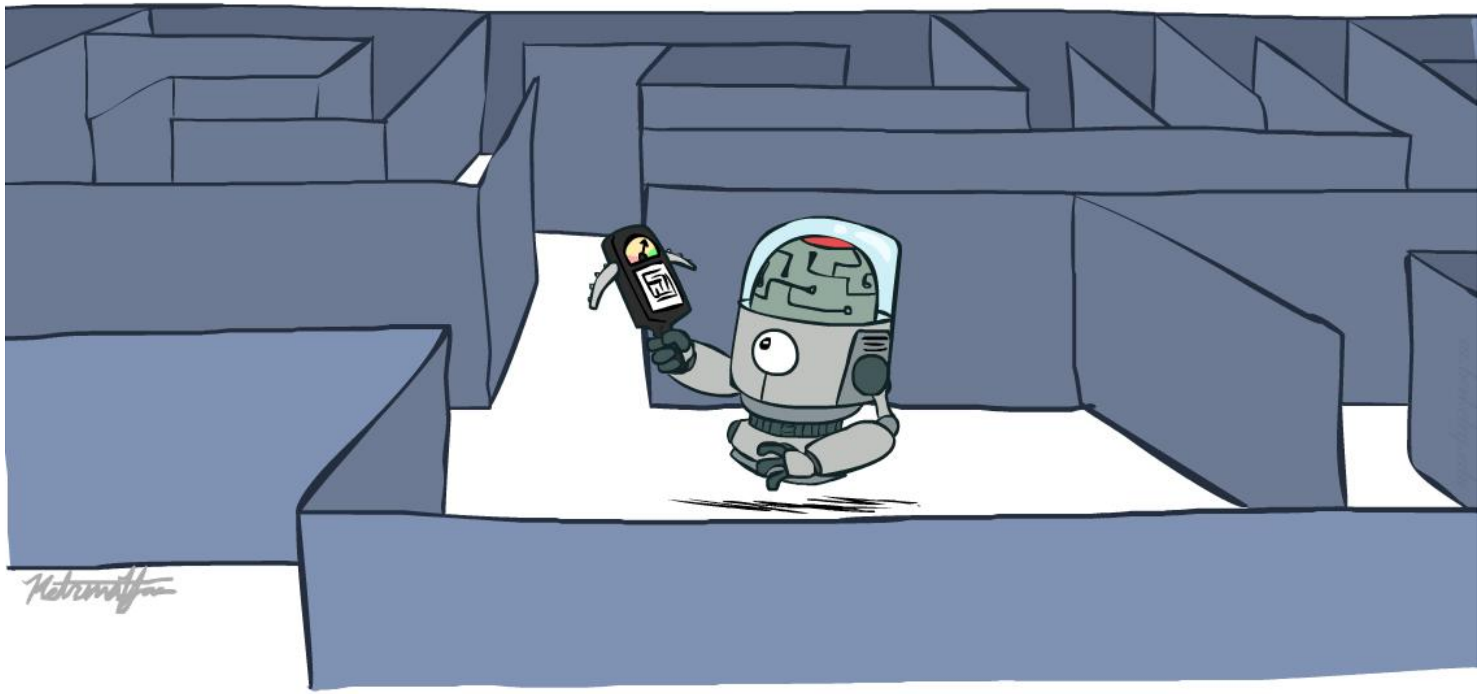
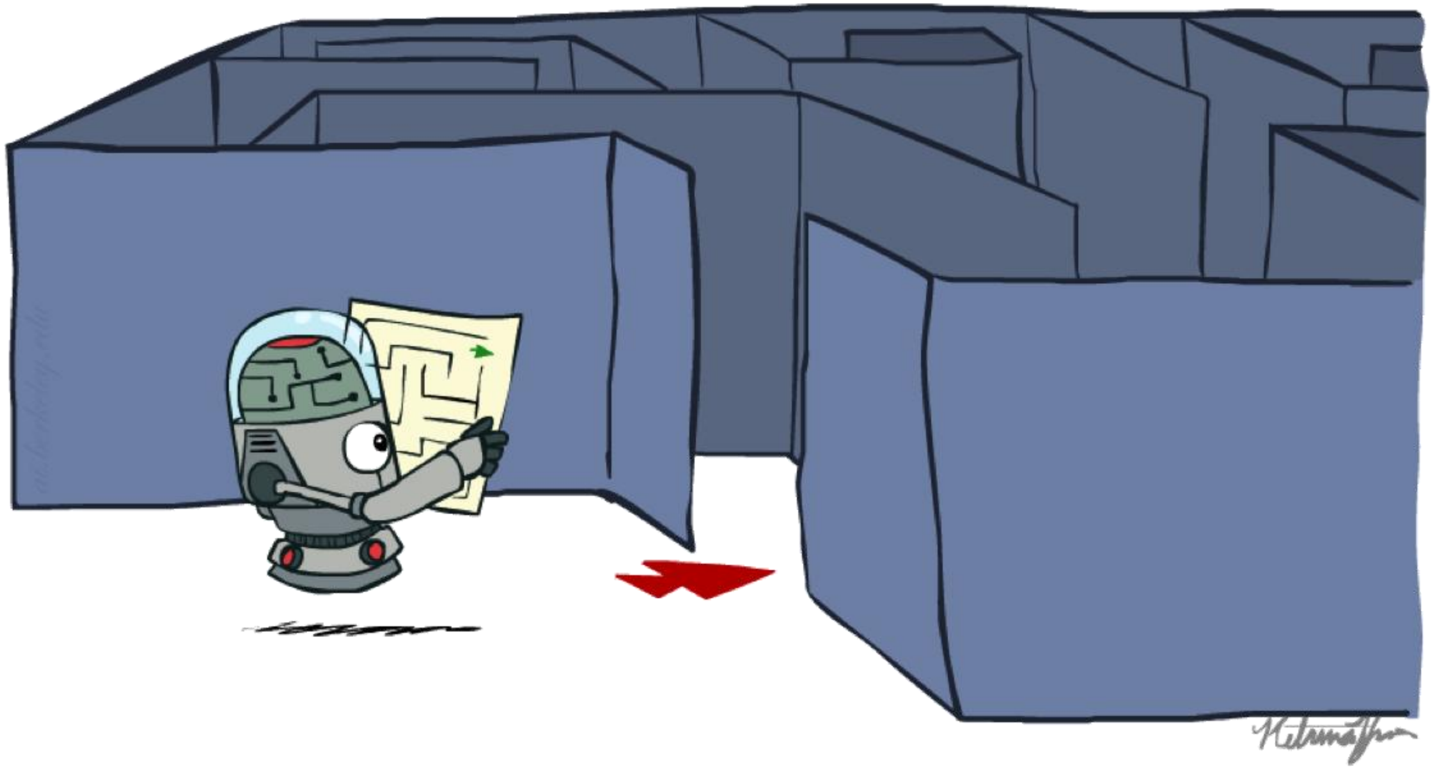
Artificial Intelligence

Search Continued



Slides by Dan Klein, Pieter Abbeel, Anca Dragan (ai.berkeley.edu)

