Search Strategies

Uninformed/Blind Search

- Breadth First Search
- Depth First Search
- Depth Limited Search
- Bidirectional Search

Informed/Heuristic Search

- Hill Climbing Search (Improvements)
- A* Algorithm

Measuring problem-Solving performance

A strategy is defined by picking the order of node expansion

What makes one search scheme better than another?

Completeness: Guarantee to find a solution?

Time complexity: How long is it to find a sol. (# of nodes)?

Optimality: Does the strategy find the shortest path (note some books use least cost)?

Space complexity: How much memory is needed (max. # of nodes in memory)?

Notations

- b: Branching Factor that is maximum number of successors of any node
- d : depth of the least cost solution
- C* : path cost of the optimal solution
- m : maximum depth of the state space

Breadth First Search

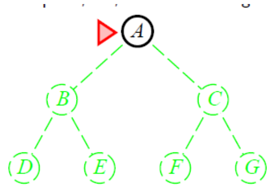
- Simple Strategy
- The root is expanded first, Then all its successors, Then all their successors
- At a given depth, All nodes are expanded.
- With branching factor b, at level d, we have

$1+b+b^2+b^3+...b^d + b(b^d -1) = O(b^{d+1})$ Nodes

- At level 12 with branching factor 10, we have 10^{13} nodes
- Space Problem !

Breadth First Search

- Expand the shallowest node



Breadth First Search

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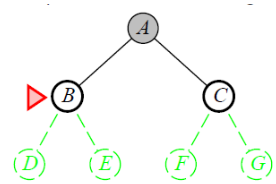
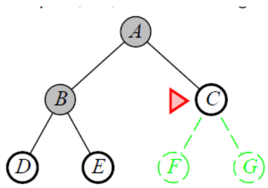


Breadth First Search

- Expand the shallowest node



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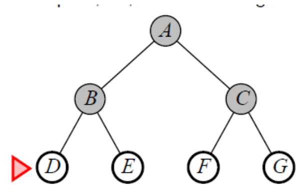


BFS

Completeness?

Yes, if solution exists, there is a guarantee to find it

Time complexity?

$O(b^{d+1})$

Space complexity?

$O(b^{d+1})$ *:* keeps every node in memory

Optimality?

Yes :finds shortest path

Remark:

If the definition of optimality is to find lowest cost path them BFS is not optimal

Bidirectional Search

BFS in both directions

How could this help?

b^{d+1} vs $2b^{(d+1)/2}$

- Can reduce time complexity,
- Not always applicable
- May require lots of space
- Hard to implement

Bidirectional Search

Completeness?

Yes, if solution exists, there is a guarantee to find it

Time complexity?

$O(b^{(d+1)/2})$, b is branching factor, d is least cost to goal

Space complexity?

$O(b^{(d+1)/2})$

Optimality?

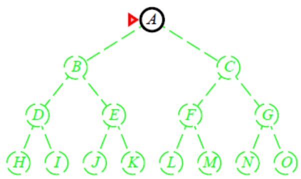
yes

Depth First Search

- Always expand deepest node in the fringe of the tree.
- Modest memory requirement, stores only single path from root to leaf.
- With branching factor b, at level d, we store only bm+1 i.e. O(bm)
- It may stuck in an infinite path and never finds solution

Depth First Search

- Expand deepest unexpanded node



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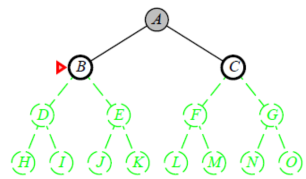

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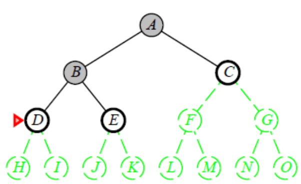

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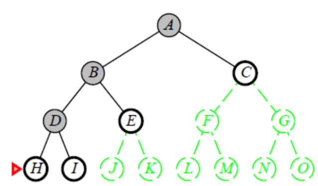

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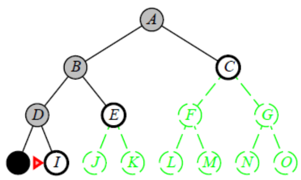

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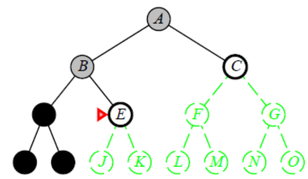

