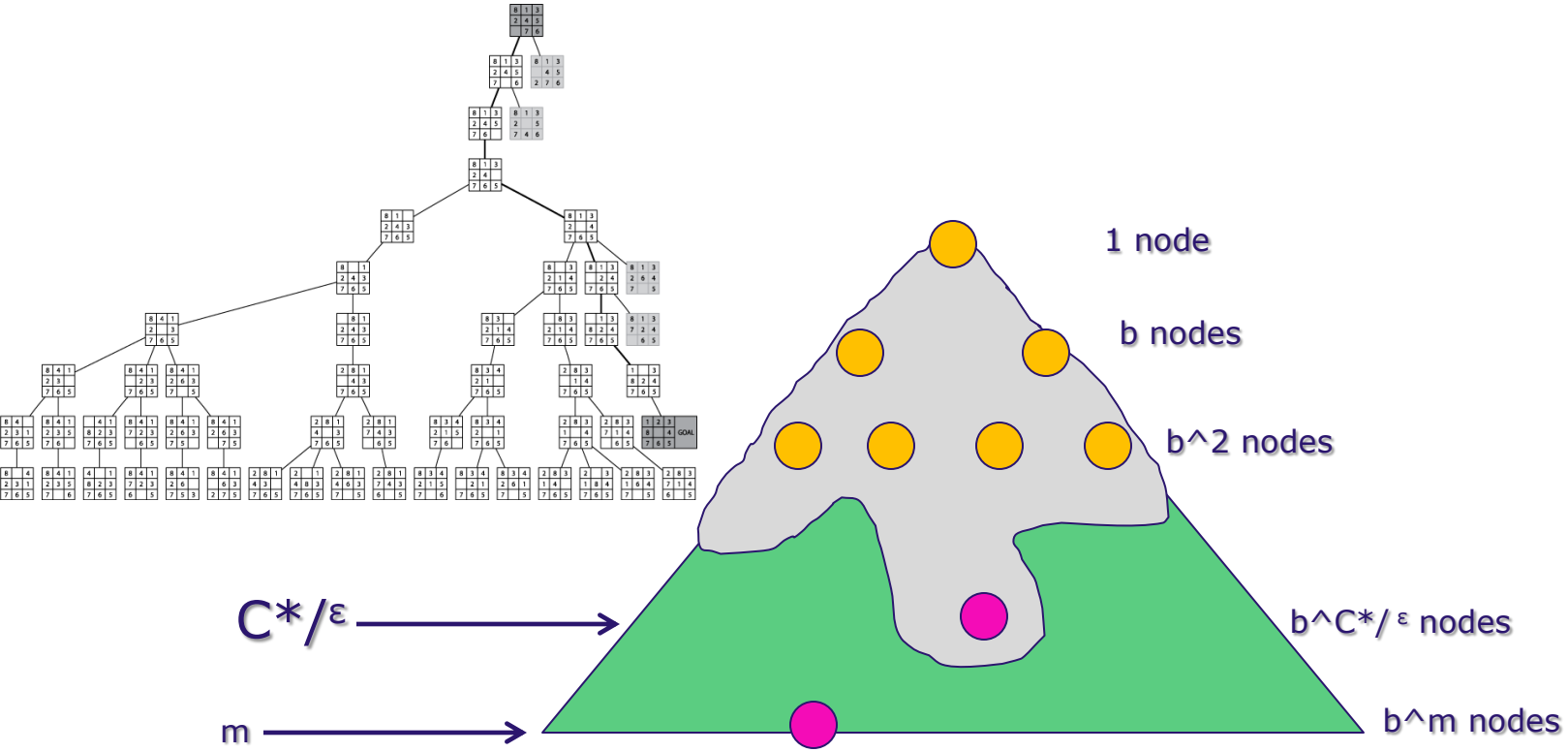
UCS



- Process all the nodes with the cost least than the cheapest solution
- Cost of optimal solution is C^* and the cost of every action is ε

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

UCS



- Process all the nodes with the cost least than the cheapest solution
- Cost of optimal solution is C^* and the cost of every action is ε

Time? $O(b^{c^*/\varepsilon+1})$

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

Blind Search, evaluation

2. Uniform-cost search (UCS)

- Complete? Yes (if $g > \epsilon$)
- Time? # of nodes with $g \leq$ cost of optimal solution
- Space? # of nodes with $g \leq$ cost of optimal solution
- Optimal? Yes

Equivalent to BFS if step costs all equal

DFS

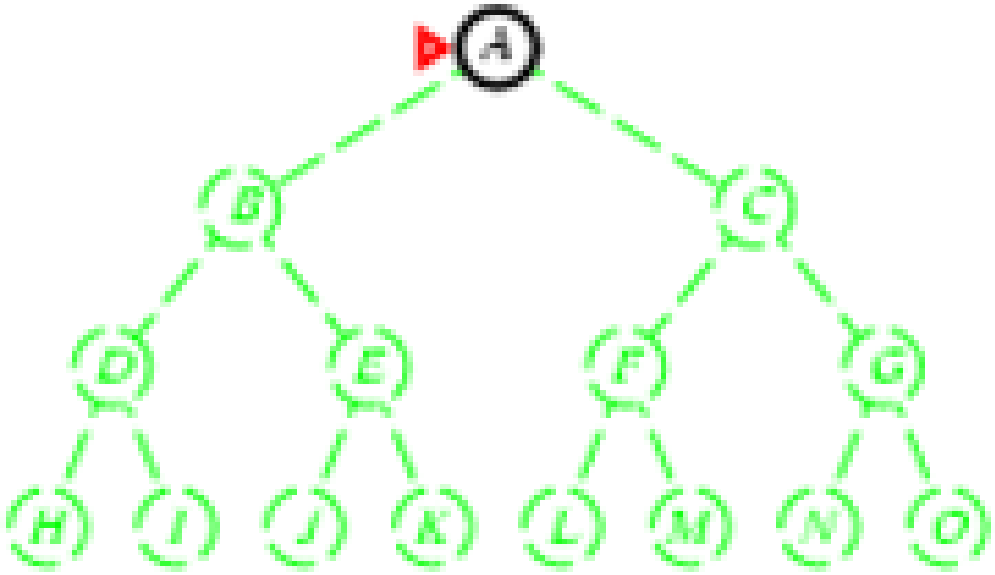
Image Credit: CS188 Artificial Intelligence (Spring 2013) by Prof. Pieter Abbeel, UC Berkeley

Blind Search

3. Depth-first search (DFS)

- Expand deepest unexpanded node
- Nodes are stored in LIFO stack(put successors at front)

Stack: [A]



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Blind Search

3. Depth-first search (DFS)

- Expand deepest unexpanded node
- Nodes are stored in LIFO stack (put successors at front)

Stack: [B,C]

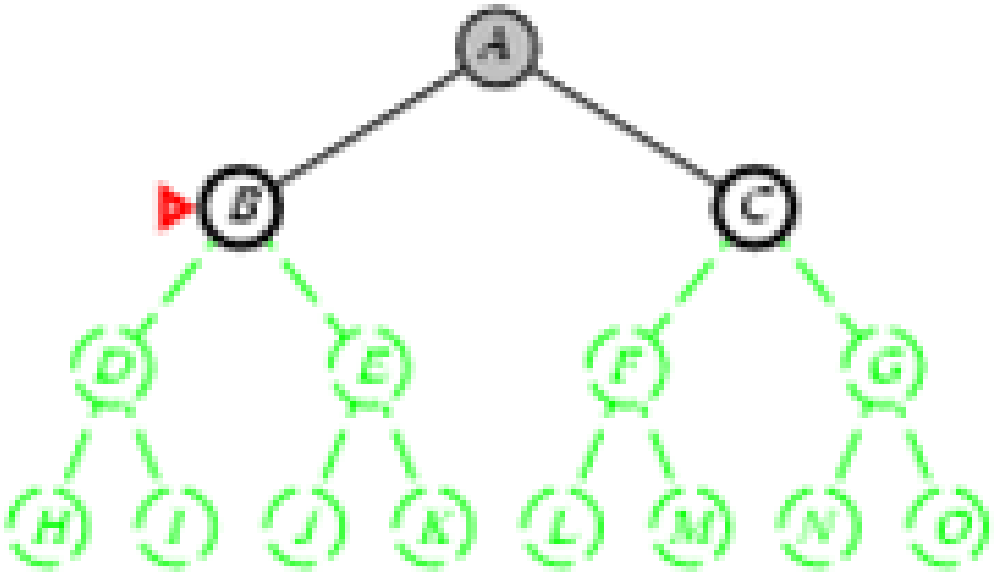


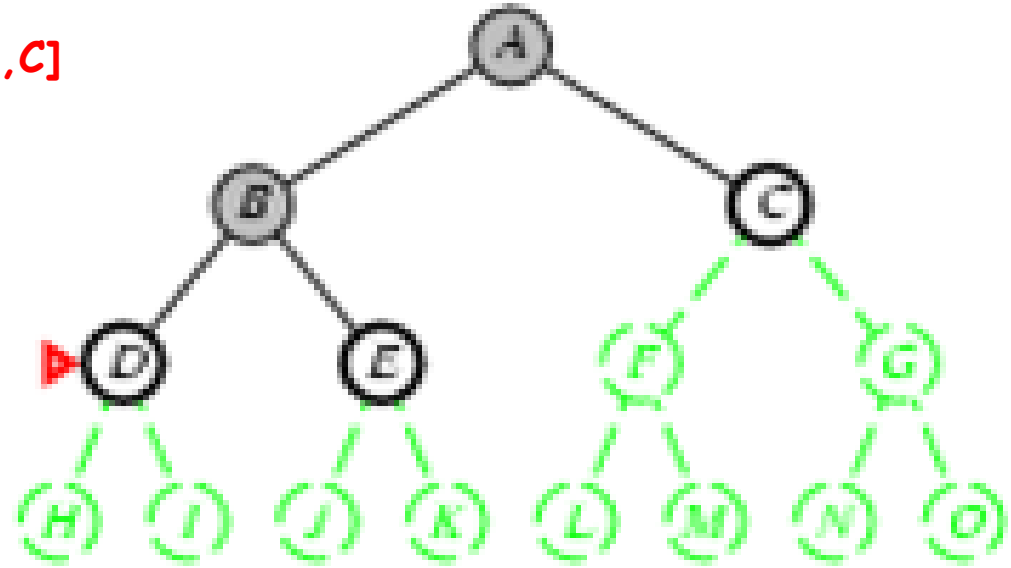
Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

Blind Search

3. Depth-first search (DFS)

- Expand deepest unexpanded node
- Nodes are stored in LIFO stack (put successors at front)

Stack: [D,E,C]



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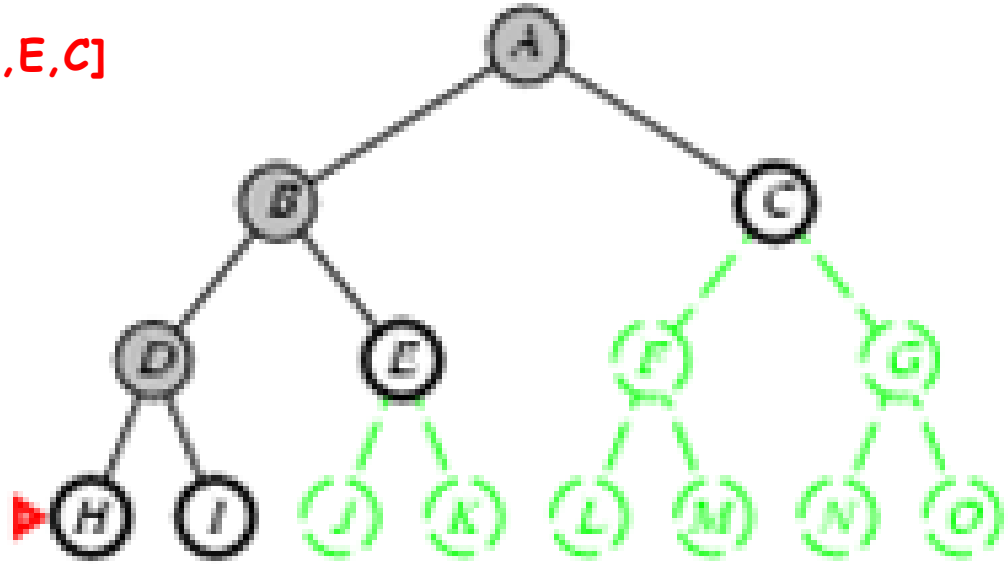
Blind Search