Recap: Search

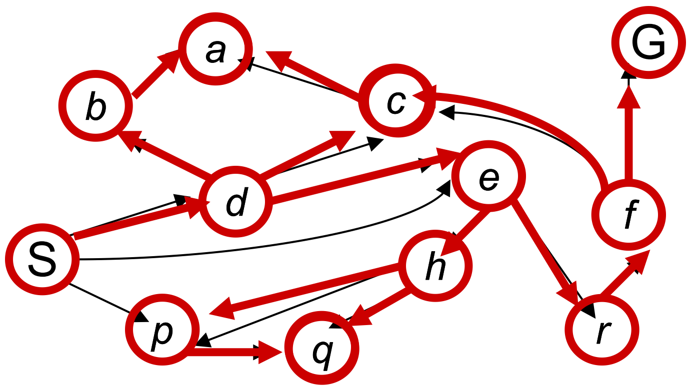


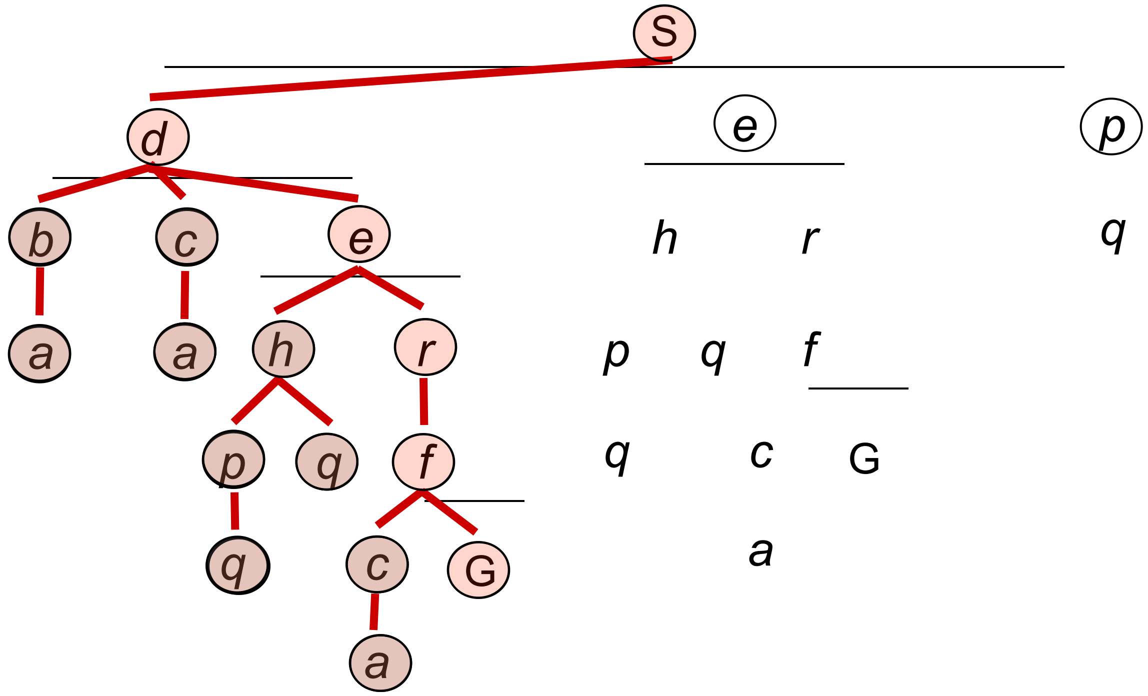
Depth-First (Tree) Search

Depth-First Search

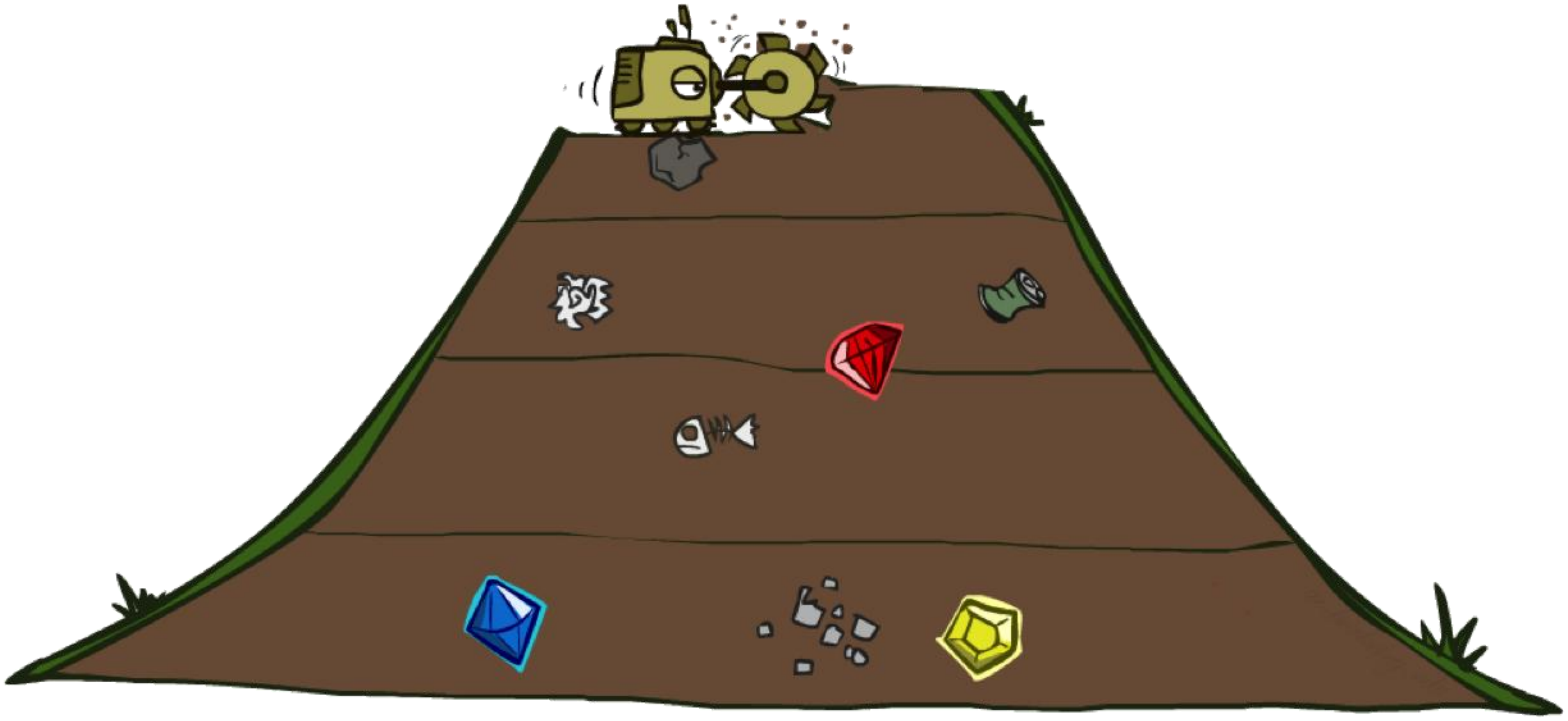
Strategy: expand a deepest node first

Implementation: Fringe is a LIFO stack





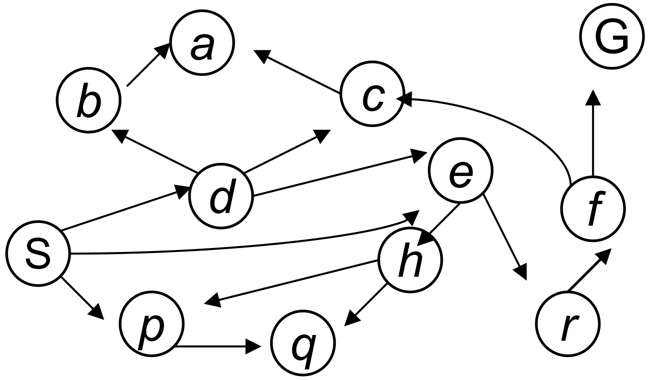
Breadth-First (Tree) Search

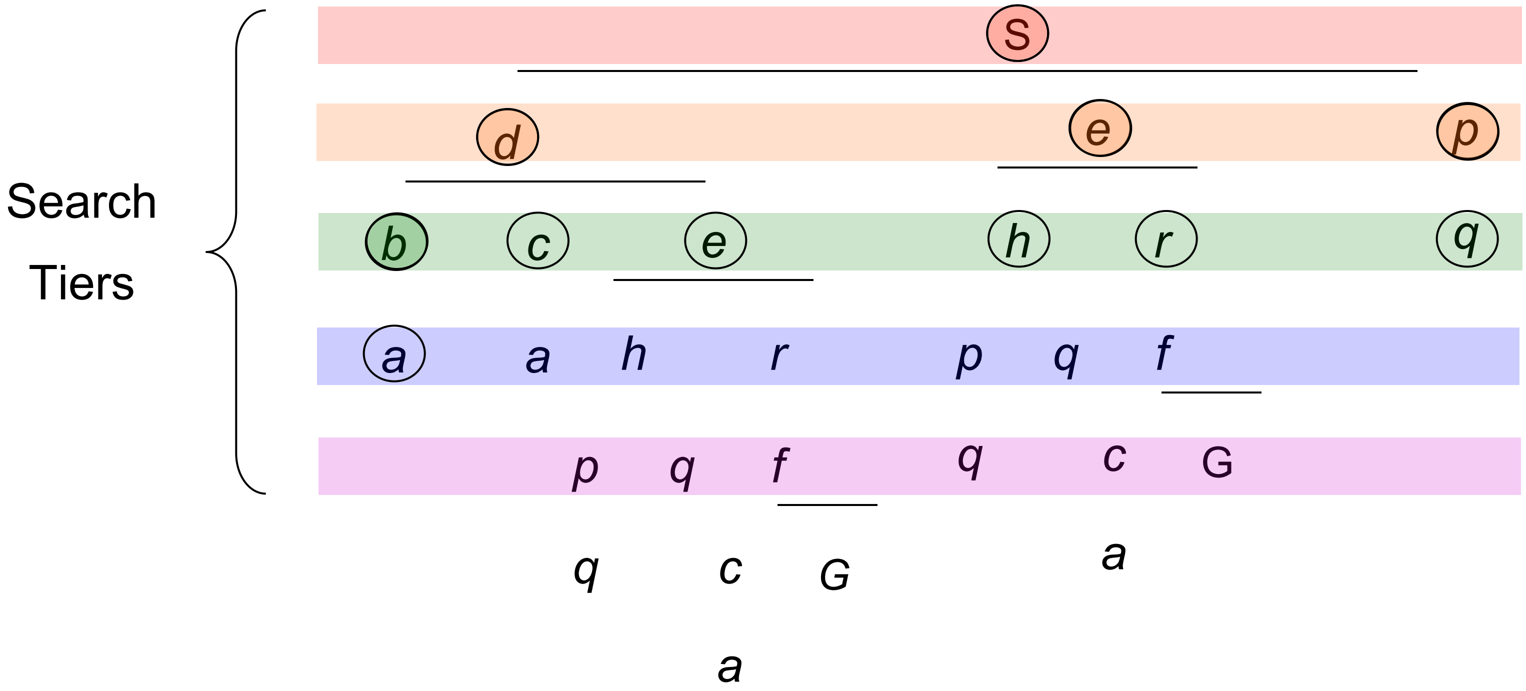


Breadth-First Search

Strategy: expand a shallowest node first

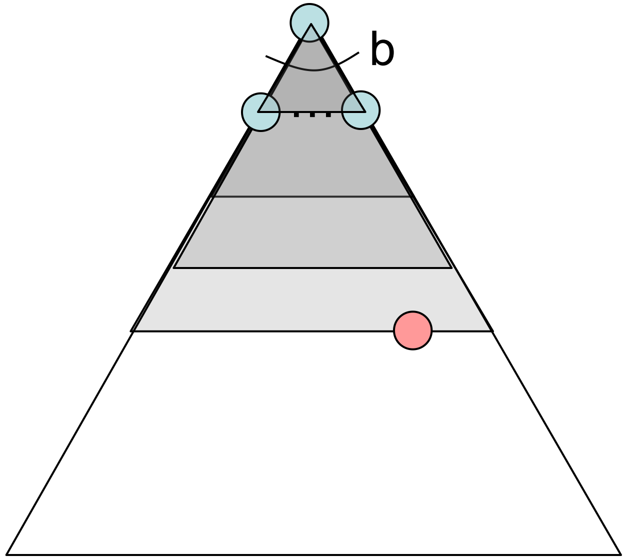
Implementation: Fringe is a FIFO queue





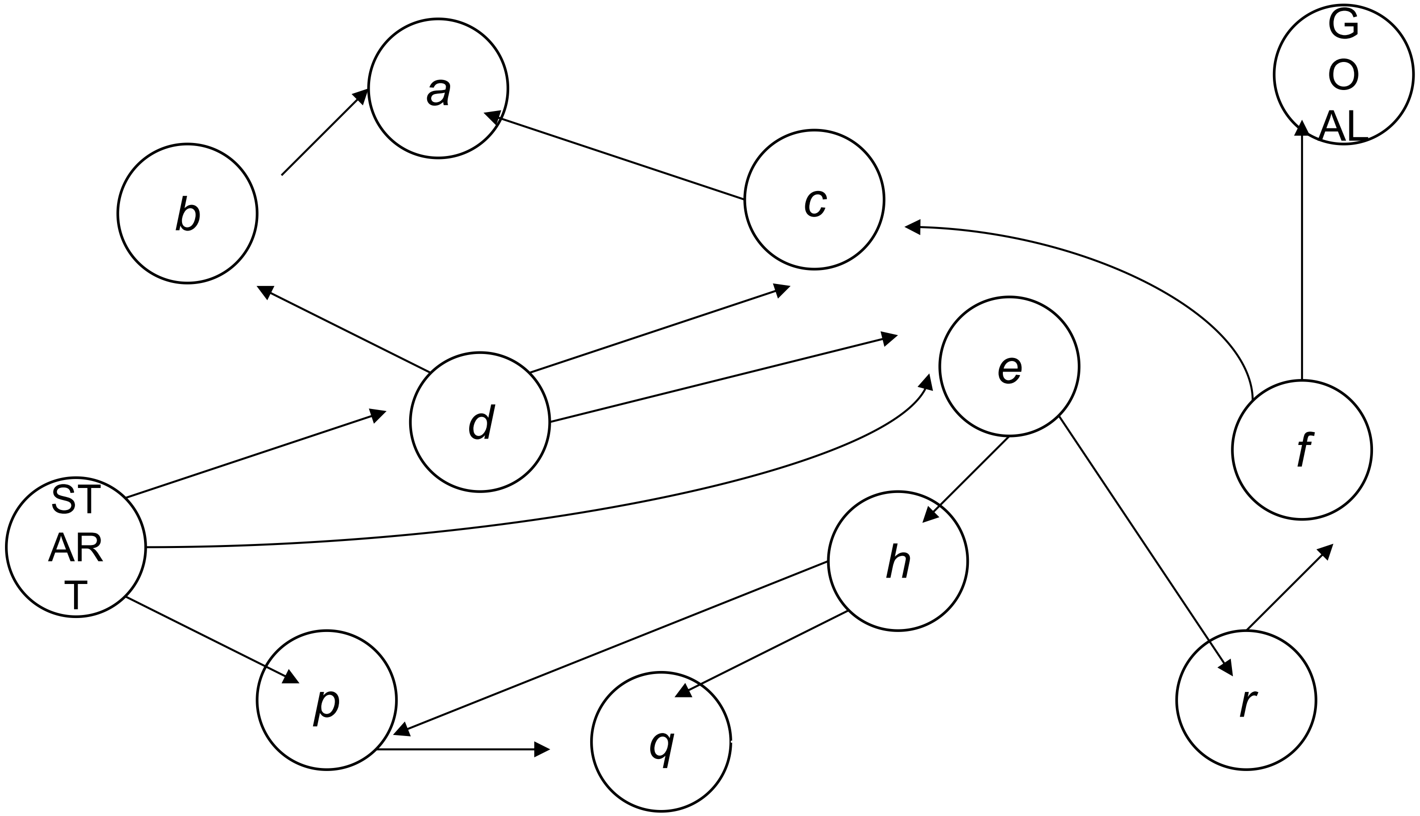
Iterative Deepening

- Idea: get DFS's space advantage with BFS's time / shallow-solution advantages
  - Run a DFS with depth limit 1. If no solution…
  - Run a DFS with depth limit 2. If no solution…
  - Run a DFS with depth limit 3. …..

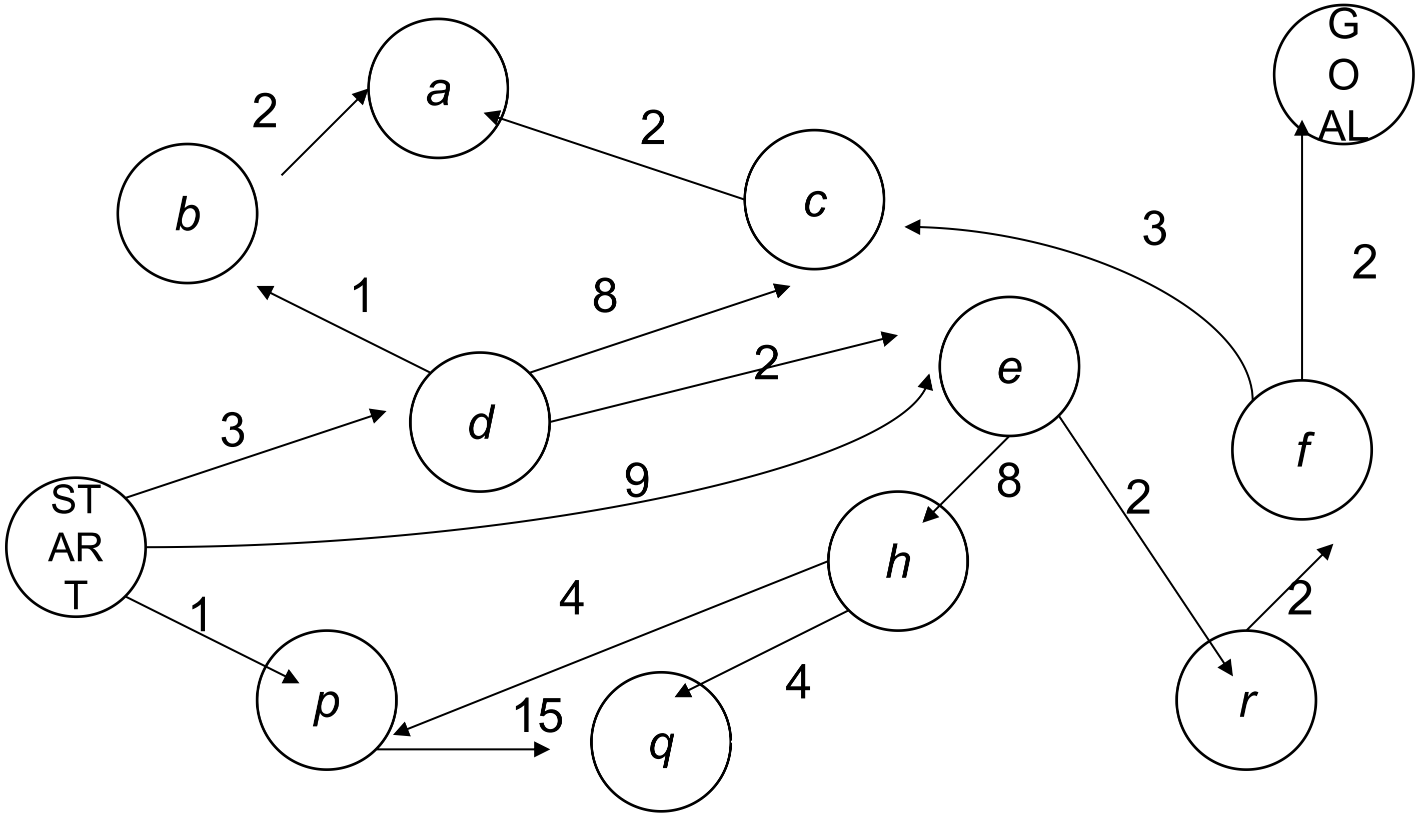


- Isn't that wastefully redundant?
  - Generally most work happens in the lowest level searched, so not so bad!