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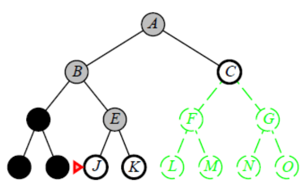

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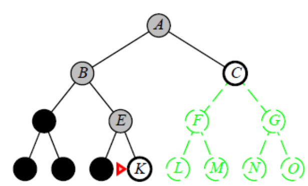

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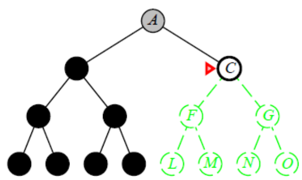

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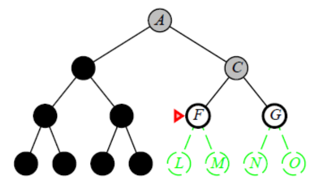

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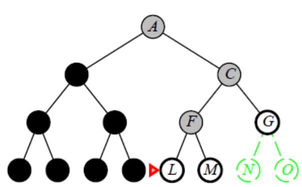

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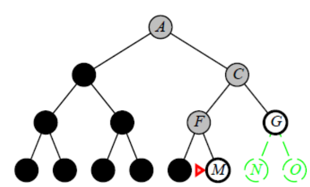


DFS

Completeness?

No, fails in infinite depth spaces or spaces with loops

Yes, assuming state space finite.

Time complexity?

$O(b^m)$, terrible if m is much bigger than d. can do well if lots of goals

Space complexity?

$O(bm)$, i.e. linear

Optimality?

No may find a solution with long path

Depth-limited Search

Put a limit to the level of the tree

DFS, only expand nodes depth ≤ L.

Completeness?

No, if L ≤ d.

Time complexity?

$O(b^L)$

Space complexity?

$O(bL)$

Optimality?

No

Iterative Deepening

- Calls depth-limited search with increasing limits until goal is found

Limit = 0

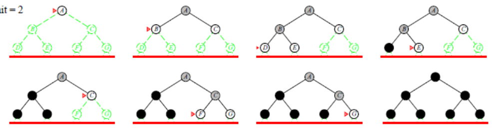
Iterative Deepening

- Calls depth-limited search with increasing limits until goal is found

Limit = 1

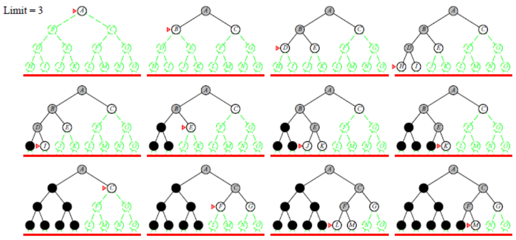
Iterative Deepening

- Calls depth-limited search with increasing limits until goal is found



Iterative Deepening

- Calls depth-limited search with increasing limits until goal is found



Iterative Deepening

- Completeness?

  Yes.

  Time complexity?

  $O(b^d) = (d+1)\, b^0 + d b^1 + \ldots + b^d$

  Space complexity?

  $O(bd)$

  Optimality?

  Yes; if looking for shortest path

  Remark: IDS performs much faster than BFS:

  Numerical comparison for $b = 10$ and $d = 5$, solution at far right leaf:

  $$N(\text{IDS}) = 50 + 400 + 3,000 + 20,000 + 100,000 = 123,450$$
  $$N(\text{BFS}) = 10 + 100 + 1,000 + 10,000 + 100,000 + 999,990 = 1,111,100$$

Remarks

- BFS works as a queue. Pick the leftmost element of the open list , evaluate it and add its children to the end of the list, FIFO
- DFS works as a stack. Pick the leftmost element of the open list , evaluate it and add its children to the beginning of the list, LIFO

Informed Search

- Blind search - no notion concept of the "right direction"
  - can only recognize goal once it's achieved
- Heuristic search – we have rough idea of how good various states are, and use this knowledge to guide our search
- Can find solutions more efficient than uninformed
- General approach is *best-first-search*
- A node is selected based on an *evaluation function f(n)*
- A node that **seems** to be best is picked and it may not be the actual best

Best First Search

- The Idea:
  - use an ***evaluation function*** for each node... estimate of ``desirability''
  - Expand most desirable unexpanded node