3. Depth-first search (DFS)

- Expand deepest unexpanded node
- Nodes are stored in LIFO stack (put successors at front)

Stack: [H,I,E,C]



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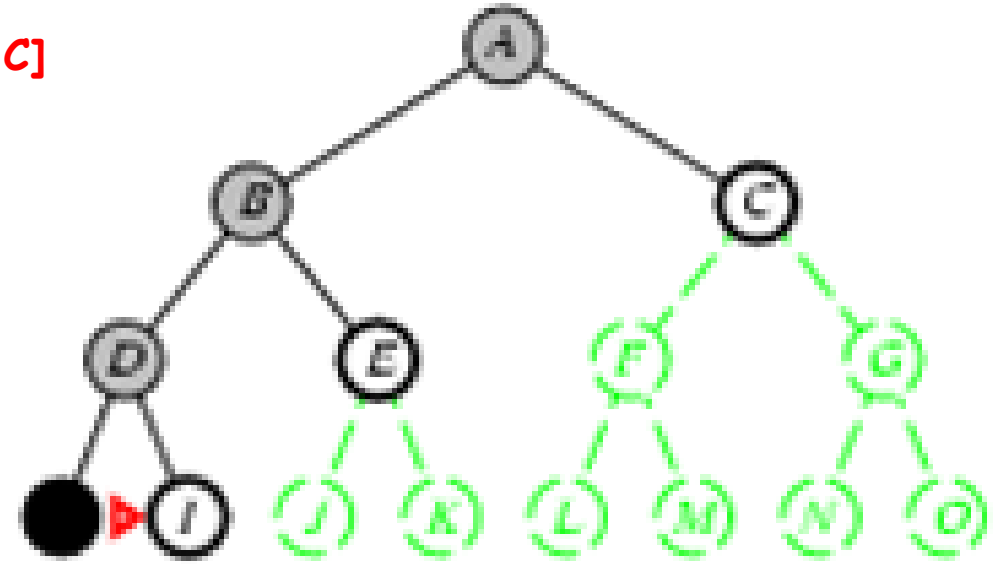
Blind Search

3. Depth-first search (DFS)

- Expand deepest unexpanded node
- Nodes are stored in LIFO stack (put successors at front)

Stack: [I,E,C]



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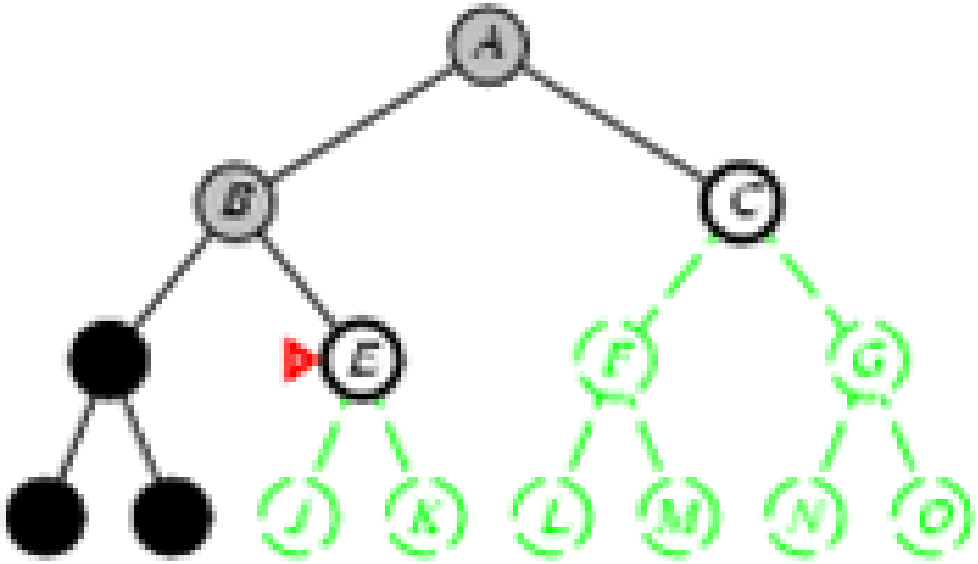
Blind Search

3. Depth-first search (DFS)

- Expand deepest unexpanded node
- Nodes are stored in LIFO stack (put successors at front)

Stack: [E,C]



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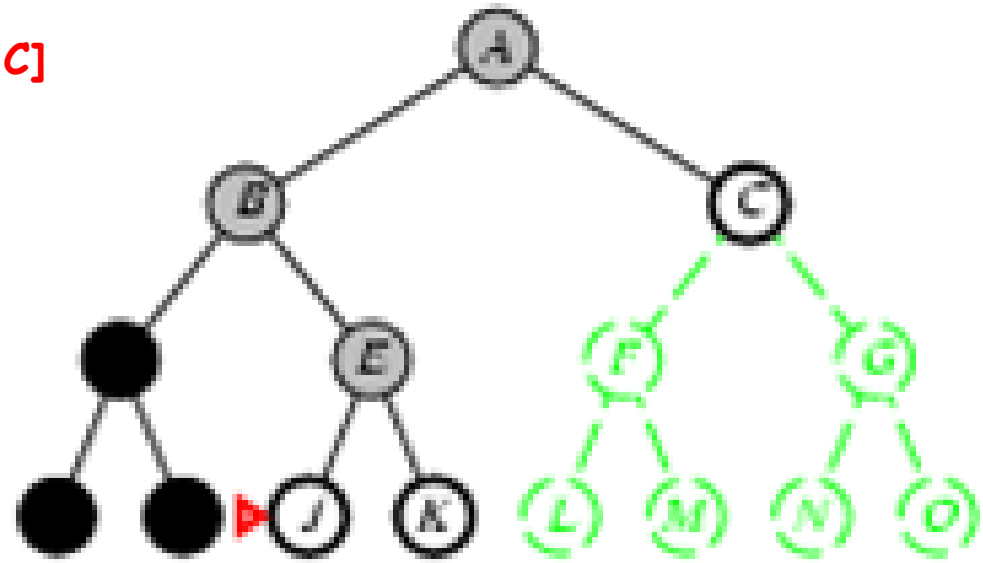
Blind Search

3. Depth-first search (DFS)

- Expand deepest unexpanded node
- Nodes are stored in LIFO stack (put successors at front)

Stack: [J,K,C]



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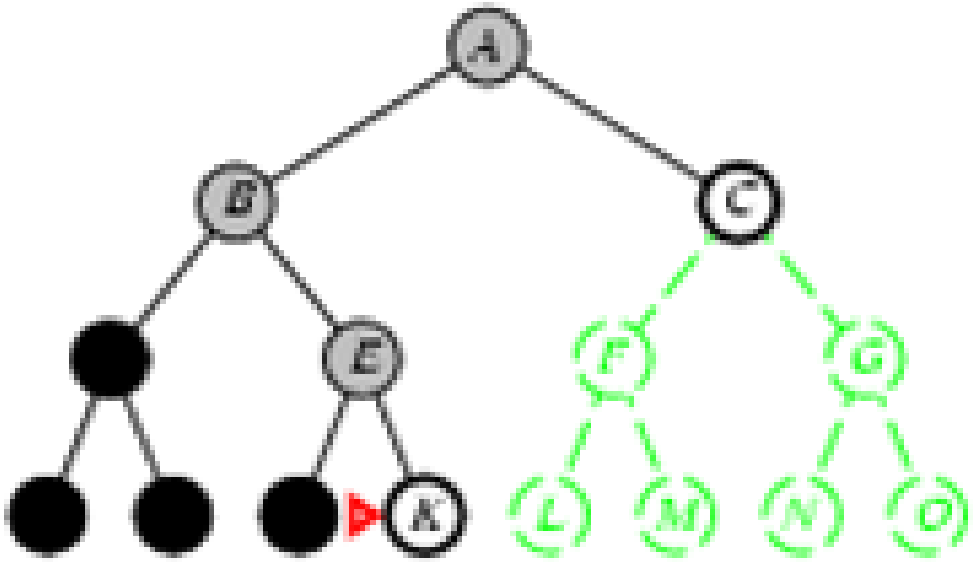
Blind Search

3. Depth-first search (DFS)

- Expand deepest unexpanded node
- Nodes are stored in LIFO stack (put successors at front)

Stack: [K,C]



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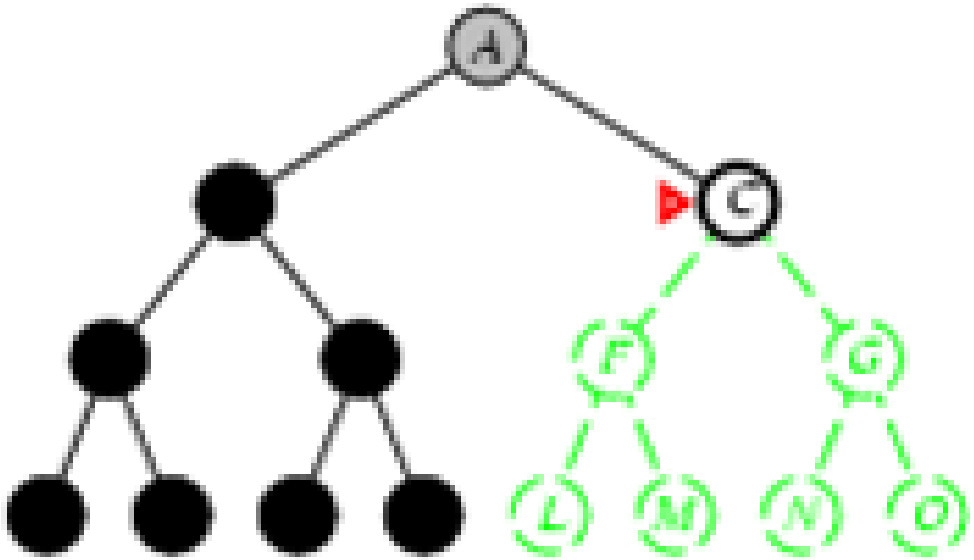
Blind Search

3. Depth-first search (DFS)

- Expand deepest unexpanded node
- Nodes are stored in LIFO stack (put successors at front)

Stack: [C]



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Blind Search

3. Depth-first search (DFS)

- Expand deepest unexpanded node
- Nodes are stored in LIFO stack (put successors at front)

Stack: [F,G]