Cost-Sensitive Search



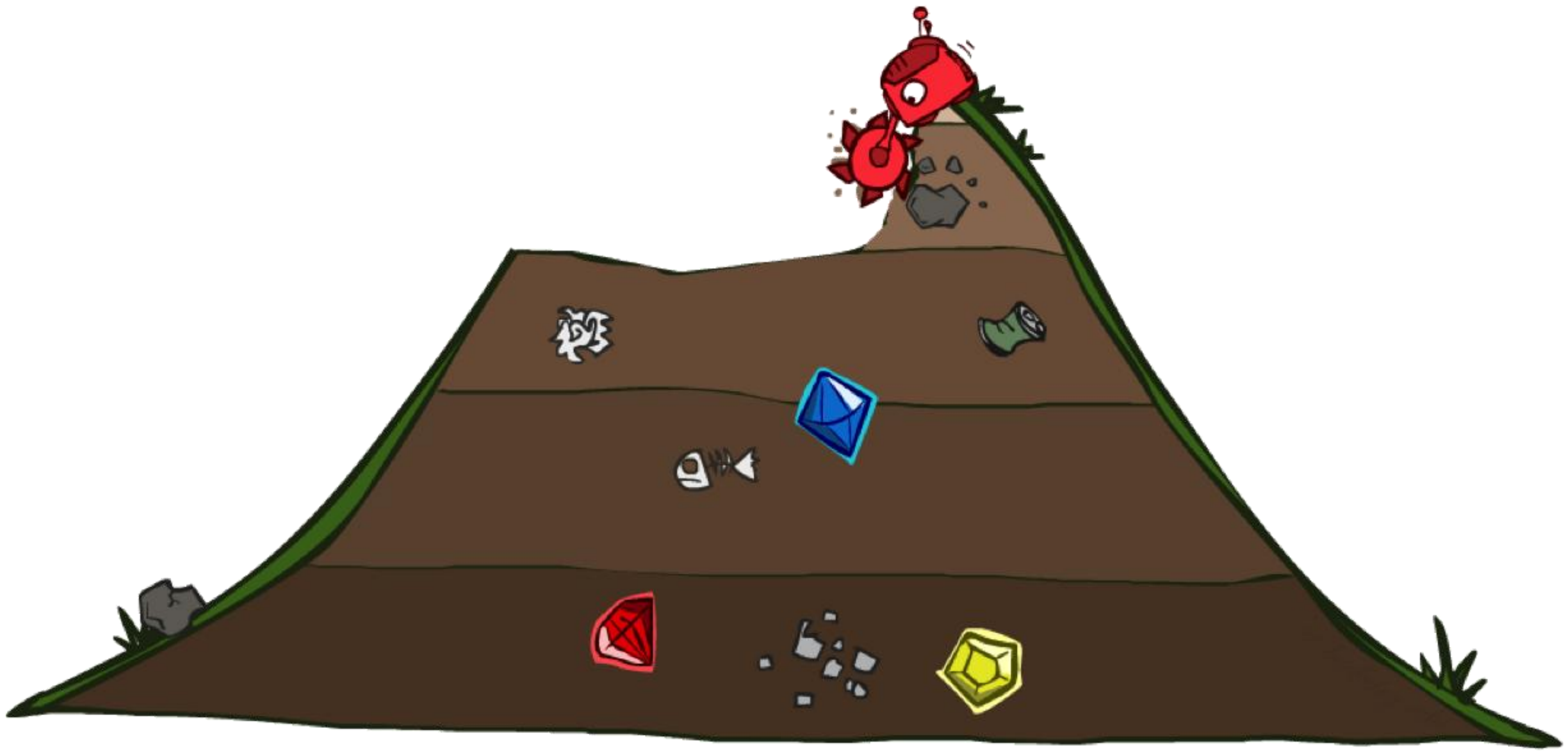
Cost-Sensitive Search



BFS finds the shortest path in terms of number of actions.
It does not find the least-cost path. We will now cover
a similar algorithm which does find the least-cost path.

How?

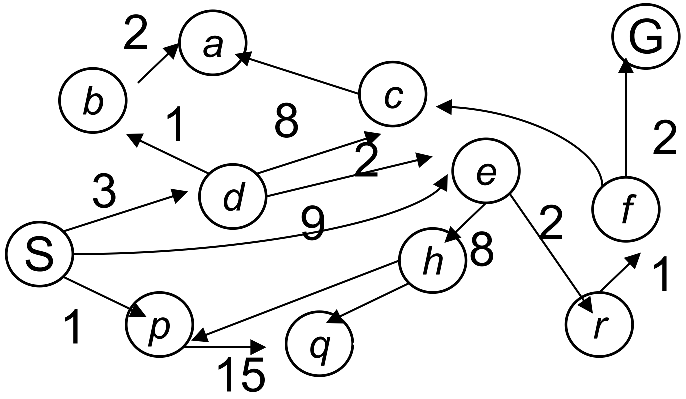
Uniform Cost Search



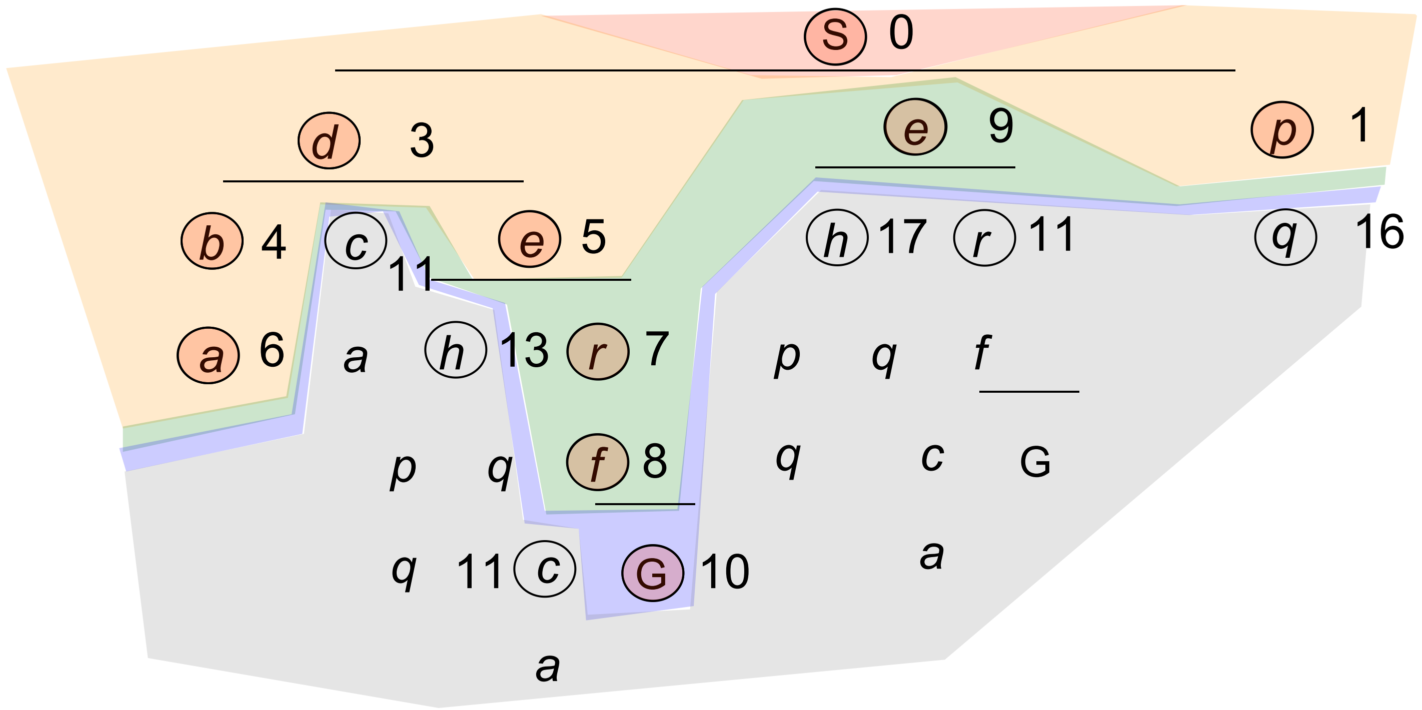
Uniform Cost Search

Strategy: expand a cheapest node first:

Fringe is a priority queue (priority: cumulative cost)

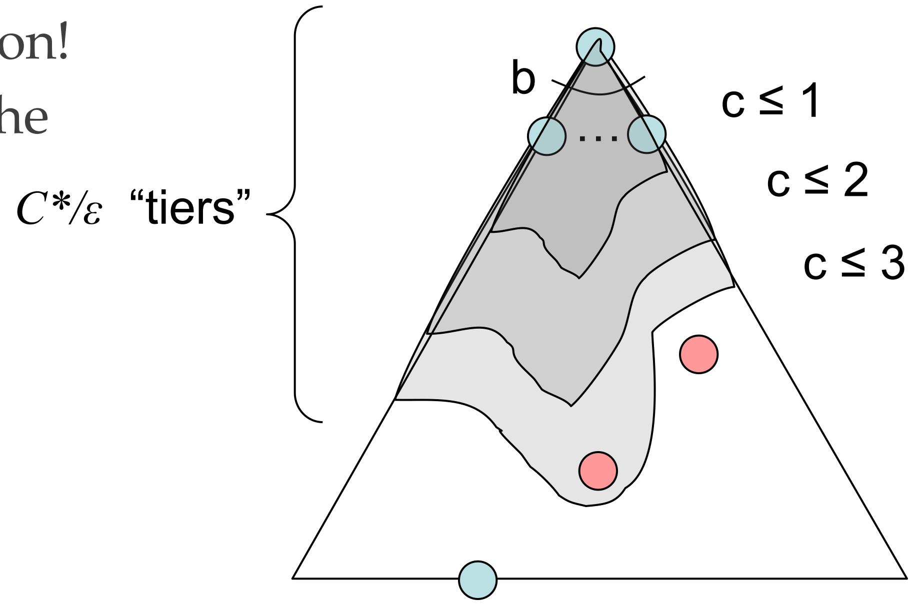


Cost contours



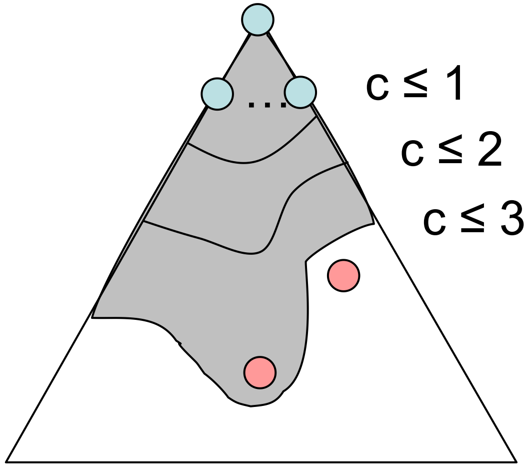
Uniform Cost Search (UCS) Properties

- What nodes does UCS expand?
  - Processes all nodes with cost less than cheapest solution!
  - If that solution costs C^* and arcs cost at least ε , then the "effective depth" is roughly C^*/ε
  - Takes time $O(b^{C^*/\varepsilon})$ (exponential in effective depth)
- How much space does the fringe take?
  - Has roughly the last tier, so $O(b^{C^*/\varepsilon})$
- Is it complete?
  - Assuming best solution has a finite cost and minimum arc cost is positive, yes! (if no solution, still need depth != ∞)
- Is it optimal?
  - Yes! (Proof via A*)



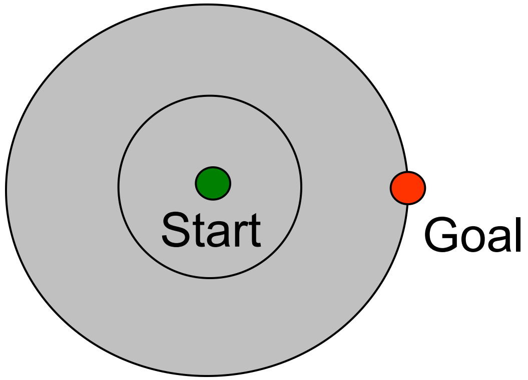
Uniform Cost Issues

- Remember: UCS explores increasing cost contours



- The good: UCS is complete and optimal!