Implementation

- Fringe: is a queue sorted in decreasing order of desirability

Special cases

Greedy

A*

Cost function *f(n)*

- A function f is maintained for each node

$f(n) = g(n) + h(n)$, n is the node in the open list

- "Node chosen" for expansion is the one with least f value
- $g(n)$ is the cost from root S to node n
- $h(n)$ is the estimated cost from node n to a goal
- For BFS: $f = 0$,
- For DFS: $f = 0$,
- For greedy g =0

Greedy search

- Expands a node it sees closest to a the goal
- ***f(n) =h(n)***
- Resembles DFS in that it prefers to follow a single path all the way to the goal
- Also suffers from the same defects of DFS, it may stuck in a loop i.e. not complete As well as it is not optimal.

Hill climbing

This is a *greedy* algorithm
Expands a node it sees closest to a goal

f(n) =h(n)

The algorithm

select a heuristic function;

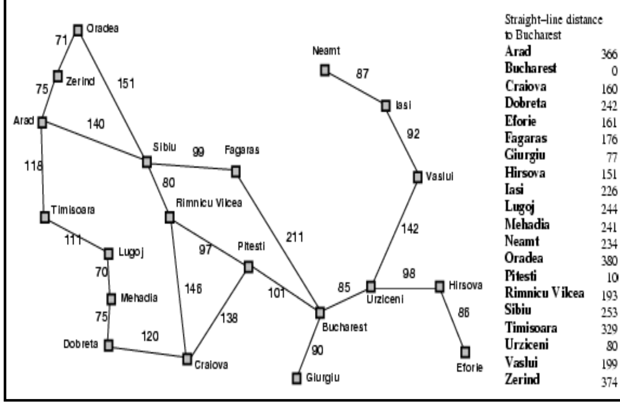
set C, the current node, to the highest-valued initial node;

Loop until success or no more children(fail)

select N, the highest-value child of C;

return C if its value is better than the value of N;

Hill Climbing search example



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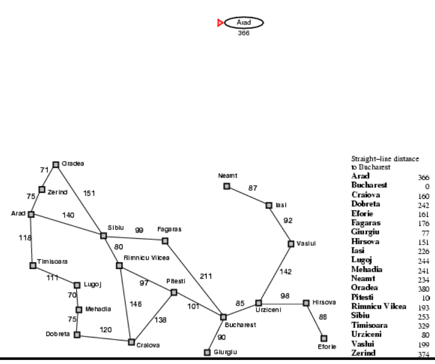

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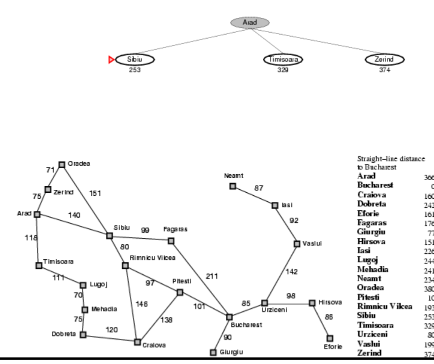

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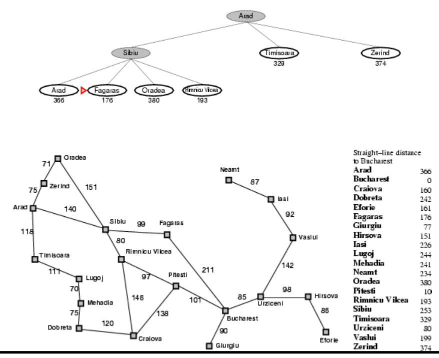

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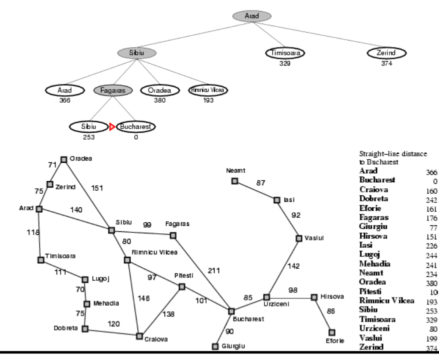

Hill climbing

Complete:

No, Can get stuck in loop. Complete if loops are avoided.

Time complexity?

O(bm), but with some good heuristic, it could give better results

Space complexity?

O(bm), keeps all nodes in memory

Optimality?

No

e.g. Arad→Sibiu→Rimnicu Virea→Pitesti→Bucharest is shorter!