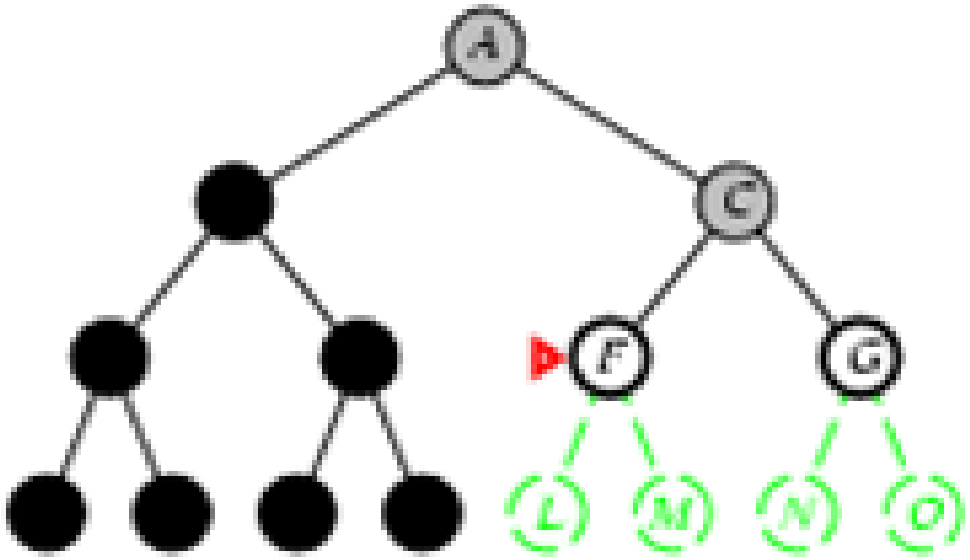


Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

Blind Search

3. Depth-first search (DFS)

- Expand deepest unexpanded node
- Nodes are stored in LIFO stack (put successors at front)

Stack: [L,M,G]

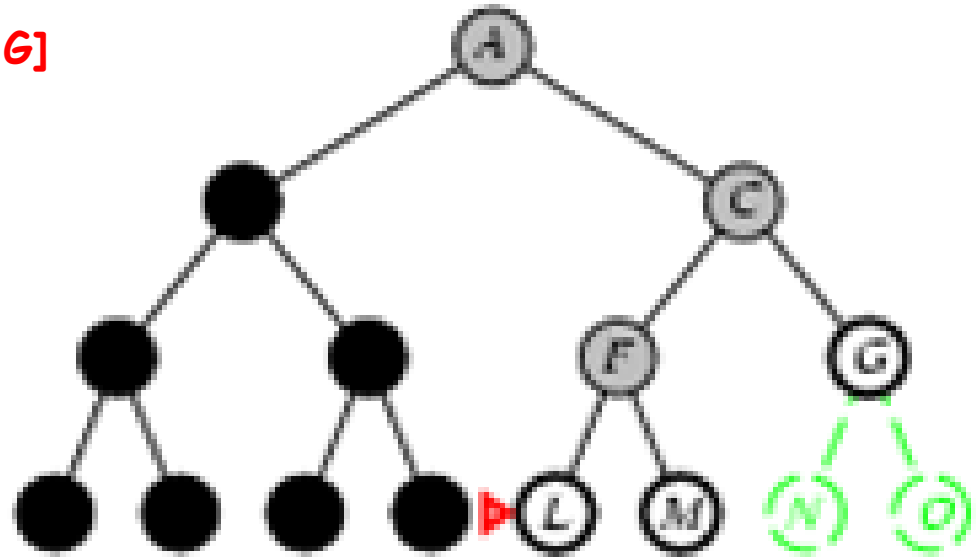


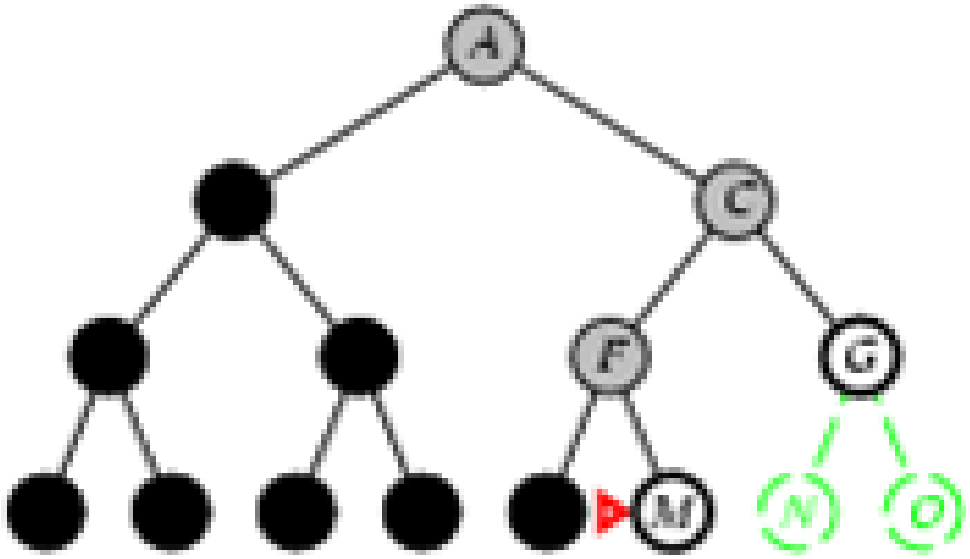
Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

Blind Search

3. Depth-first search (DFS)

- Expand deepest unexpanded node
- Nodes are stored in LIFO stack(put successors at front)

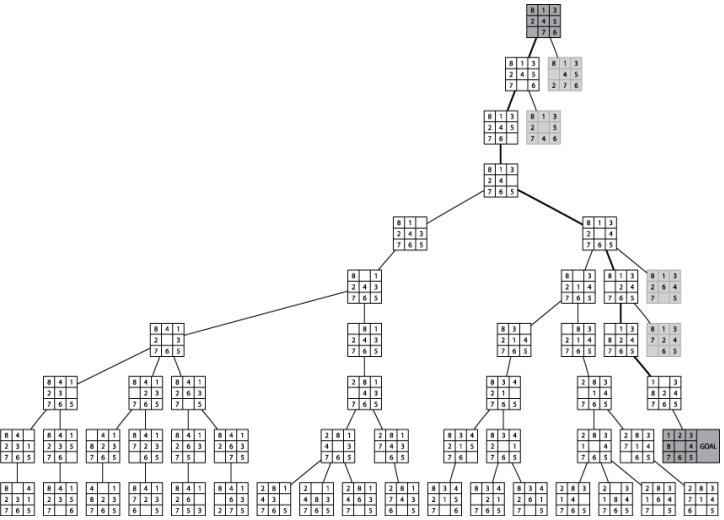
Stack: [M,G]

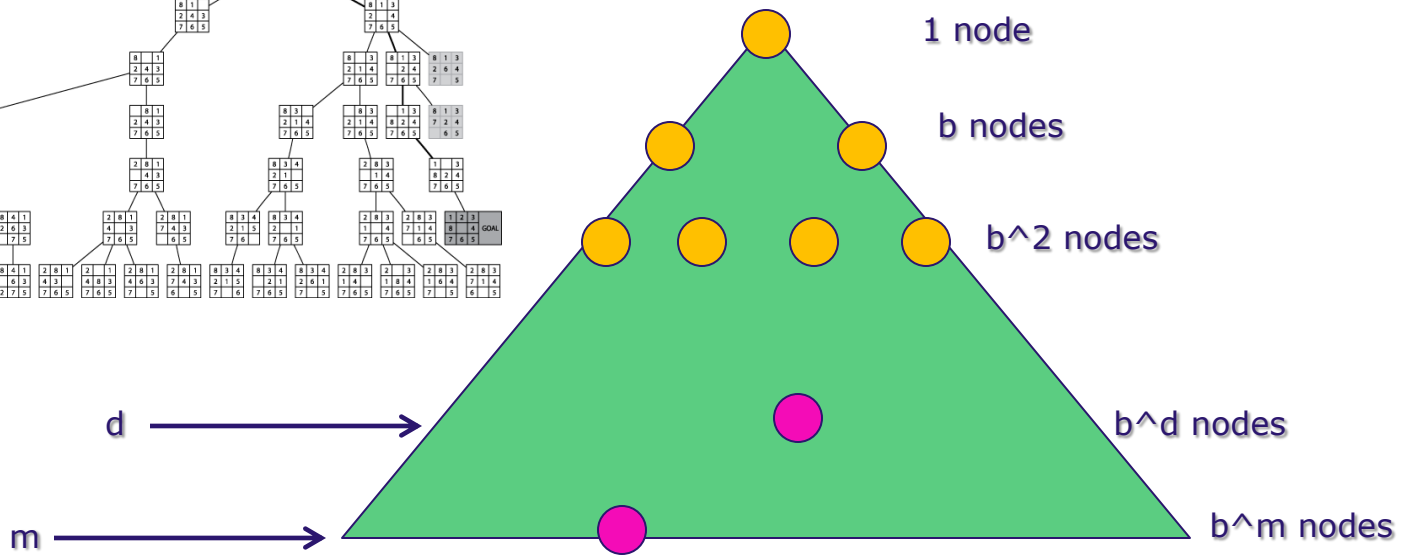


Goal is found!

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

DFS

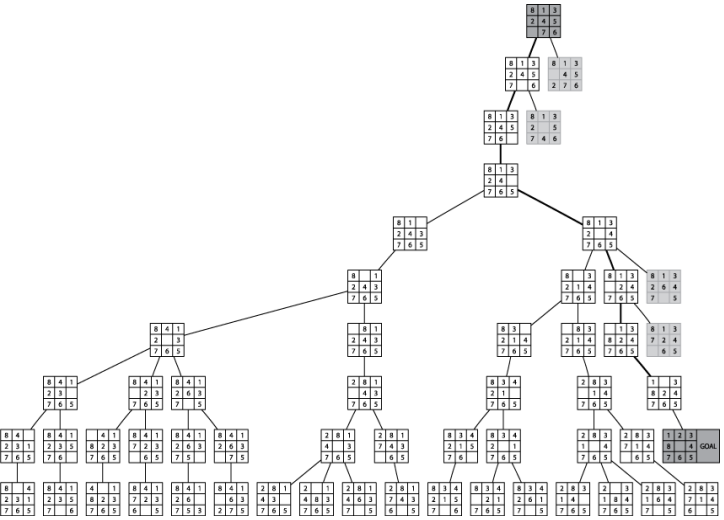




Number of Nodes on the entire tree= $1+b^2+b^3+\ldots\ldots+b^{d-1}+b^d+b^{d+1}+\ldots..+b^m= O(b^m)$

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

DFS



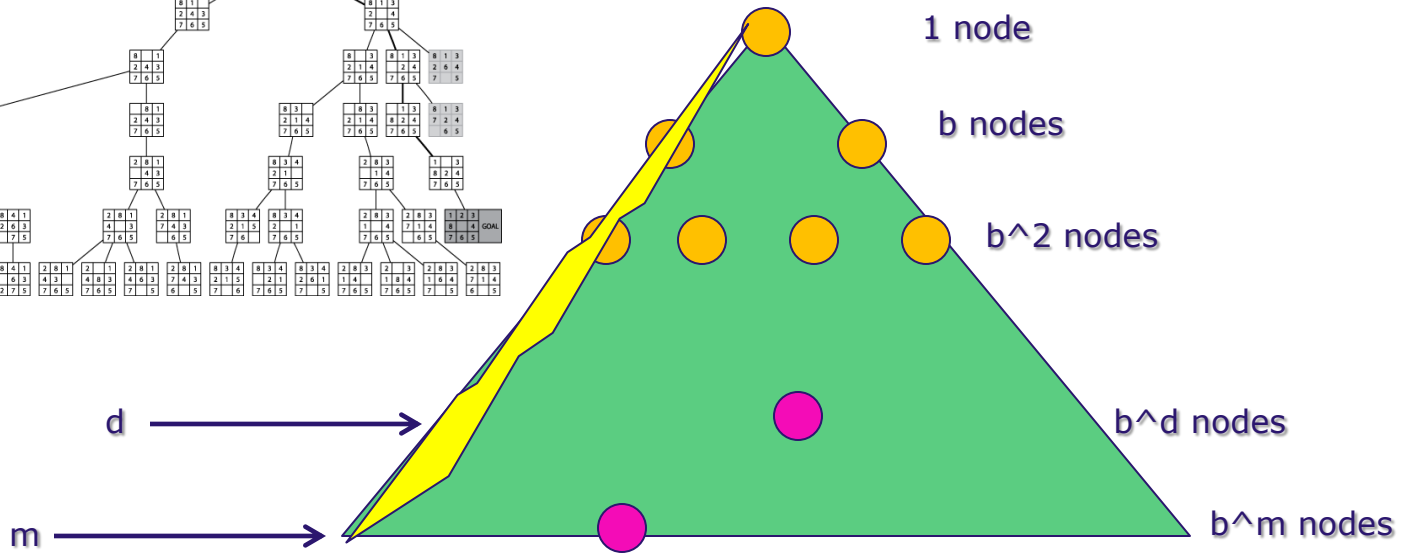
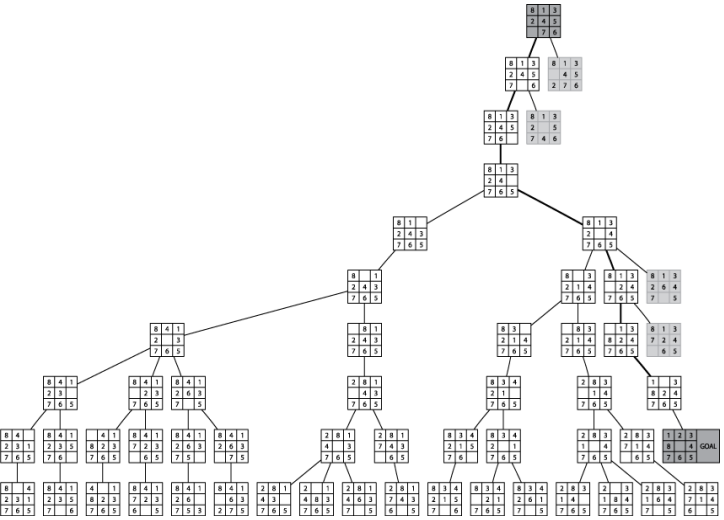


Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

DFS



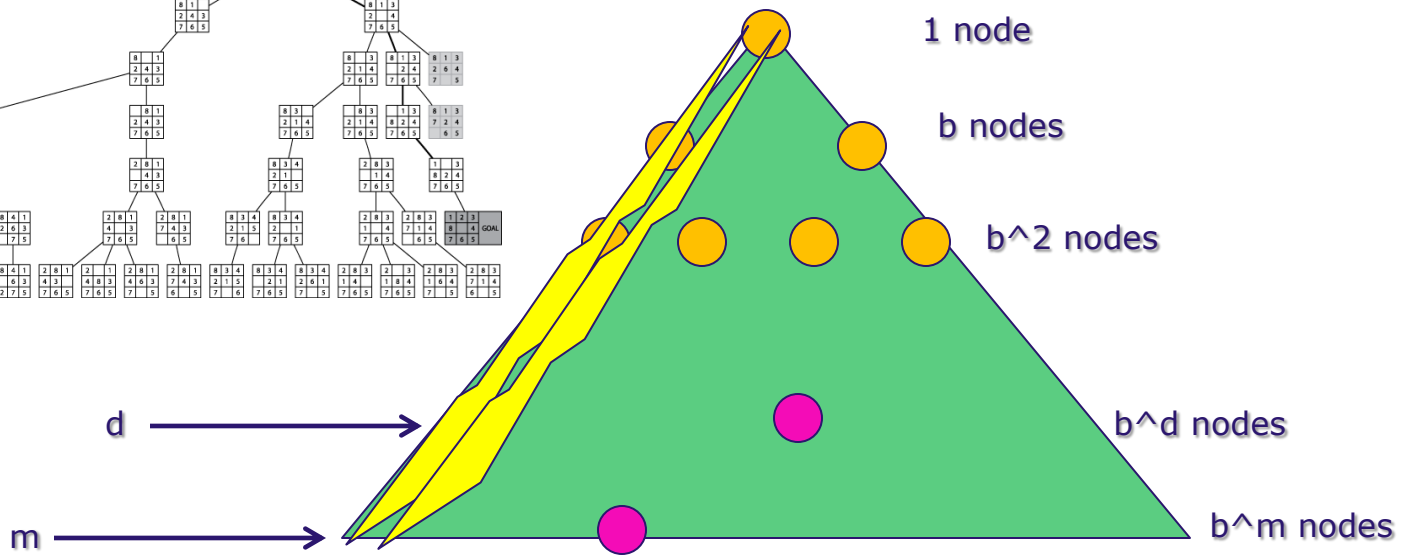
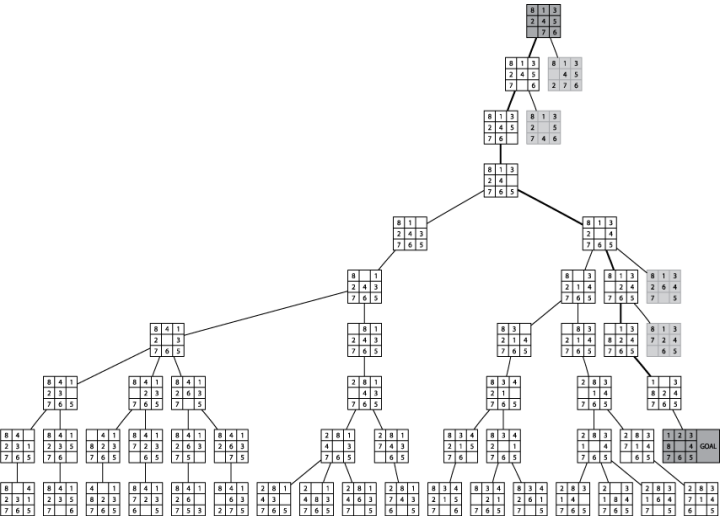


Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

DFS



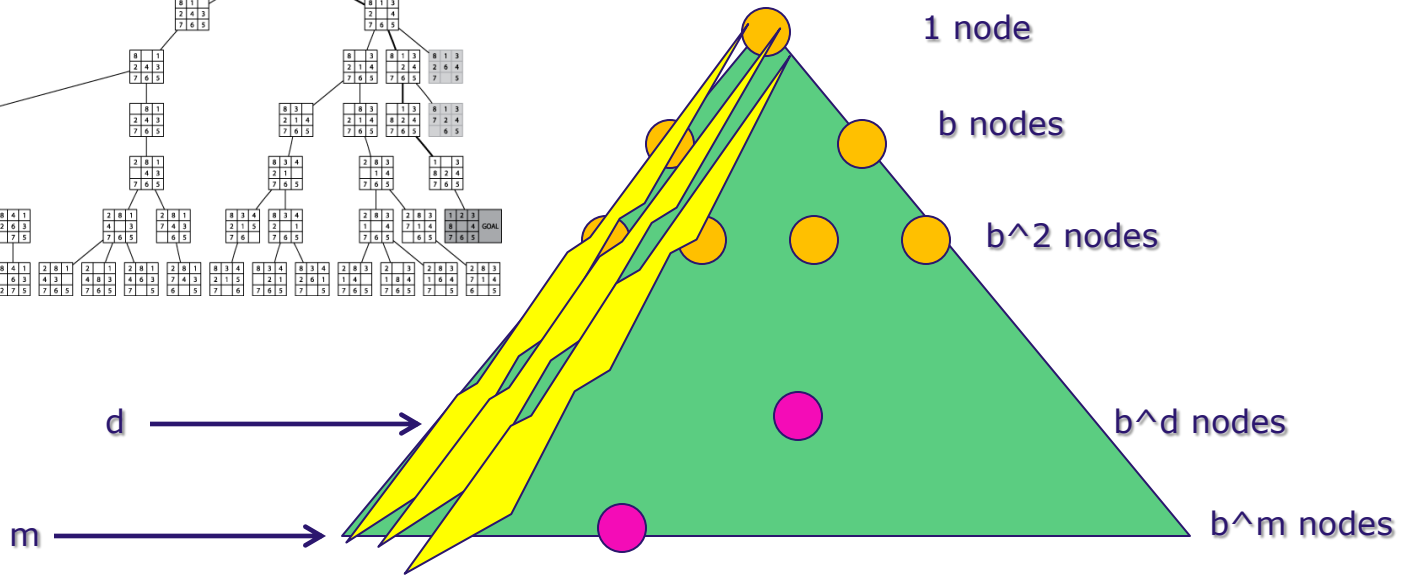
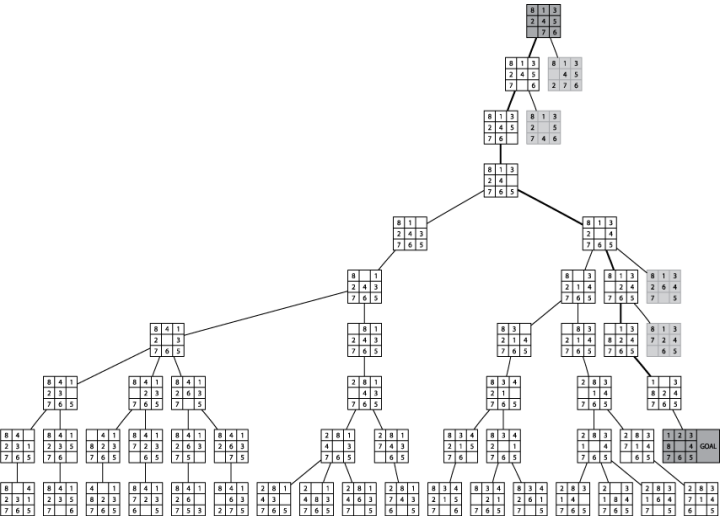
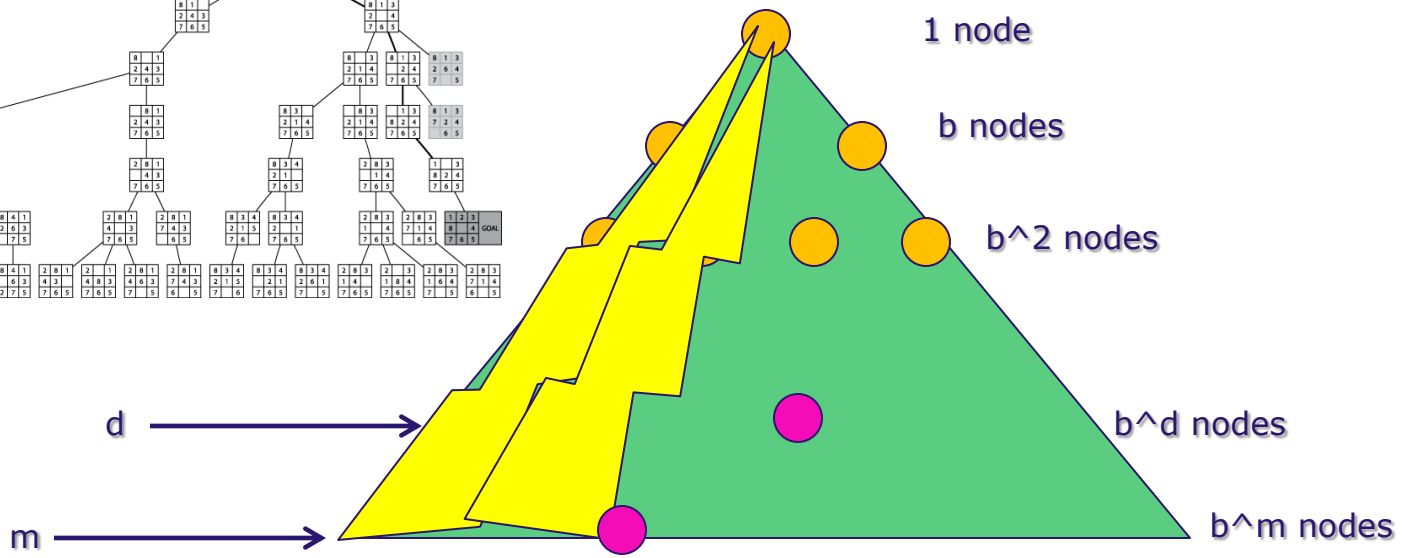


Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

DFS

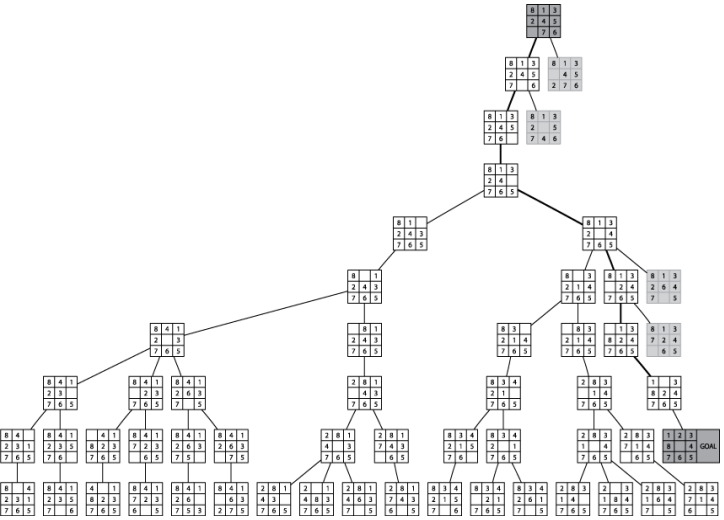


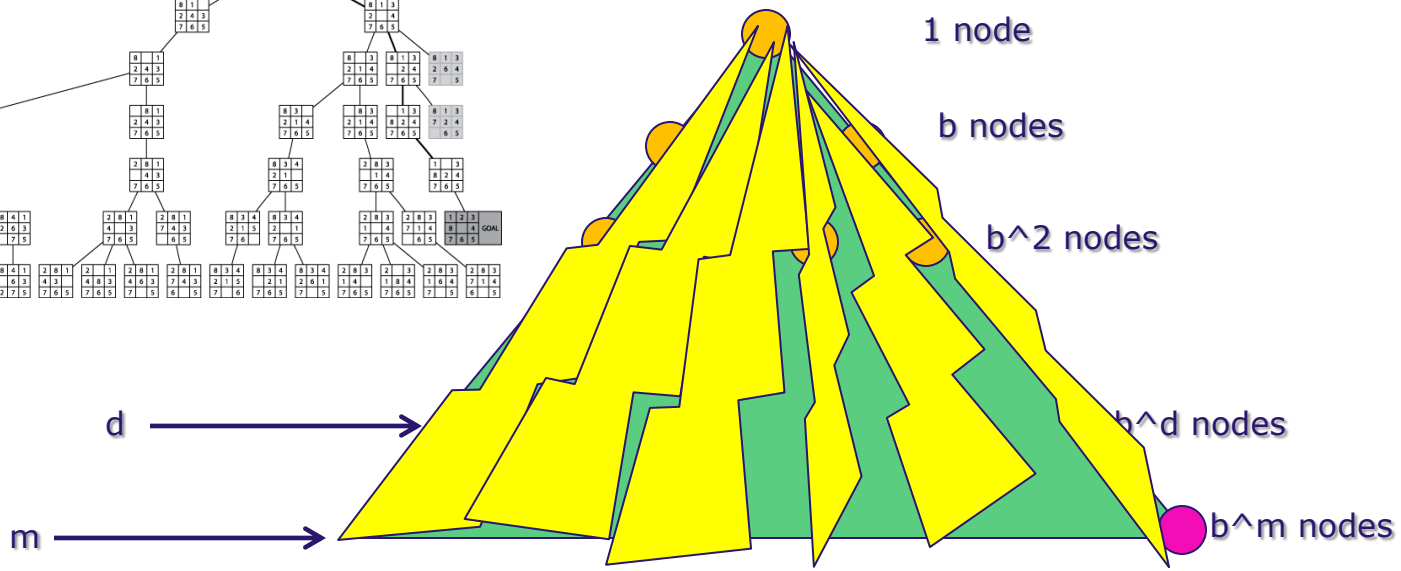


Time? $O(b^m)$

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

DFS

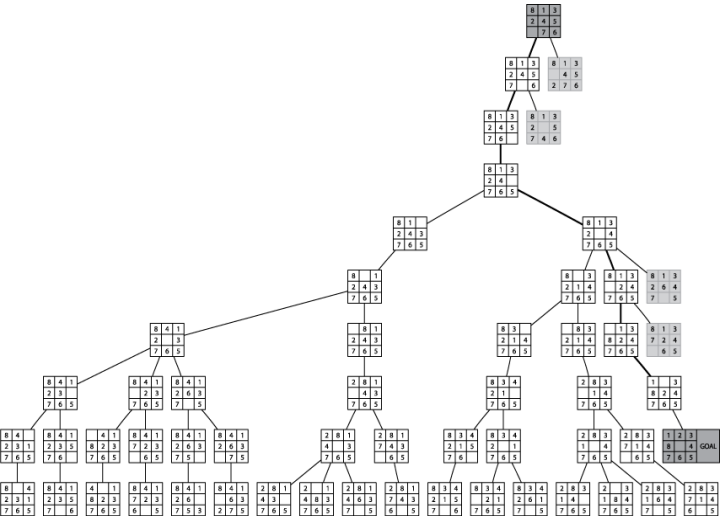


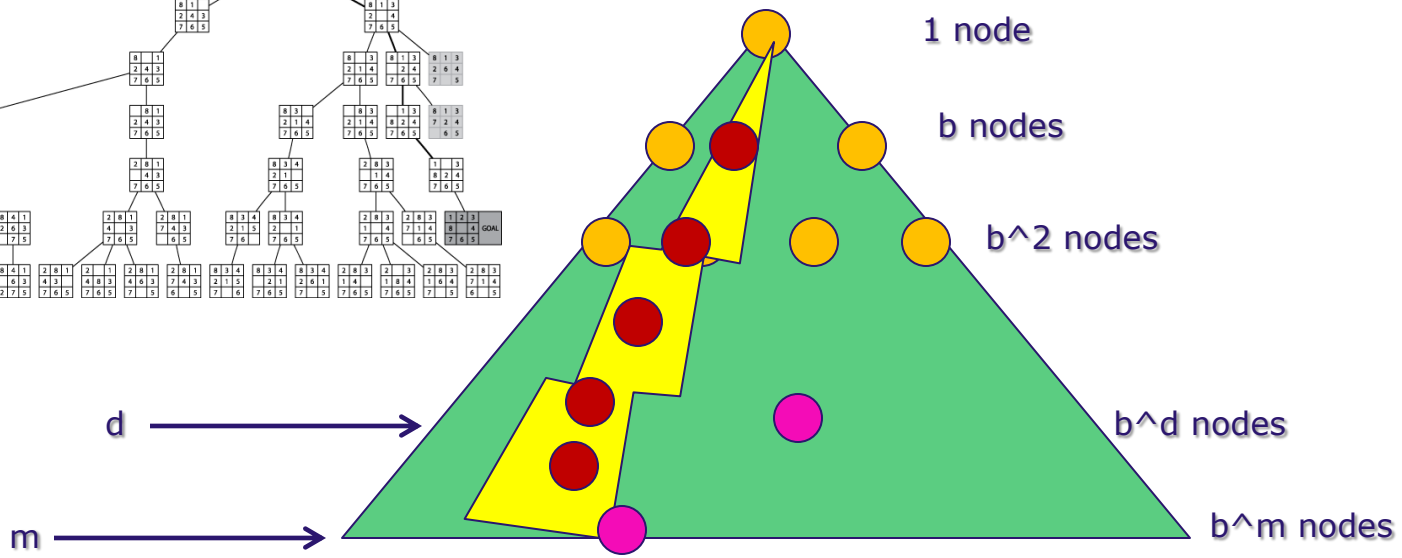


Time? $O(b^m)$

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

DFS





Space? O(b*m)

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

Blind Search, evaluation

3. Depth-first search(DFS)

- Complete? No (fails in infinite-depth spaces, spaces with loops)
- Time? $O(b^m)$
- Space? $O(b.m)$
- Optimal? No

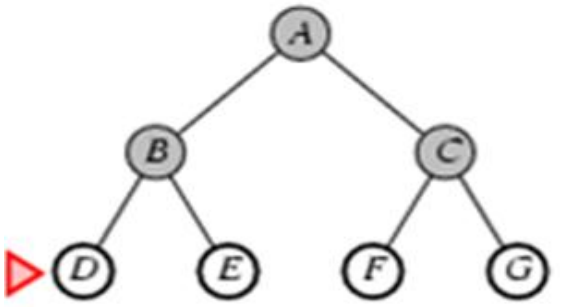


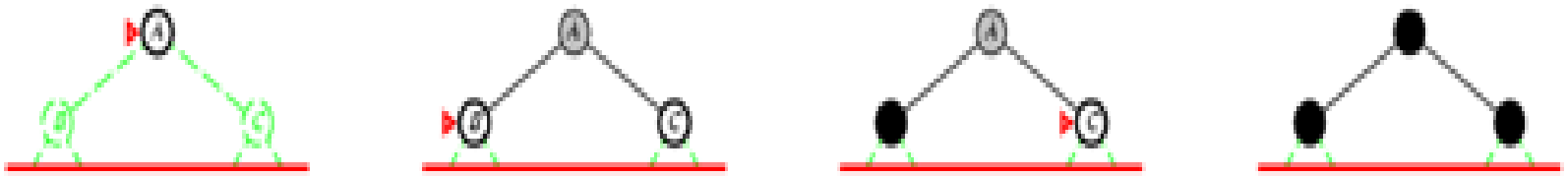
Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

Blind Search

4. Depth-limit search (DLS)

- Expand deepest unexpanded node until reach limit L
- Equivalent to depth-first search with depth limit L

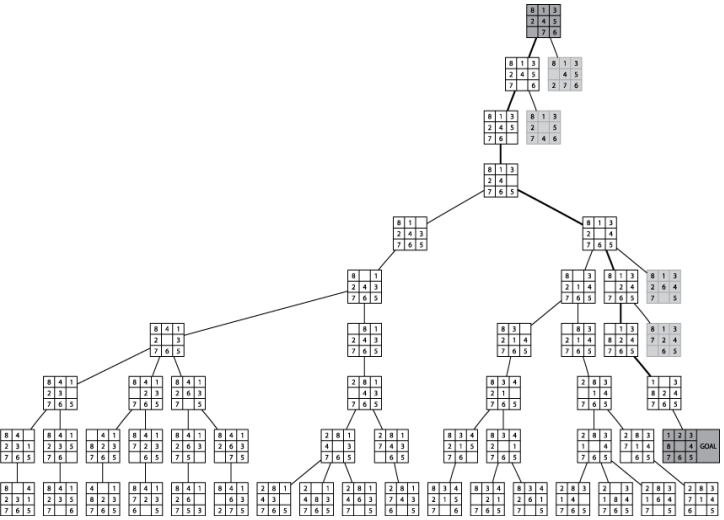
❖ **Ex**: Let L=1

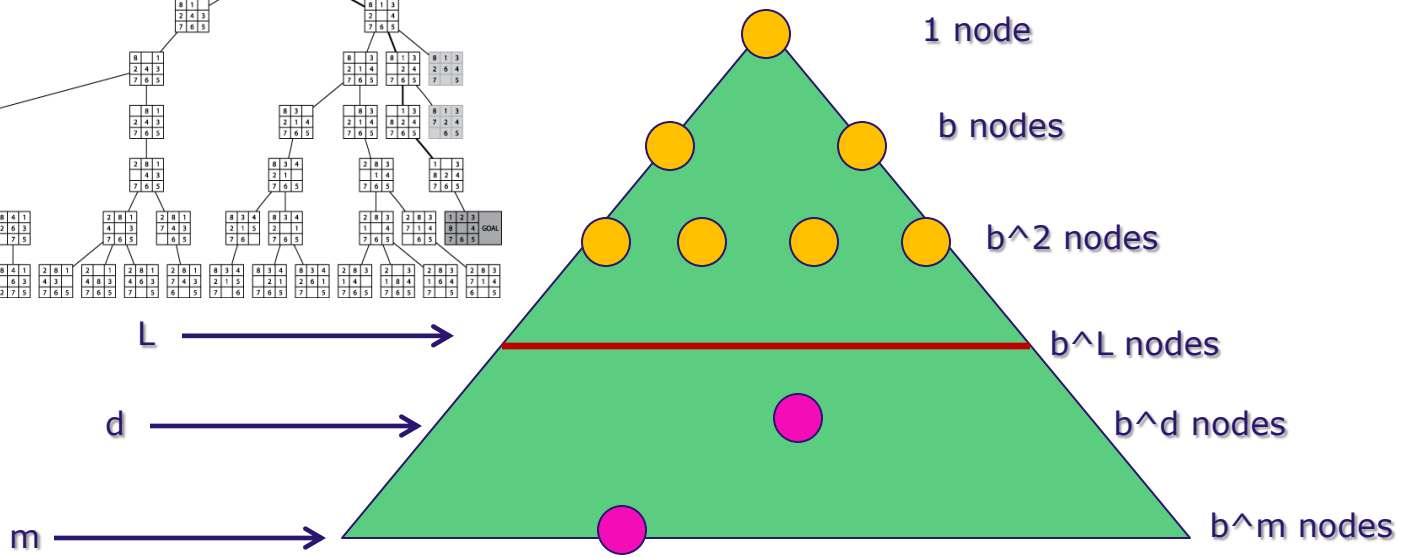


Goal is not found !