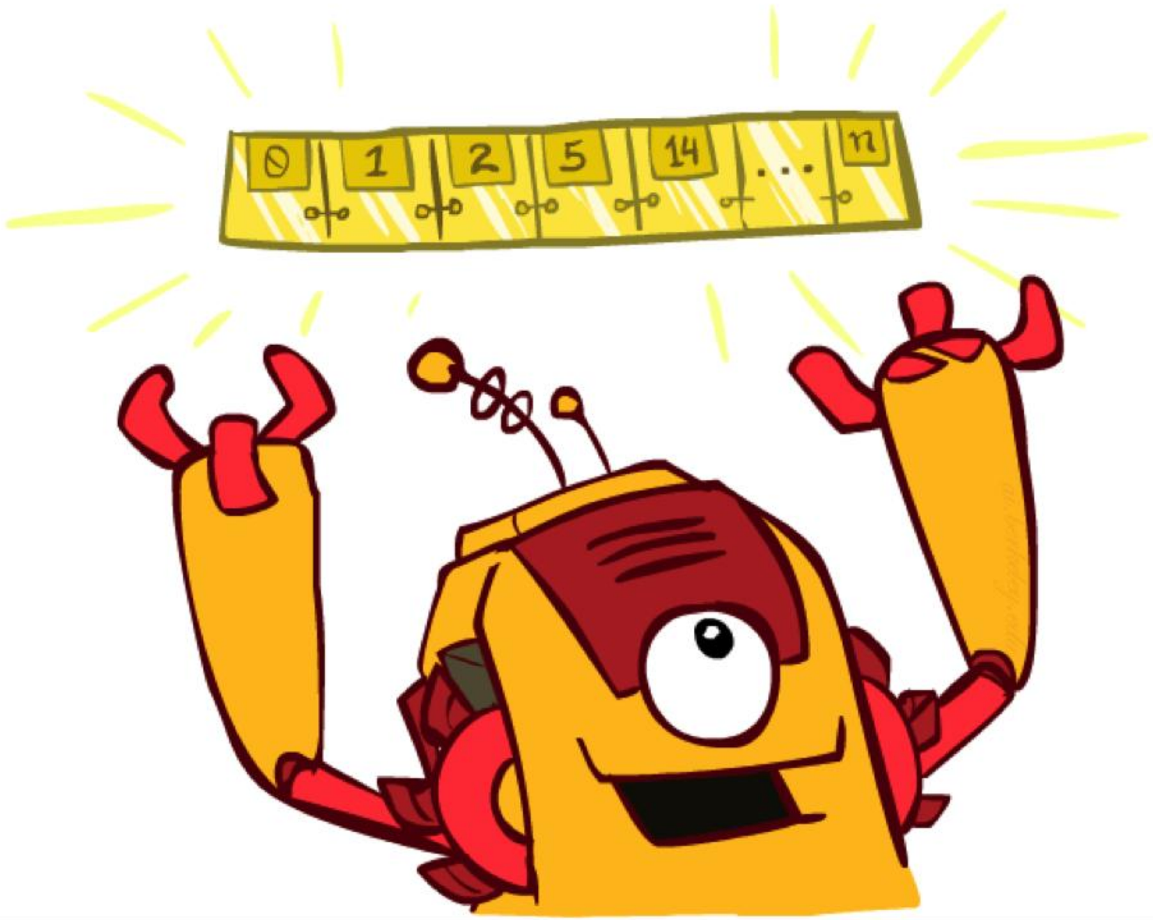
- The bad:
  - Explores options in every "direction"
  - No information about goal location



- We'll fix that soon!

The One Queue

- All these search algorithms are the same except for fringe strategies
  - Conceptually, all fringes are priority queues (i.e. collections of nodes with attached priorities)
  - Practically, for DFS and BFS, you can avoid the log(n) overhead from an actual priority queue, by using stacks and queues
  - Can even code one implementation that takes a variable queuing object



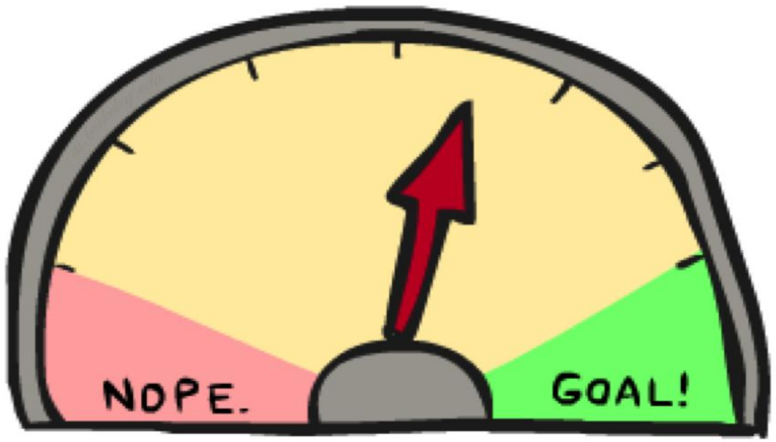
Same search function, pass different search strategies

```
function TREE-SEARCH( problem, strategy) returns a solution, or failure
    initialize the search tree using the initial state of problem
    loop do
        if there are no candidates for expansion then return failure
        choose a leaf node for expansion according to strategy
        if the node contains a goal state then return the corresponding solution
        else expand the node and add the resulting nodes to the search tree
    end
```

Up next: Informed Search

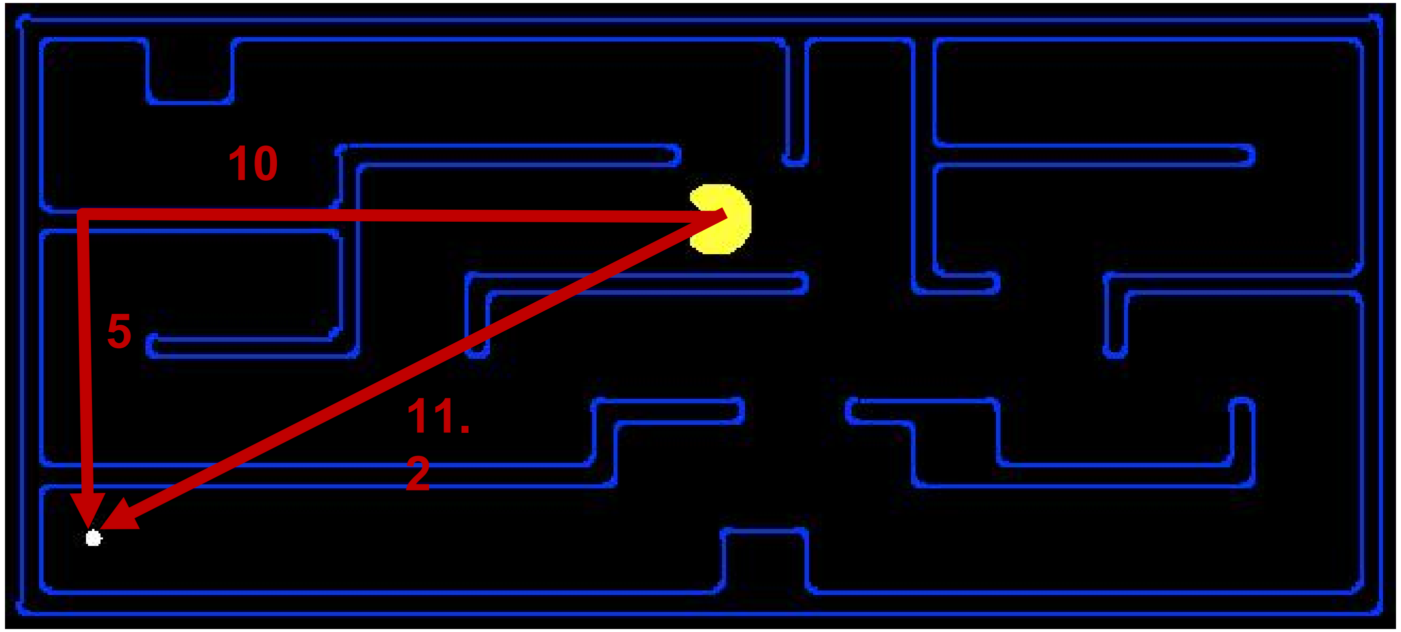
- Uninformed Search (Blind)
  - DFS
  - BFS
  - UCS

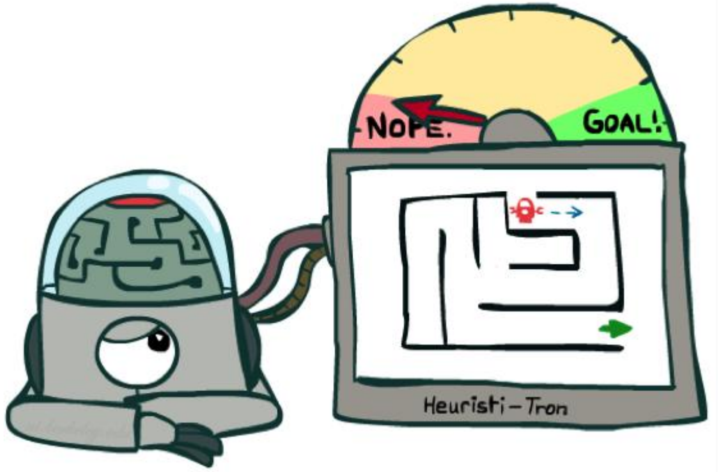
- Informed Search (has Info about where goal is)
  - Heuristics
  - Greedy Search
  - A* Search
  - Graph Search

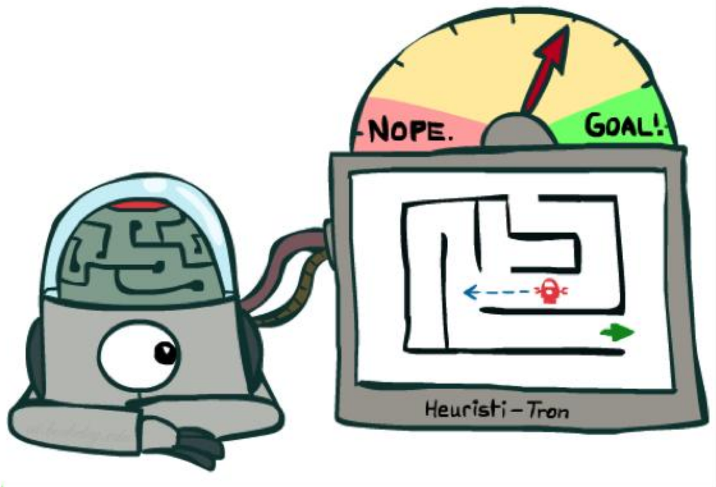


Search Heuristics

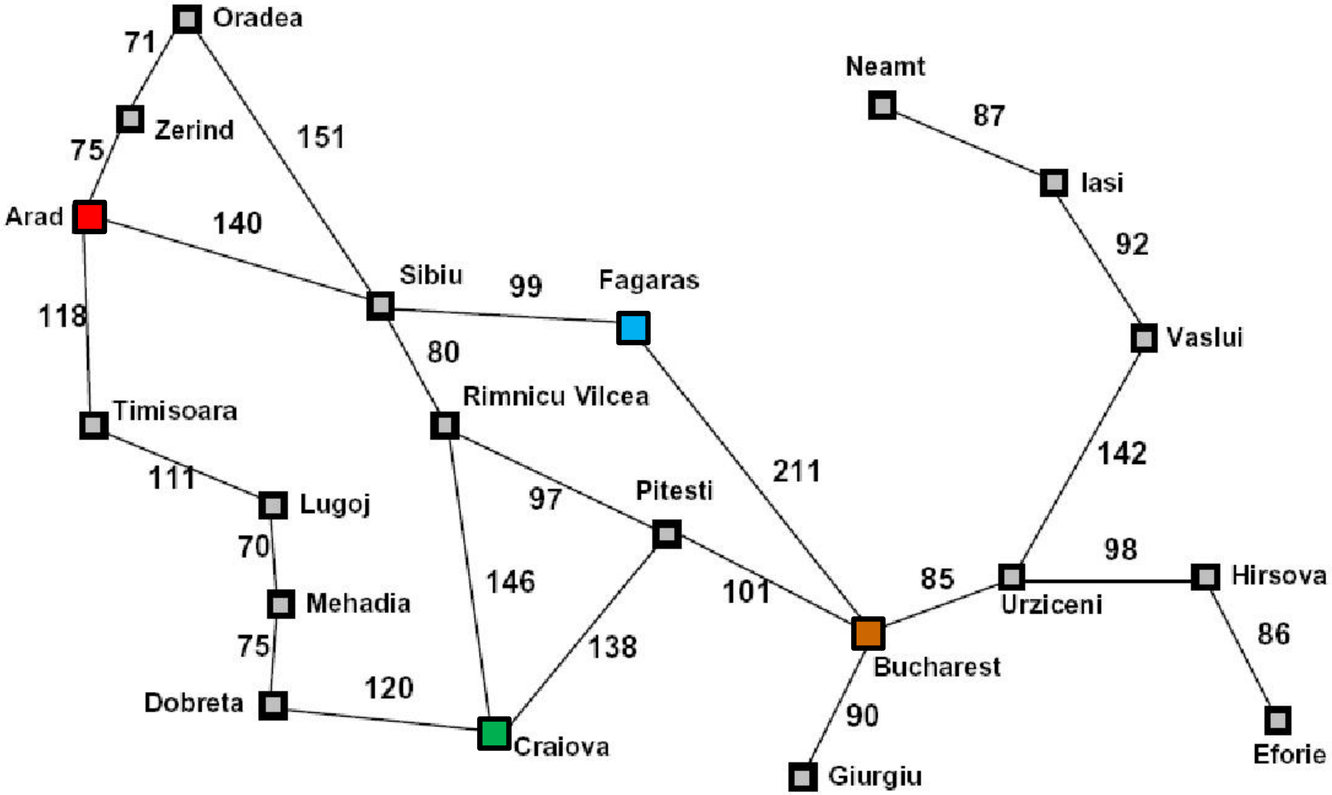
- A heuristic is:
  - A function that *estimates* how close a state is to a goal
  - Designed for a particular search problem
  - Pathing?
  - Examples: Manhattan distance, Euclidean distance for pathing







Example: Heuristic Function



Straight line distance

Straight−line distance to Bucharest

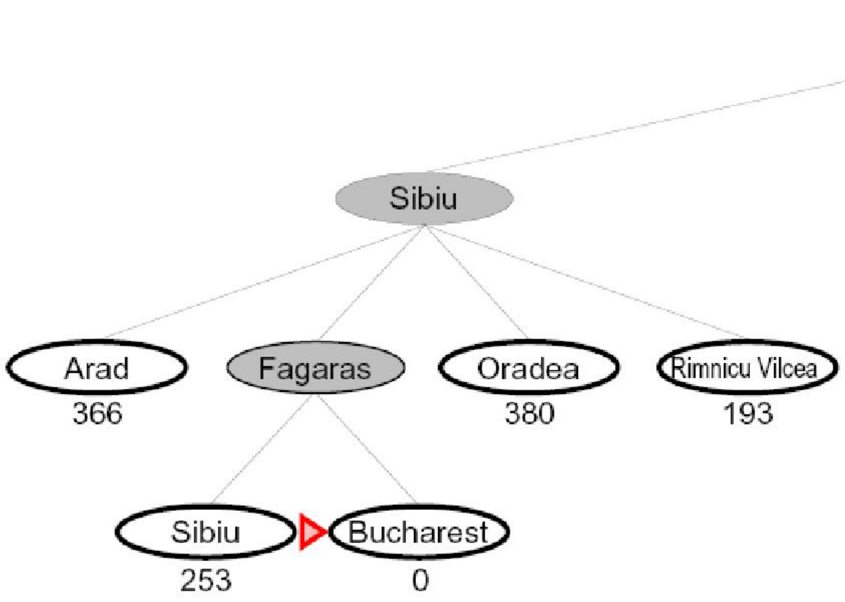
Arad	366
Bucharest	0
Craiova	160
Dobreta	242
Eforie	161
Fagaras	178
Giurgiu	77
Hirsova	151
Iasi	226
Lugoj	244
Mehadia	241
Neamt	234
Oradea	380
Pitesti	98
Rimnicu Vilcea	193
Sibiu	253
Timisoara	329
Urziceni	80
Vaslui	199
Zerind	374

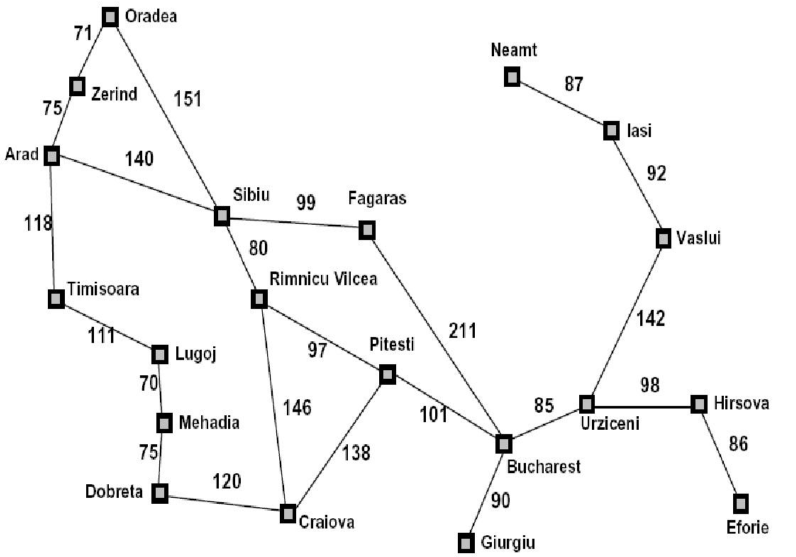
h(x)

Greedy Search

Greedy Search

- Expand the node that seems closest…





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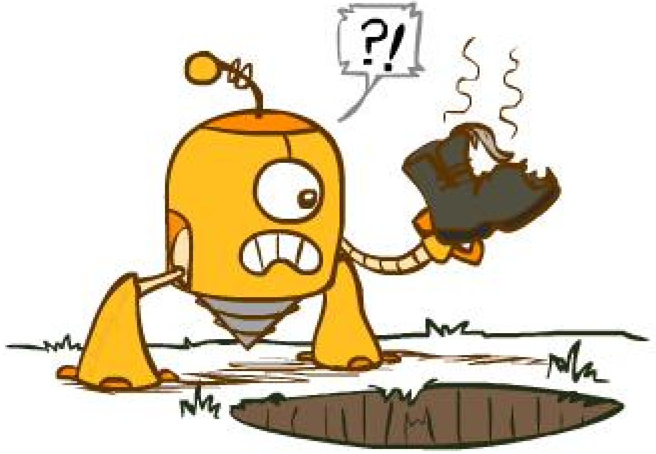
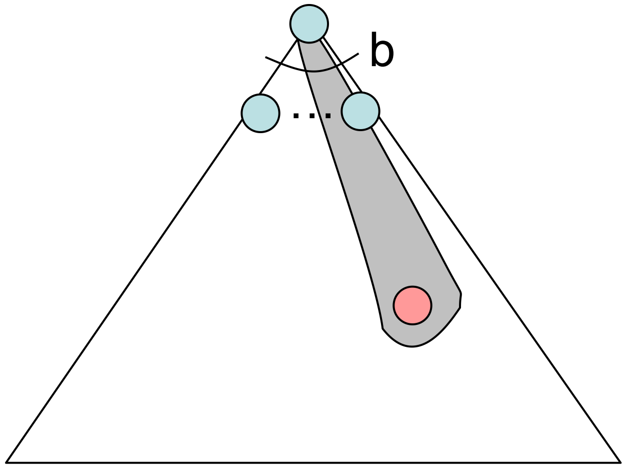


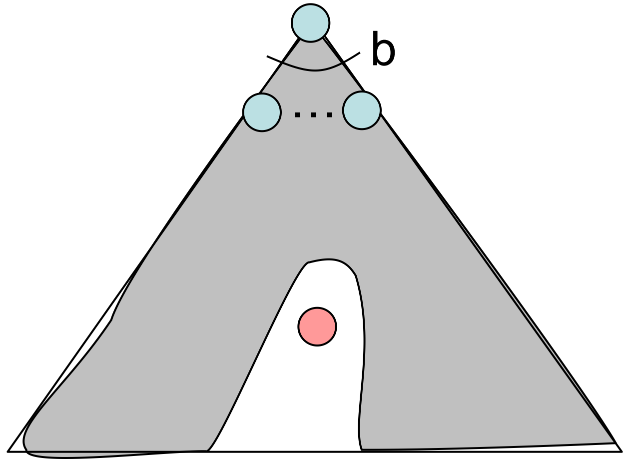
- Is it optimal?
  - No. Resulting path to Bucharest is not the shortest!

Greedy Search

- Strategy: expand a node that you think is closest to a goal state
  - Heuristic: estimate of distance to nearest goal for each state



- A common case:
  - Best-first takes you straight to the (wrong) goal



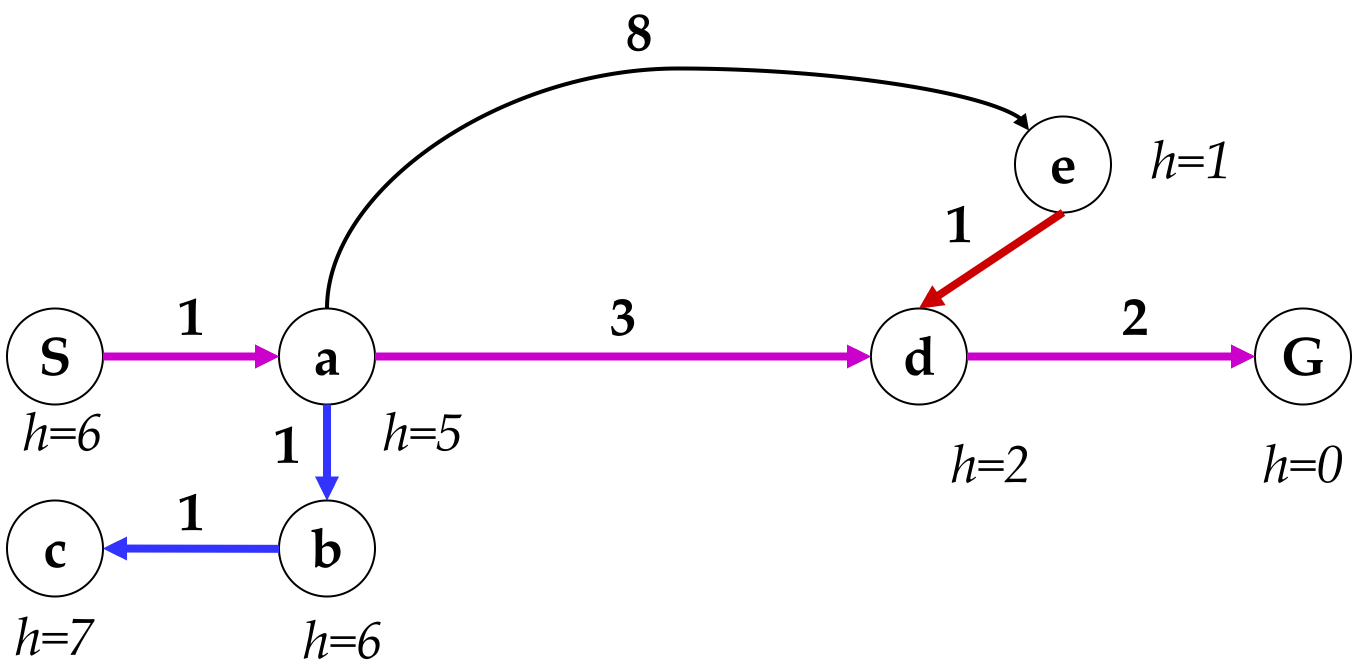
- Worst-case: like a badly-guided DFS

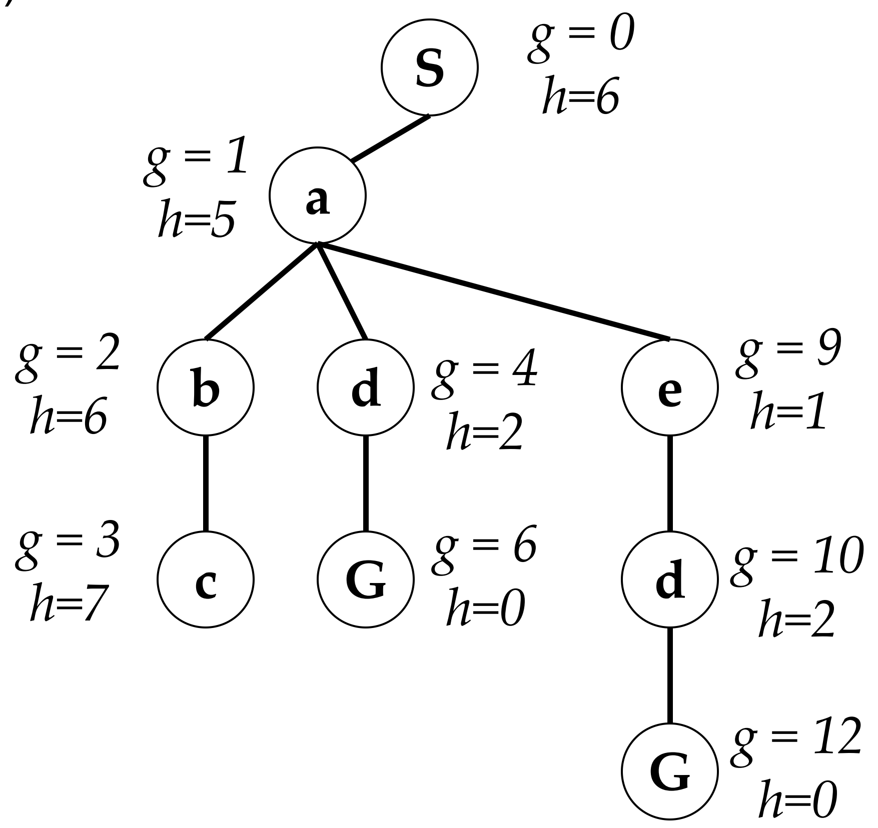
A* Search

A* Search

Combining UCS and Greedy

- Uniform-cost orders by path cost, or *backward cost* g(n)
- Greedy orders by goal proximity, or *forward cost* h(n)