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

DLS

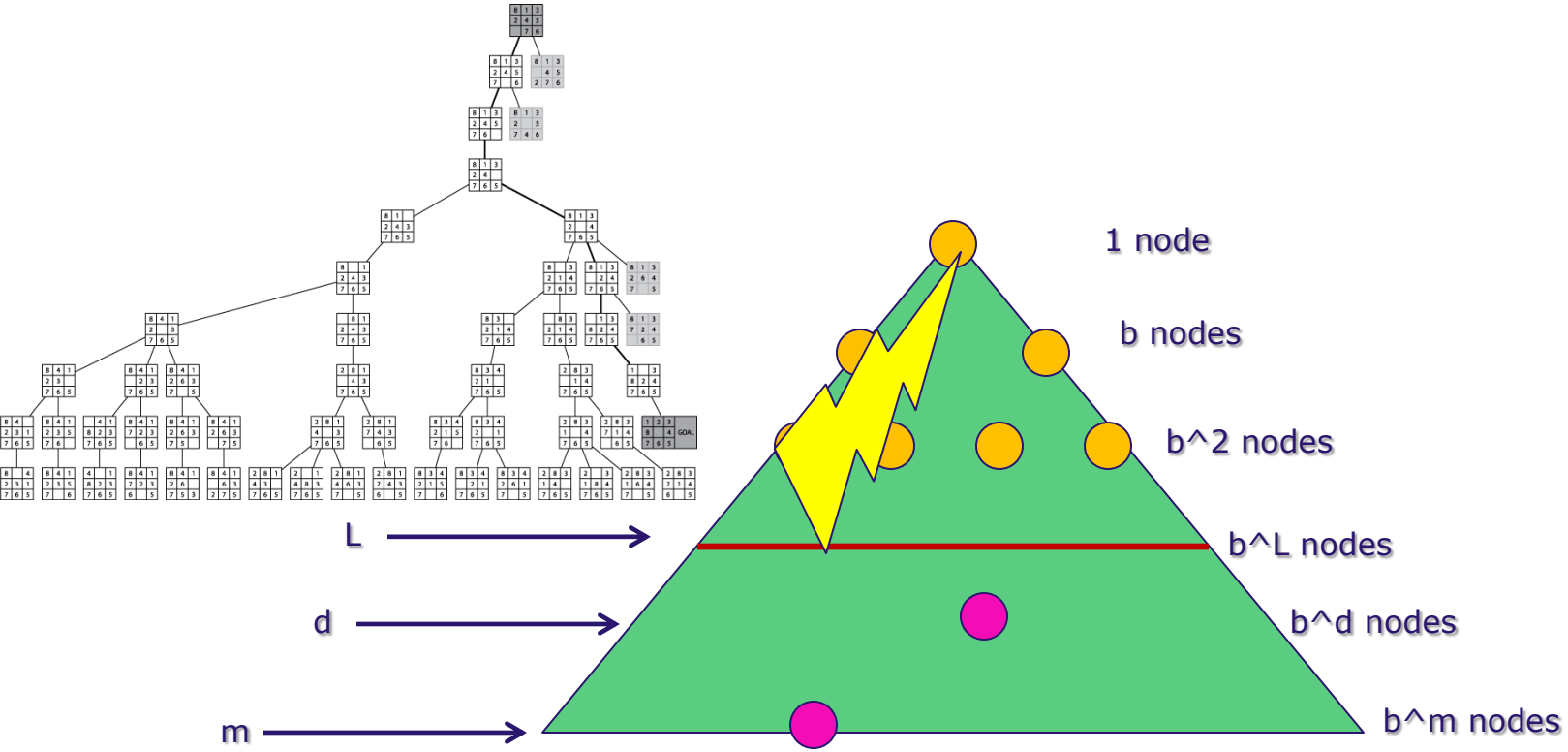




Number of Nodes on the entire tree= $1+b^2+b^3+\ldots\ldots+b^{d-1}+b^d+b^{d+1}+\ldots..+b^m= O(b^m)$

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

DLS



Time?

$O(b^L)$

Space?

$O(b*L)$

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

Blind search, evaluation

4. Depth-limit search(DLS)

- Complete? No (if d > L)

d: goal depth
L: depth Limit value

- Time? $O(b^l)$
- Space? $O(b.l)$
- Optimal? No

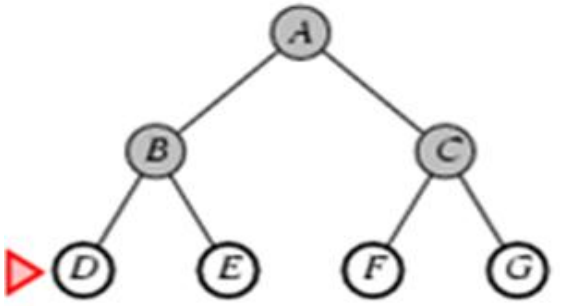


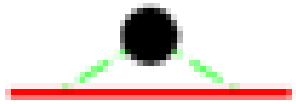
Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

Blind Search

5. Iterative Depth-search (IDS)

- Expand deepest unexpanded start with L=0
- Repeated implementation of DLS with different L

Limit = 0



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Blind Search

5. Iterative Depth-search (IDS)

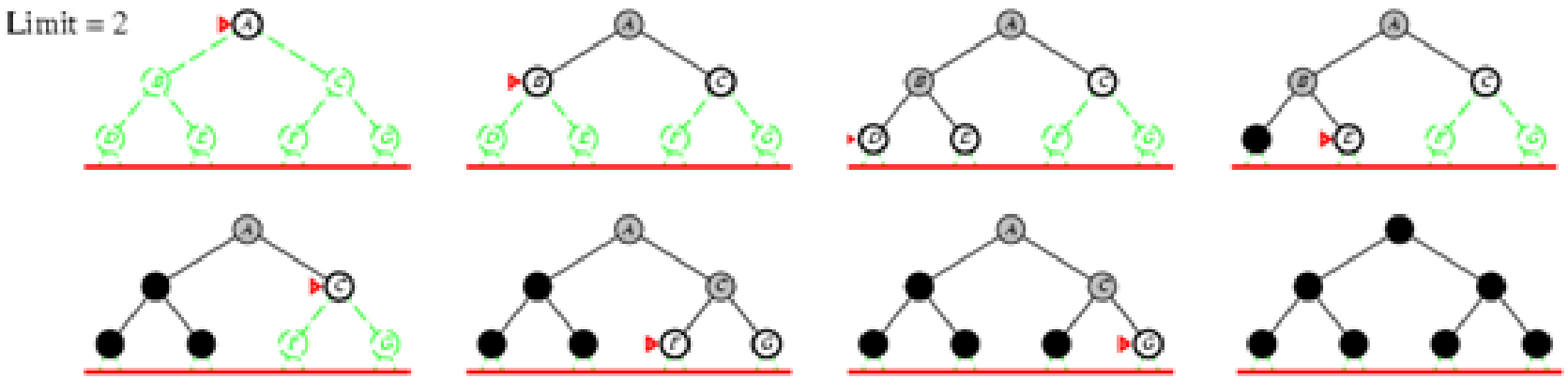
- Expand deepest unexpanded start with L=0
- Repeated implementation of DLS with different L

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

Blind Search

5. Iterative Deepening-search (IDS)

- Expand deepest unexpanded start with L=0
- Repeated implementation of DLS with different L



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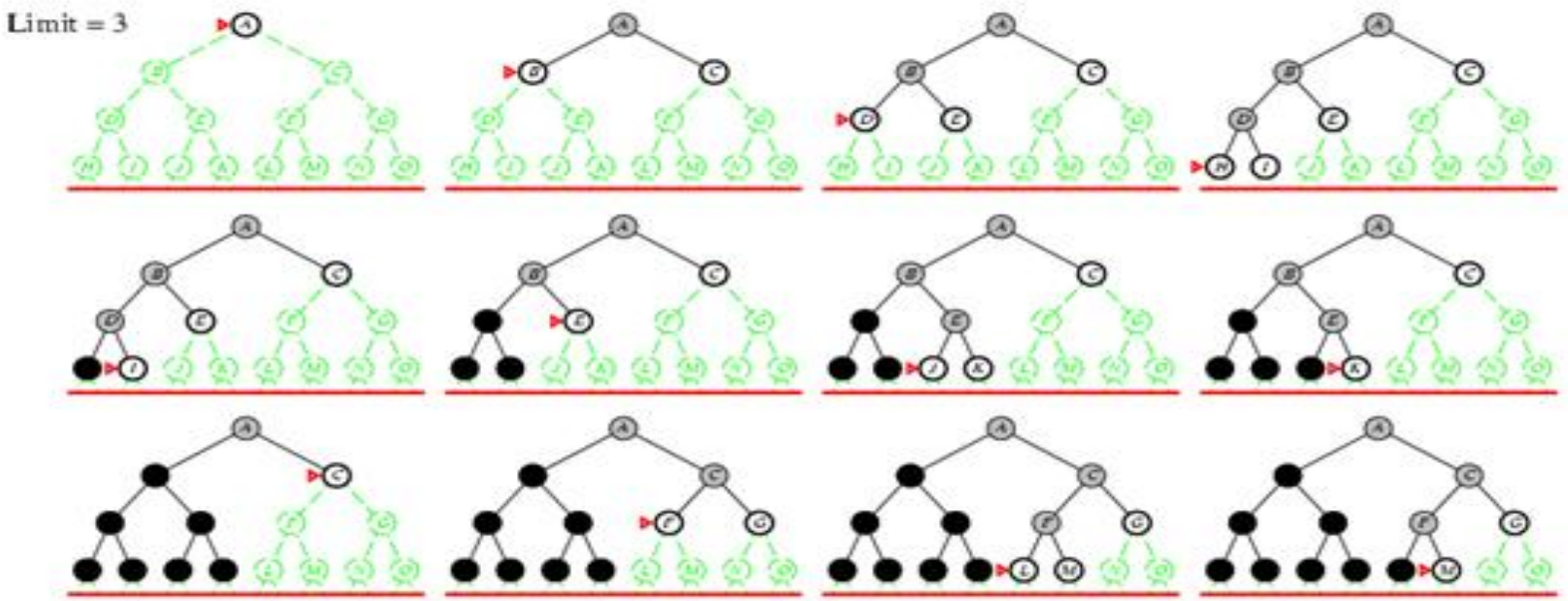
Blind Search

5. Iterative Depth-search (IDS)

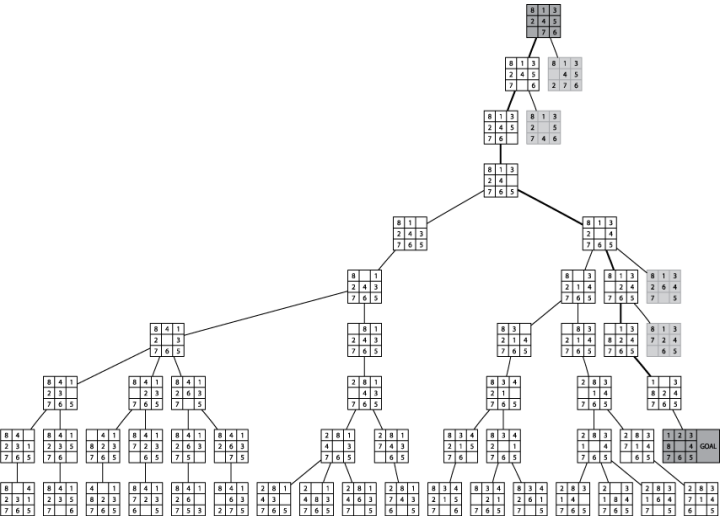
- Expand deepest unexpanded start with L=0
- Repeated implementation of DLS with different L



Goal is found !