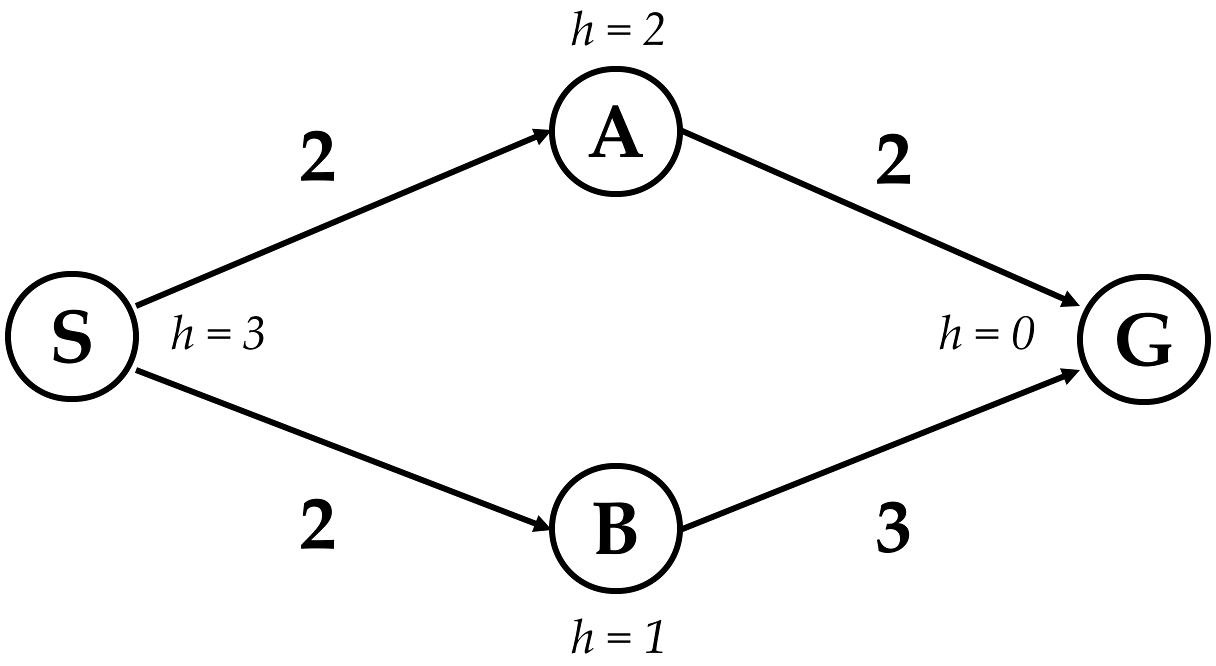




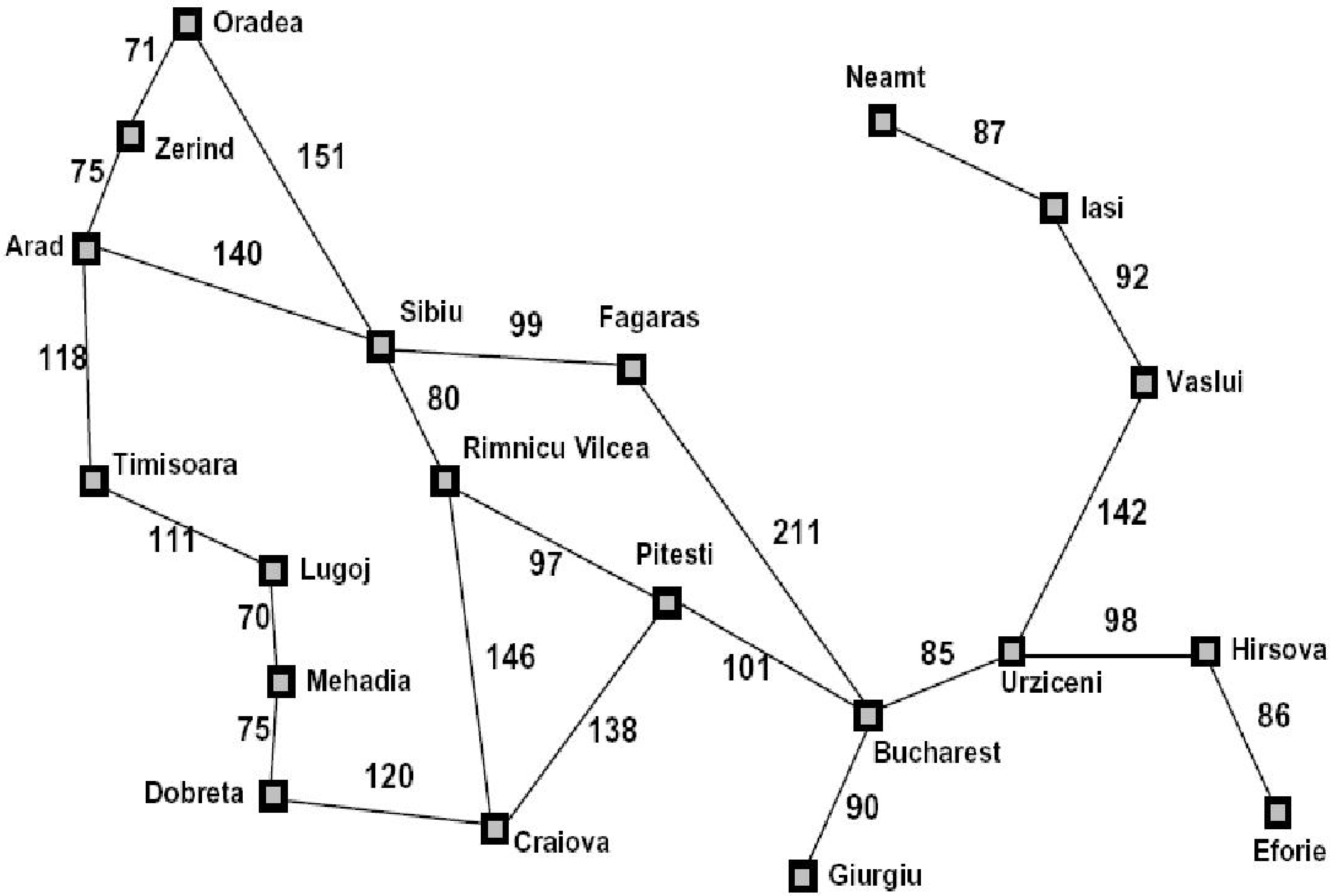
- A* Search orders by the sum: f(n) = g(n) + h(n)

When should A* terminate?

- Should we stop when we enqueue a goal?



- No: only stop when we dequeue a goal



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to Bucharest

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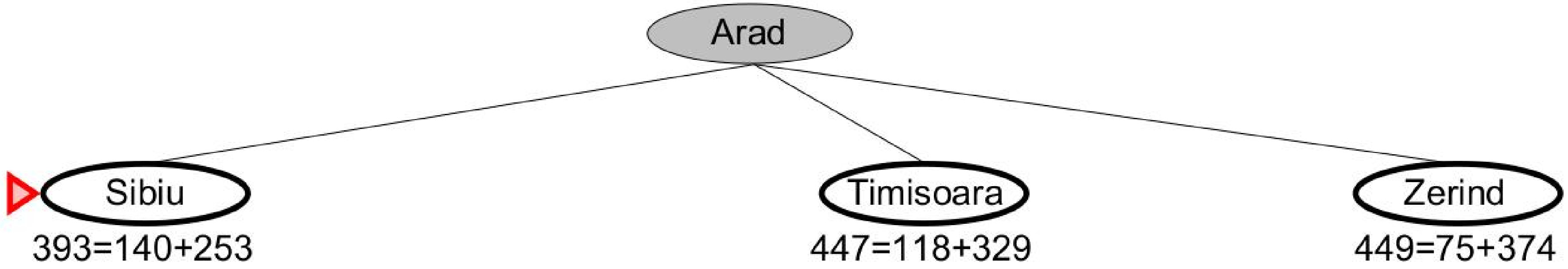
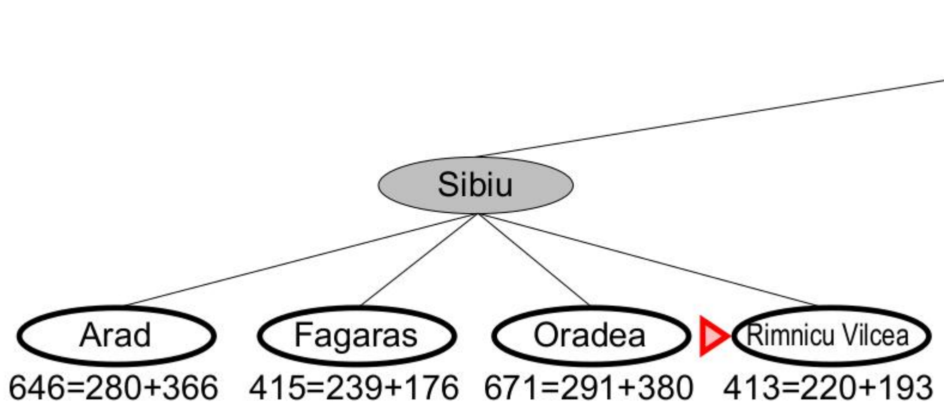
A* search example