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

IDFS



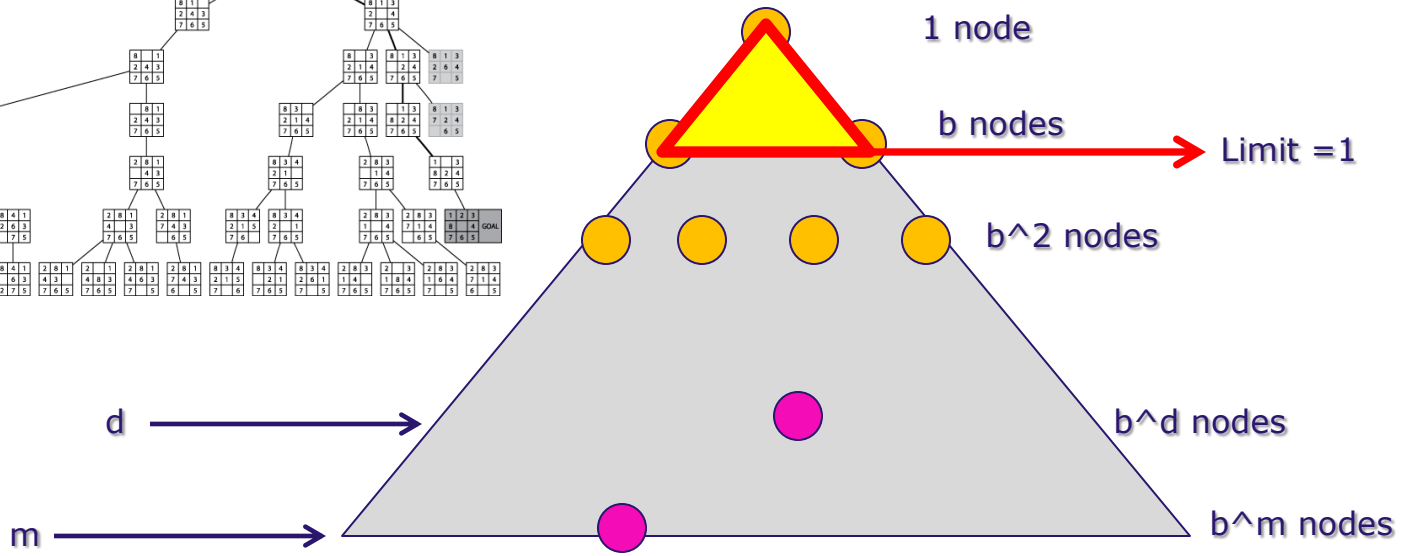
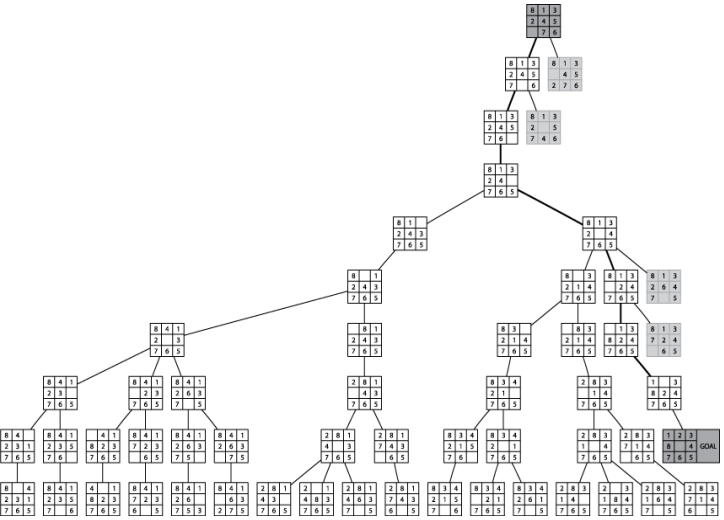
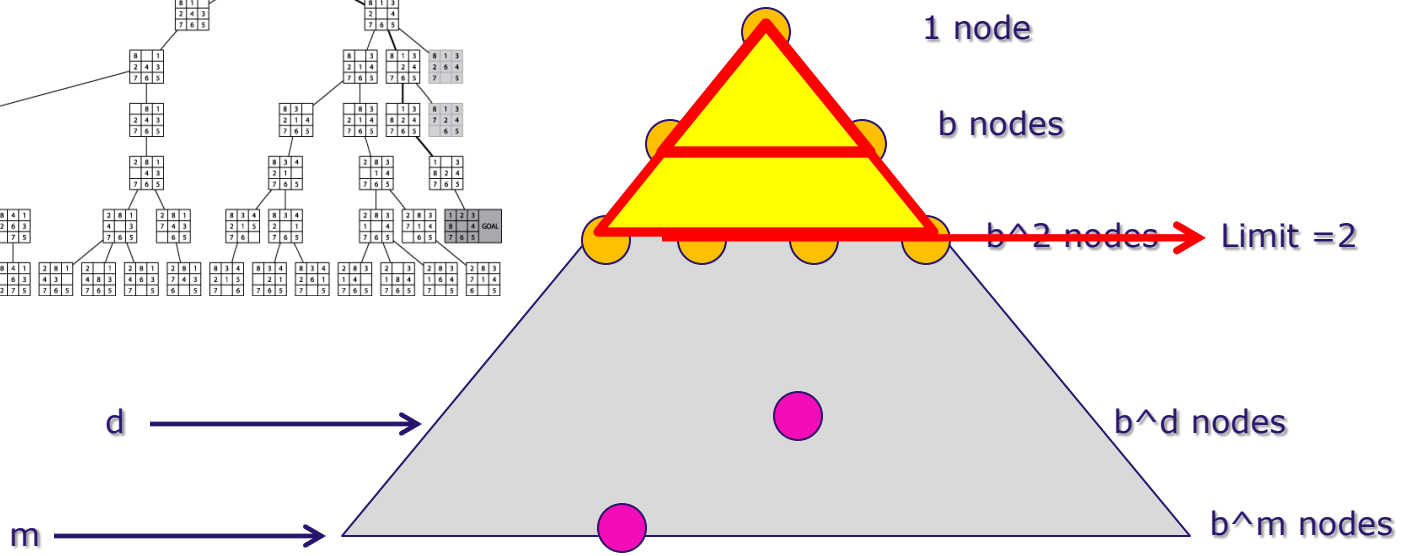


Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

IDFS





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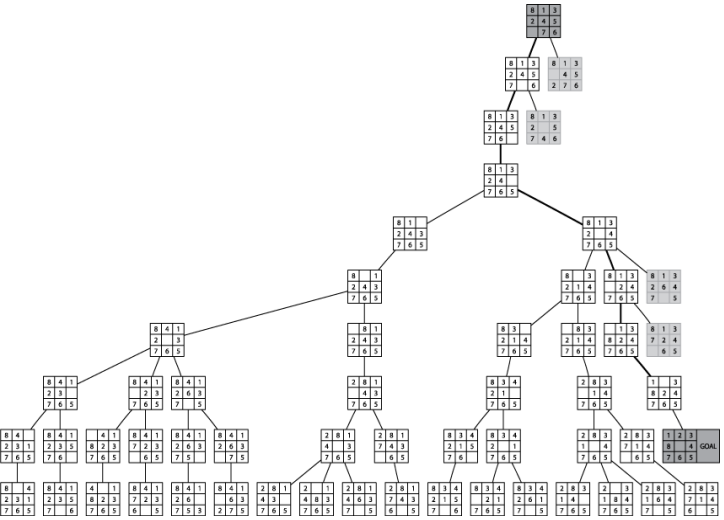
IDFS