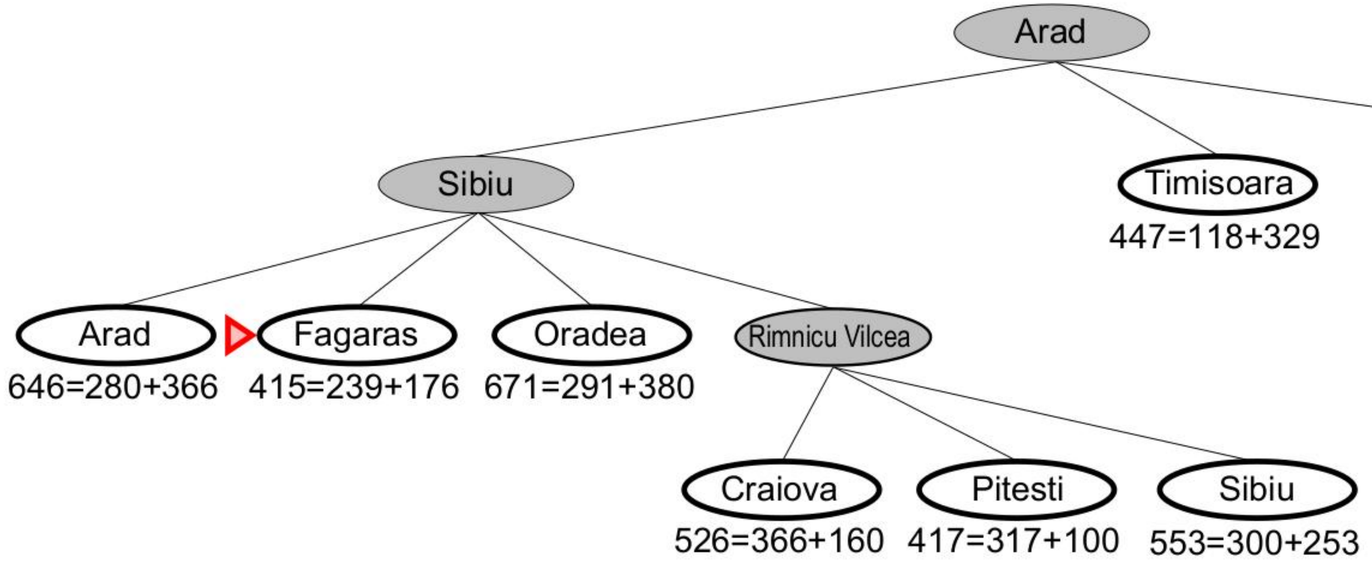
A* search example



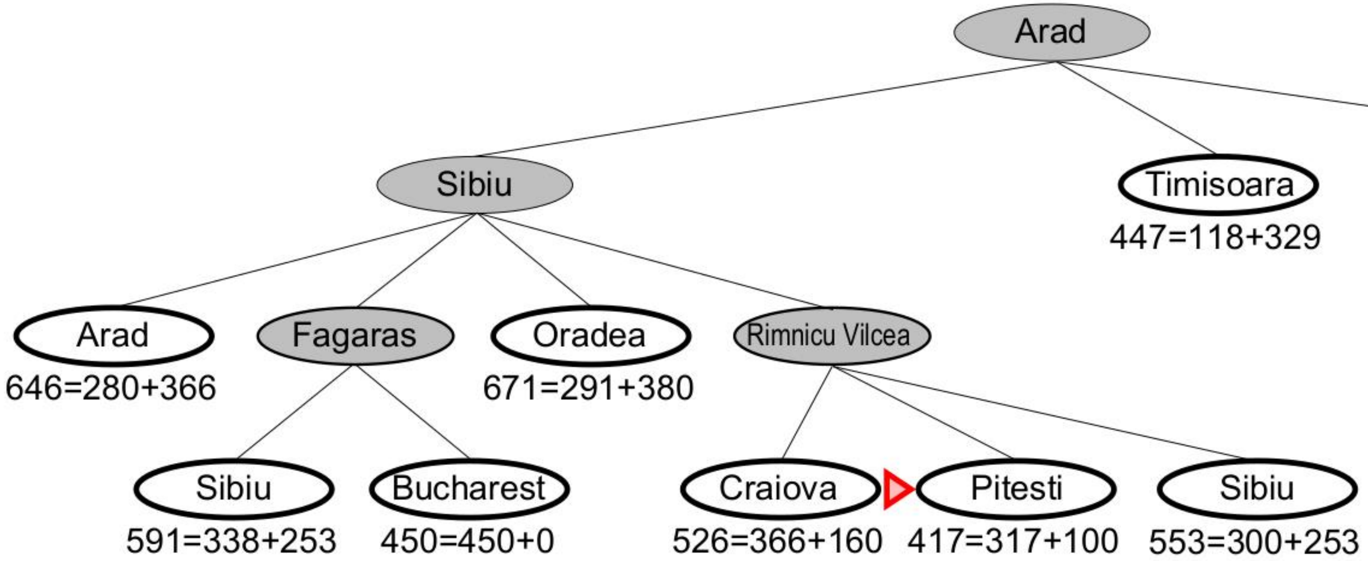
A* search example



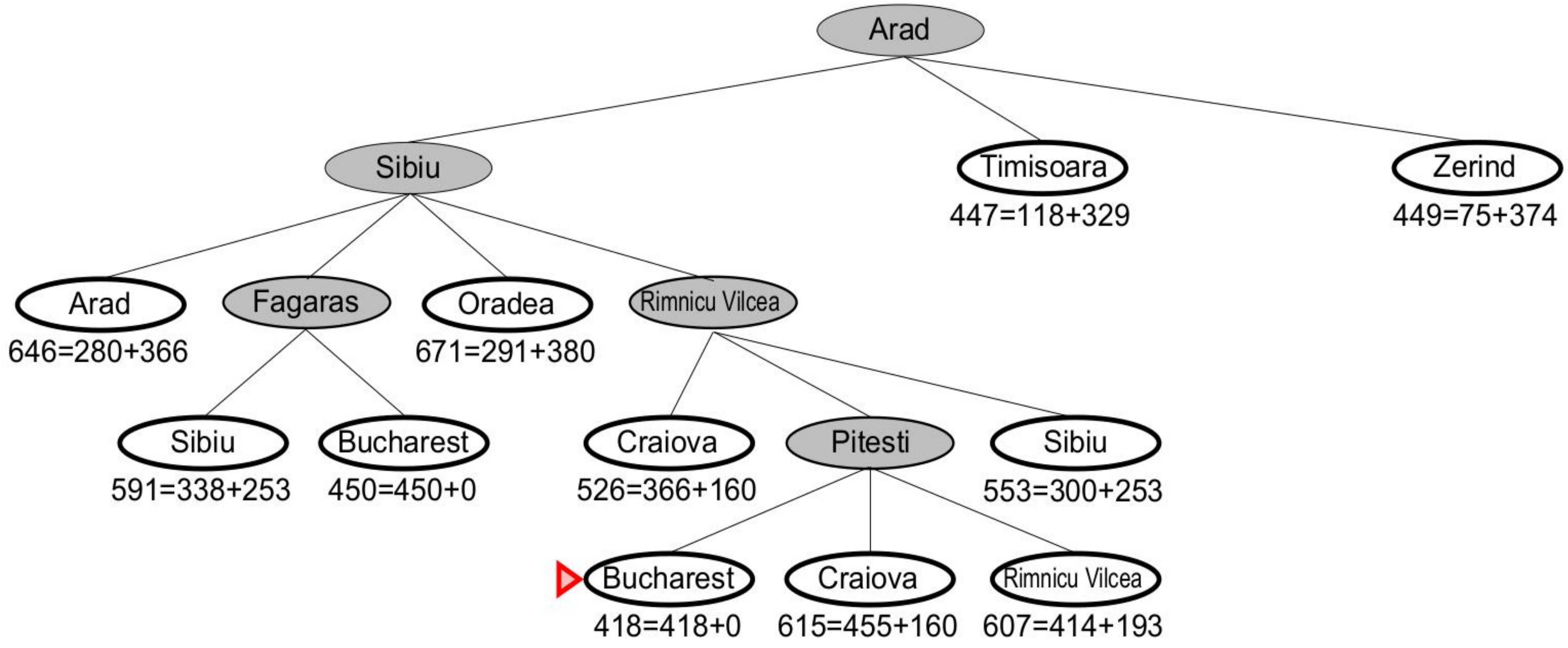
A^* search example



A* search example



A* search example

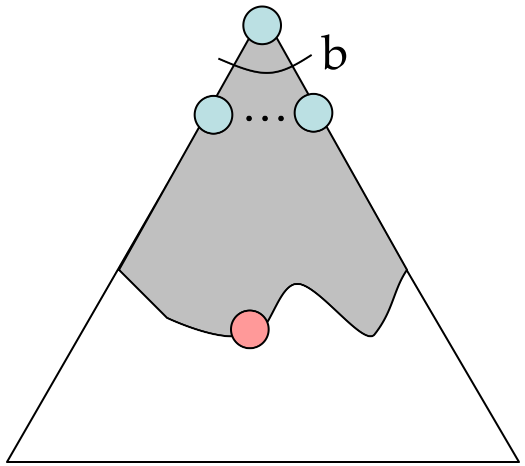


http://aispace.org/search/

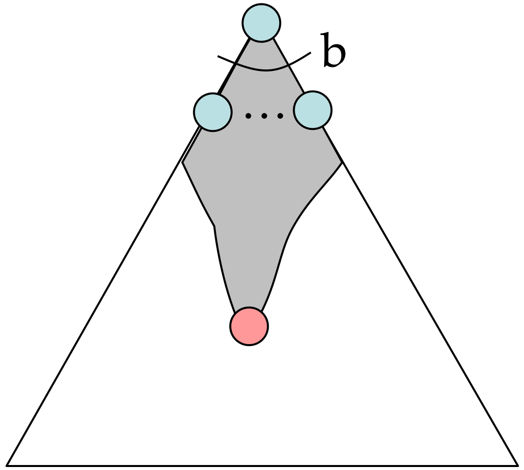
- We stop when the node with the lowest f-value is a goal state.
- Is this guaranteed to find the shortest path?

Properties of A*

Uniform-Cost

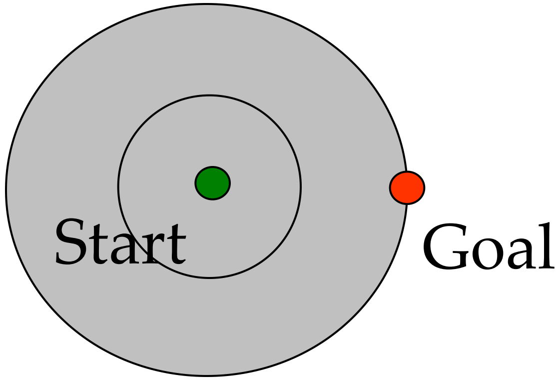


A*

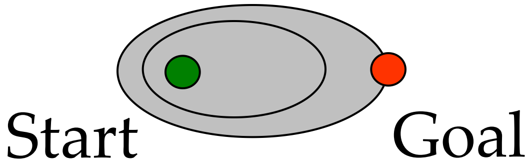


UCS vs A* Contours

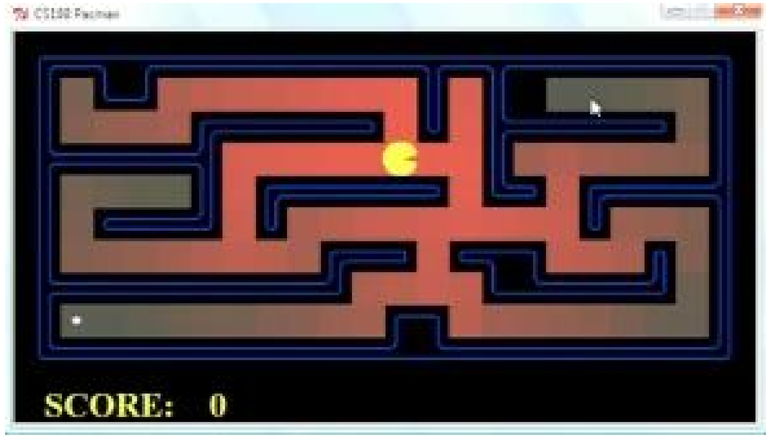
- Uniform-cost expands equally in all "directions"

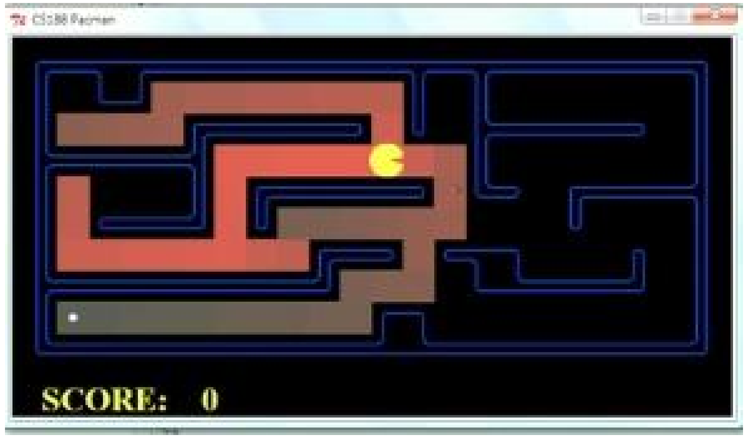


- A* expands mainly toward the goal, but does hedge its bets to ensure optimality



Comparison





Greedy

Uniform Cost

A*

A* Applications

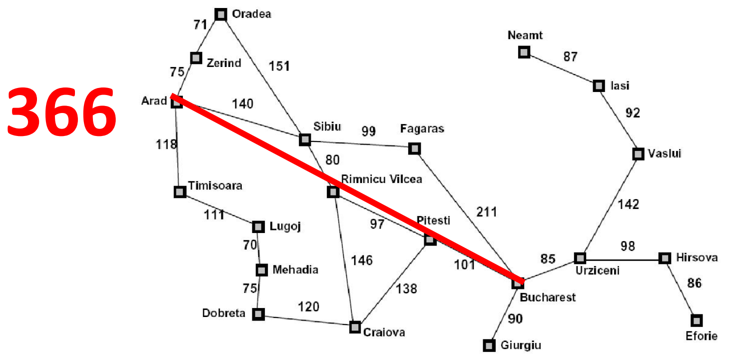
- Video games
- Pathing / routing problems
- Resource planning problems
- Robot motion planning
- Language analysis
- Machine translation
- Speech recognition
- …

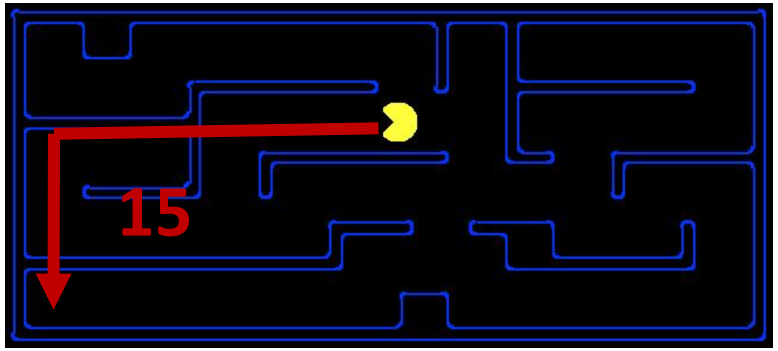
Creating Heuristics

Creating Heuristics

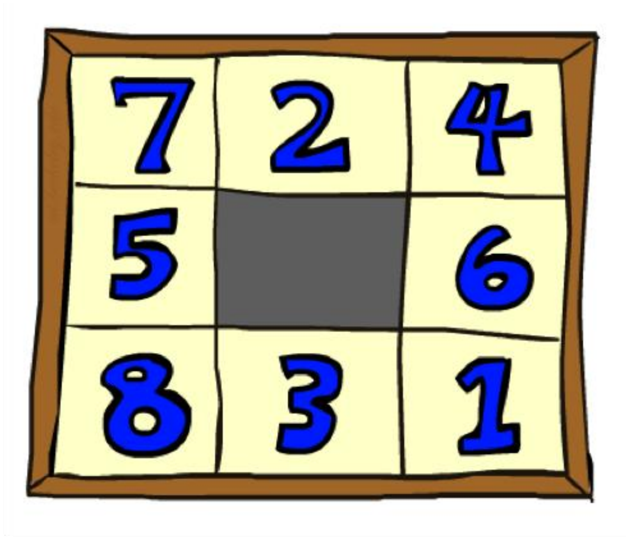
- Most of the work in solving hard search problems optimally is in coming up with heuristics

- Often, heuristics are solutions to *relaxed problems*, where new actions are available

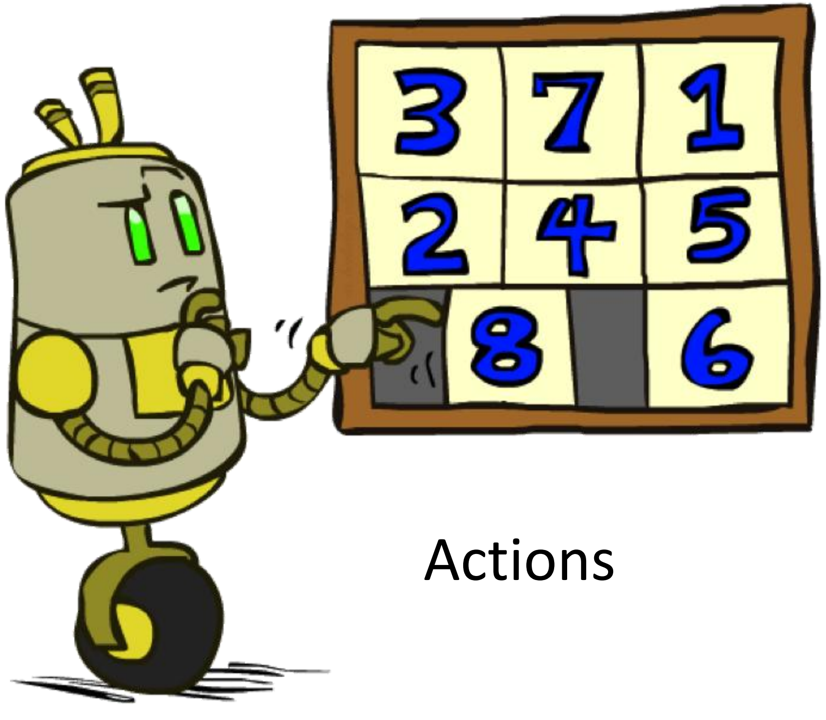




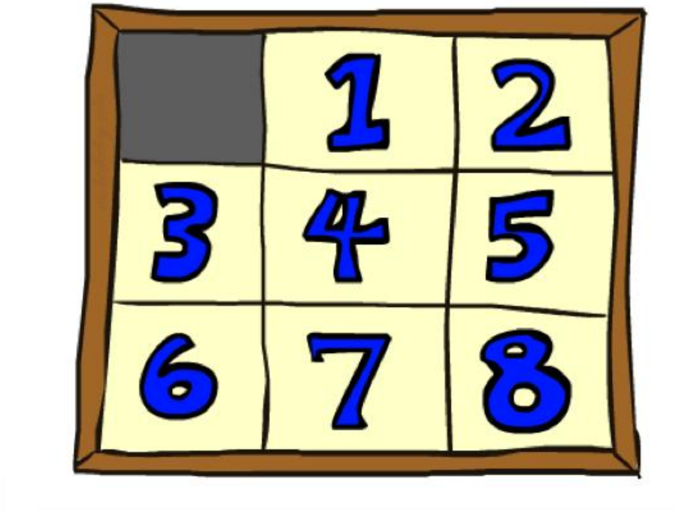
Example: 8 Puzzle



Start State



Actions



Goal State

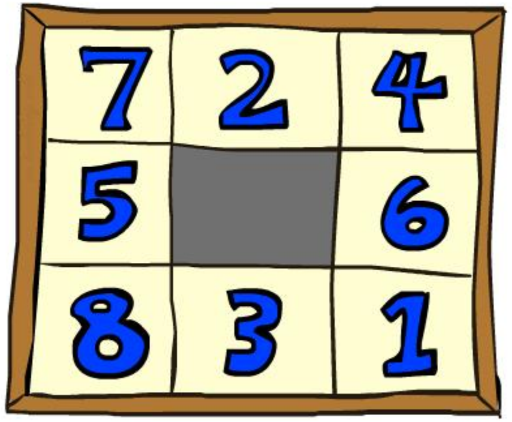
- What are the states?
- How many states?
- What are the actions?
- How many successors from the start state?
- What should the costs be?

heuristics?

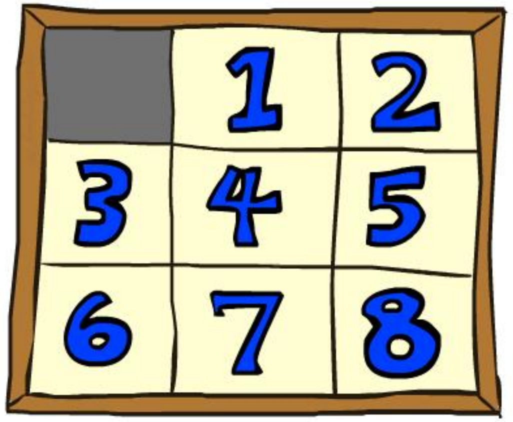
8 Puzzle I

- Heuristic: Number of tiles misplaced

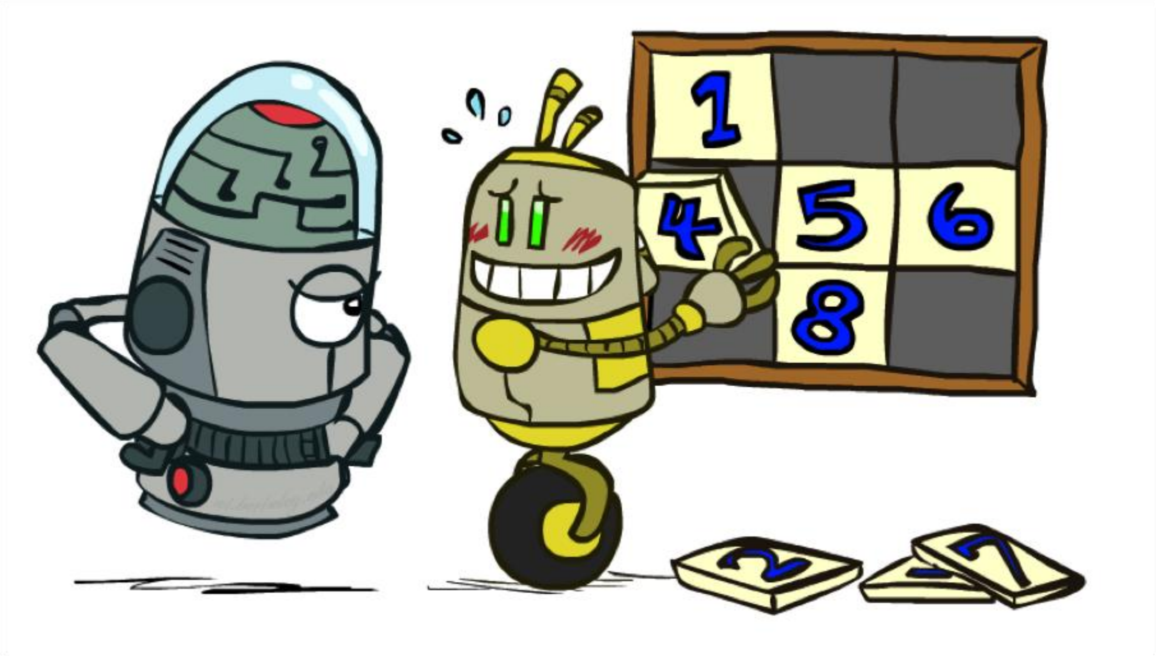
- h(start) =8
- This is a *relaxed-problem* heuristic



Start State



Goal State



	Average nodes expanded when the optimal path has…		
	…4 steps	…8 steps	…12 steps
UCS	112	6,300	3.6×10^6
TILES	13	39	227

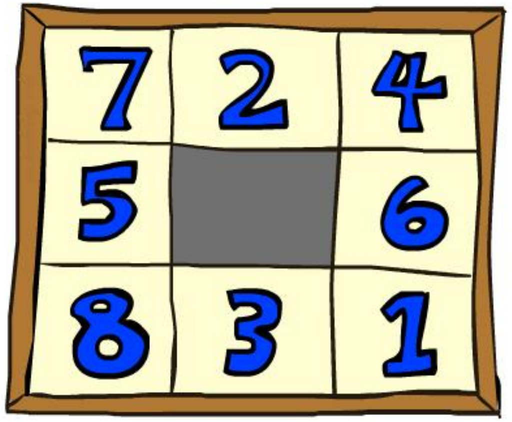
Statistics from Andrew Moore

8 Puzzle II

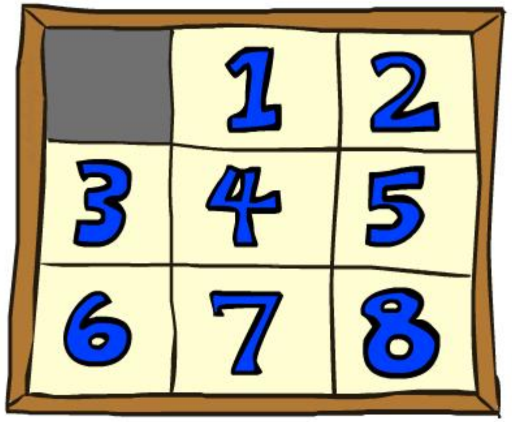
- What if we had an easier 8-puzzle where any tile could slide any direction at any time, ignoring other tiles?

- Total *Manhattan* distance

- h(start) = 3 + 1 + 2 + … = 18



Start State



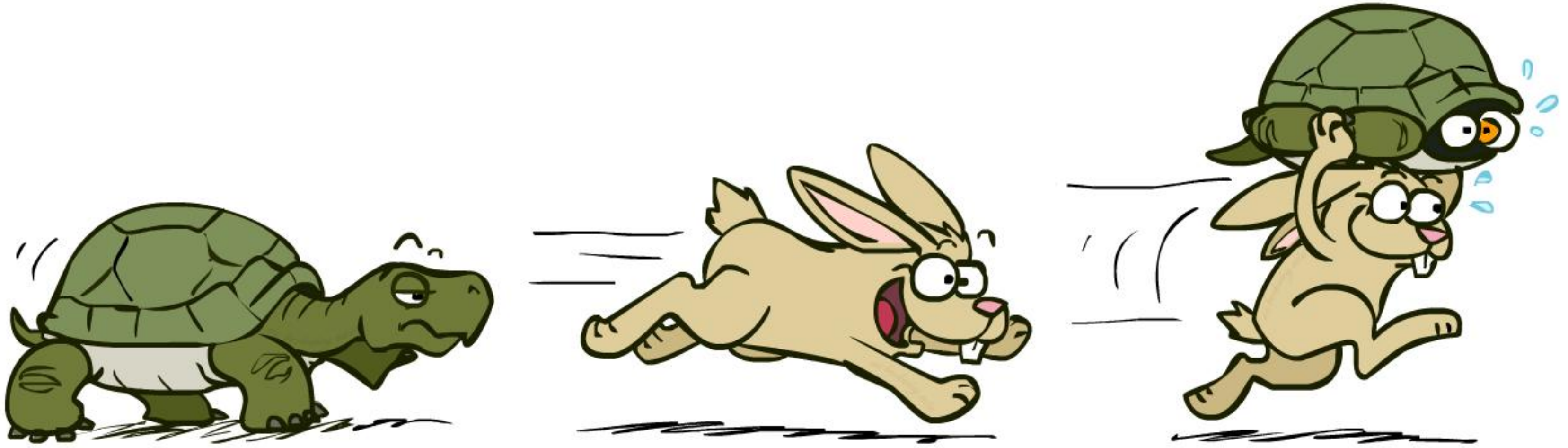
Goal State

	Average nodes expanded when the optimal path has…		
	…4 steps	…8 steps	…12 steps
TILES	13	39	227
MANHATTAN	12	25	73

A*: Summary

A*: Summary

- A* uses both backward costs and (estimates of) forward costs
- A* is optimal with consistent heuristics
- Heuristic design is key: often use relaxed problems



Tree Search Pseudo-Code

```
function TREE-SEARCH(problem, fringe) return a solution, or failure
    fringe ← INSERT(MAKE-NODE(INITIAL-STATE[problem]), fringe)
    loop do
        if fringe is empty then return failure
        node ← REMOVE-FRONT(fringe)
        if GOAL-TEST(problem, STATE[node]) then return node
        for child-node in EXPAND(STATE[node], problem) do
            fringe ← INSERT(child-node, fringe)
        end
    end
```

The One Queue

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