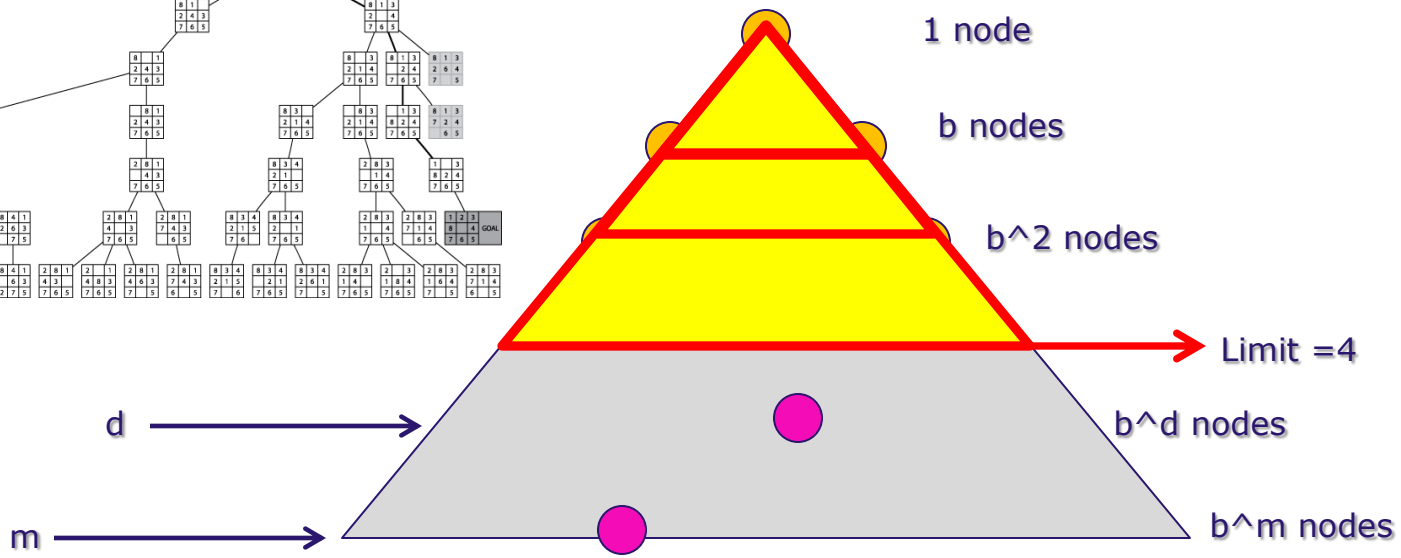
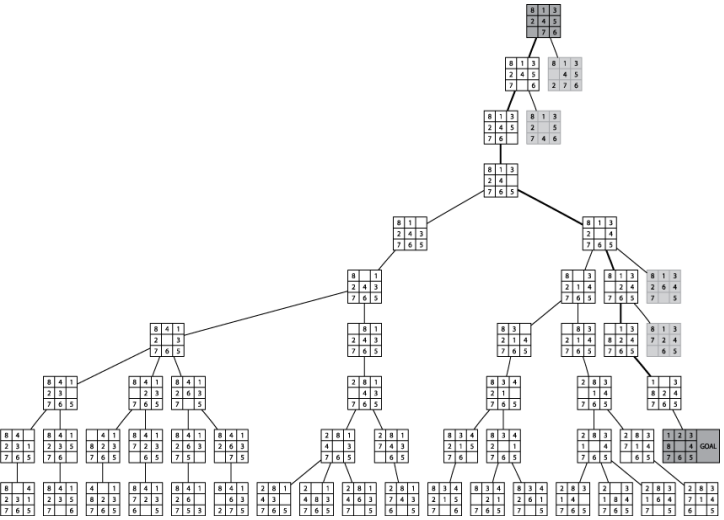
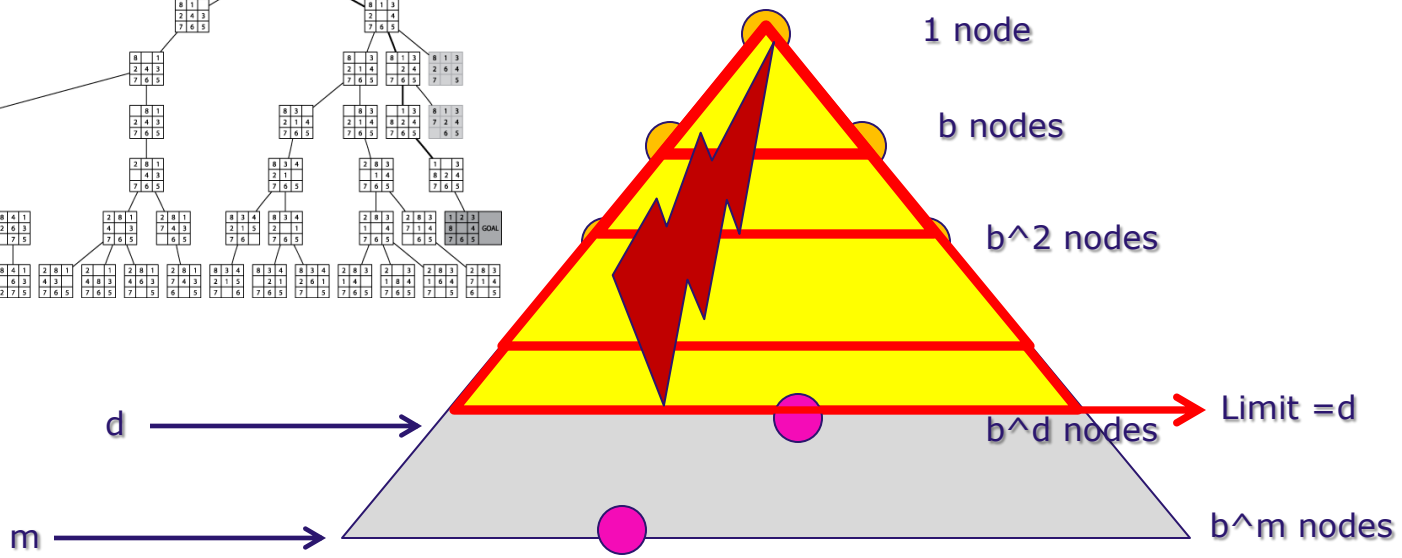


Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

IDFS





Time?

$O(b^d)$

Space?

$O(b*d)$

Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

Blind Search, evaluation

5. Iterative Depth-search (IDS)

- Complete? Yes
- Time? $O(b^d)$
- Space $O(b.d)$
- Optimal? Yes (if all trans. have same cost)

Blind Search

6. Bidirectional search (BS)

- BFS search simultaneously forward from START and backward from GOAL
- Solution is found if the two searches meet

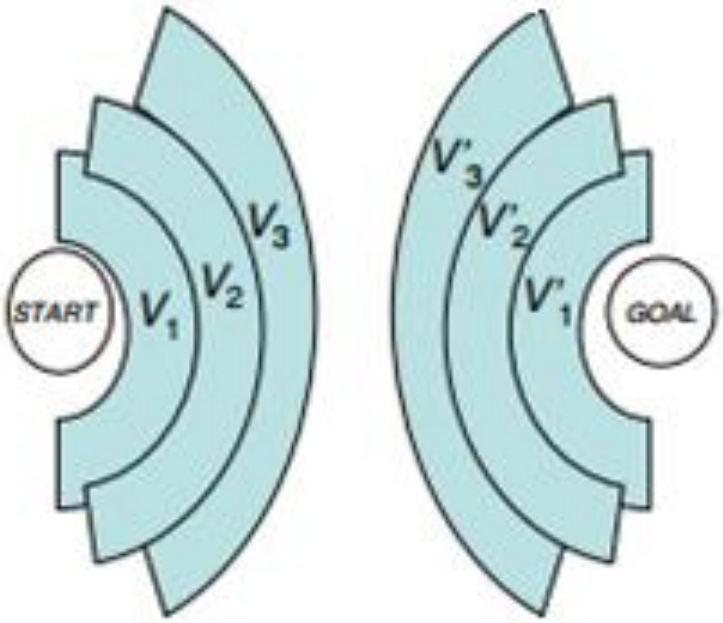
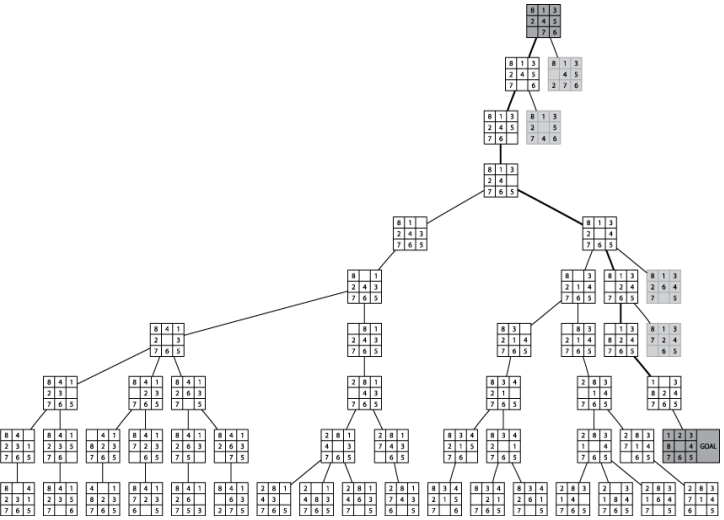


Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

BS



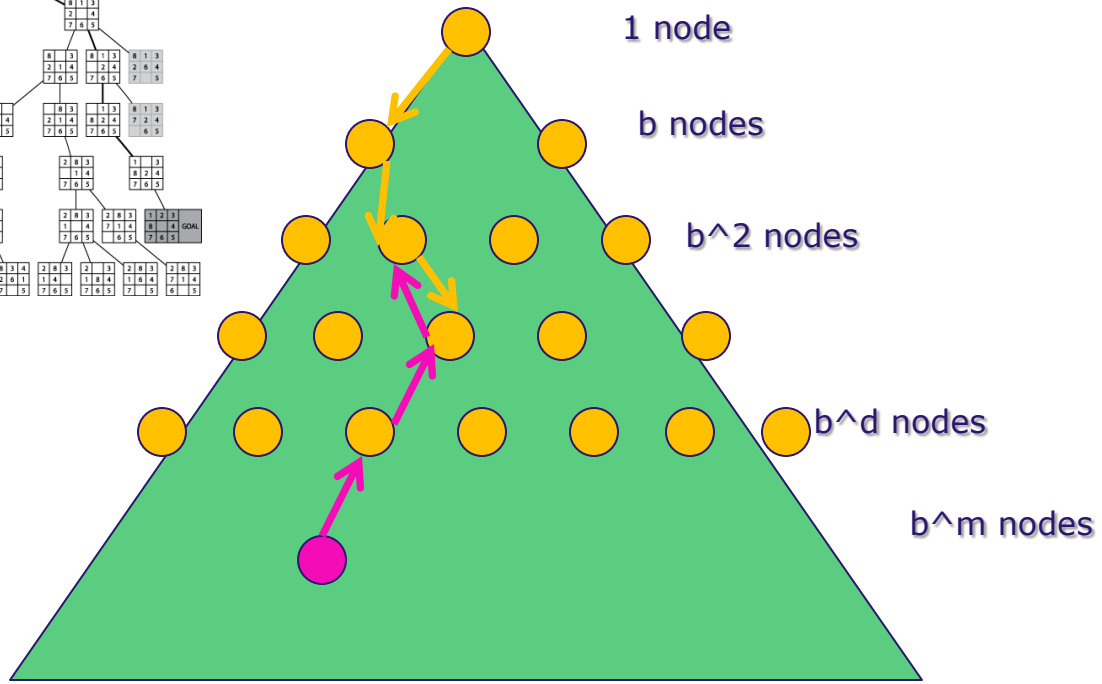


Image Credit: Artificial Intelligence A Modern Approach *Second Edition by Stuart J. Russell and Peter Norvig by 2010.*

Blind Search, evaluation

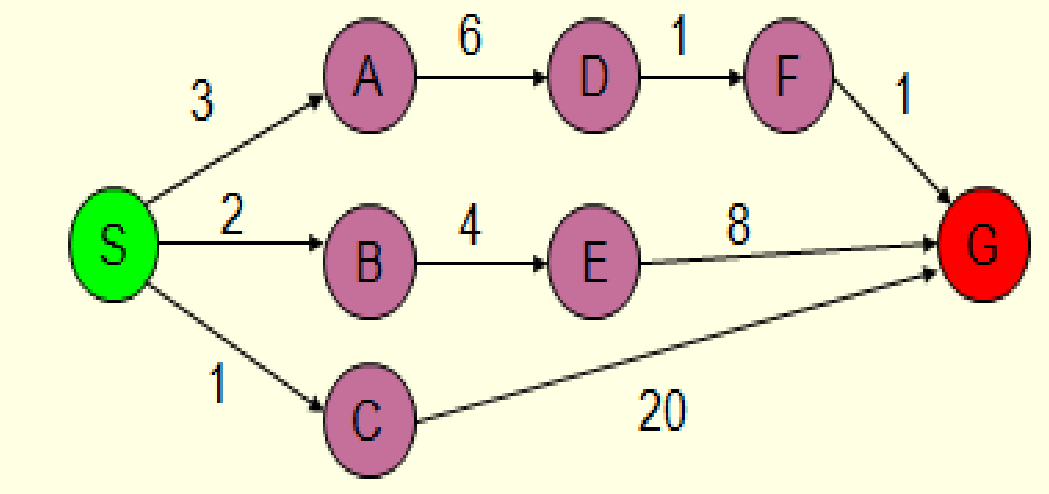
6. Bidirectional search (BS)

- Complete? Yes (if b is finite)
- Time? $O(b^{d/2})$
- Space? $O(b^{d/2})$
- Optimal? Yes (if all trans. have same cost)

Applications

- GPS Navigation systems: Google Maps, which can give directions to reach from one place to another using BFS
- Computer Networks: Peer to peer (P2P) applications such as the torrent clients need to locate a file that the client is requesting by applying BFS on the hosts on a network
- Social Networks: Facebook treats each user profile as a node on the graph search space and two nodes are said to be connected if they are each other's friends

Assignment_1



based on this graph, initial state is **S** and goal state is **G**

1. Apply **BFS** to reach destination state
2. Apply **DFS** to reach destination state
3. Apply **DLS** to reach destination state (depth limit 2)
4. Apply **UCS** to reach destination state , is this the optimal solution? Why?
5. For each algorithm:
   - Compute solution cost, (if there is a solution)
   - Express time and space in terms of # nodes


Thank You !