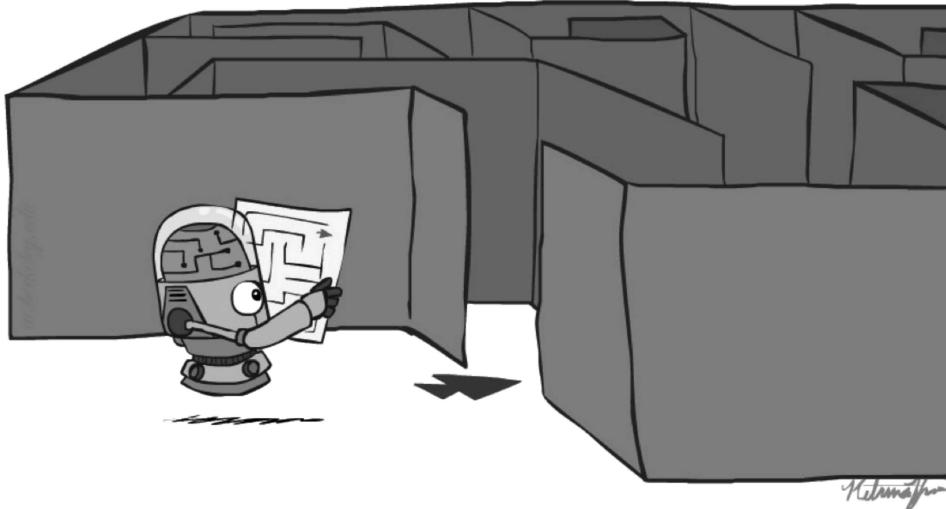


CS 106: Artificial Intelligence

Uninformed Search



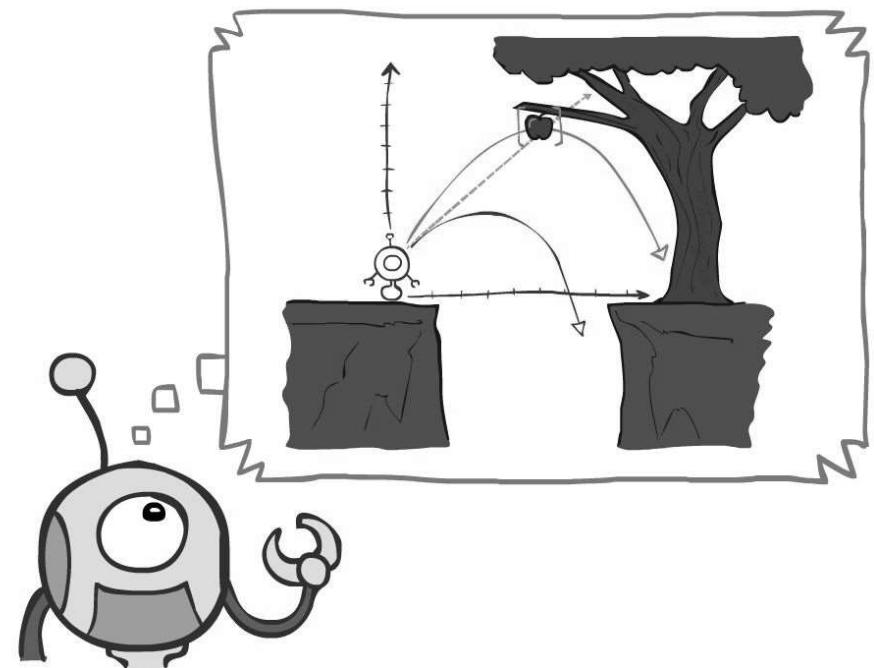
Instructor: Ngoc-Hoang LUONG, PhD.

University of Information Technology (UIT), VNU-HCM

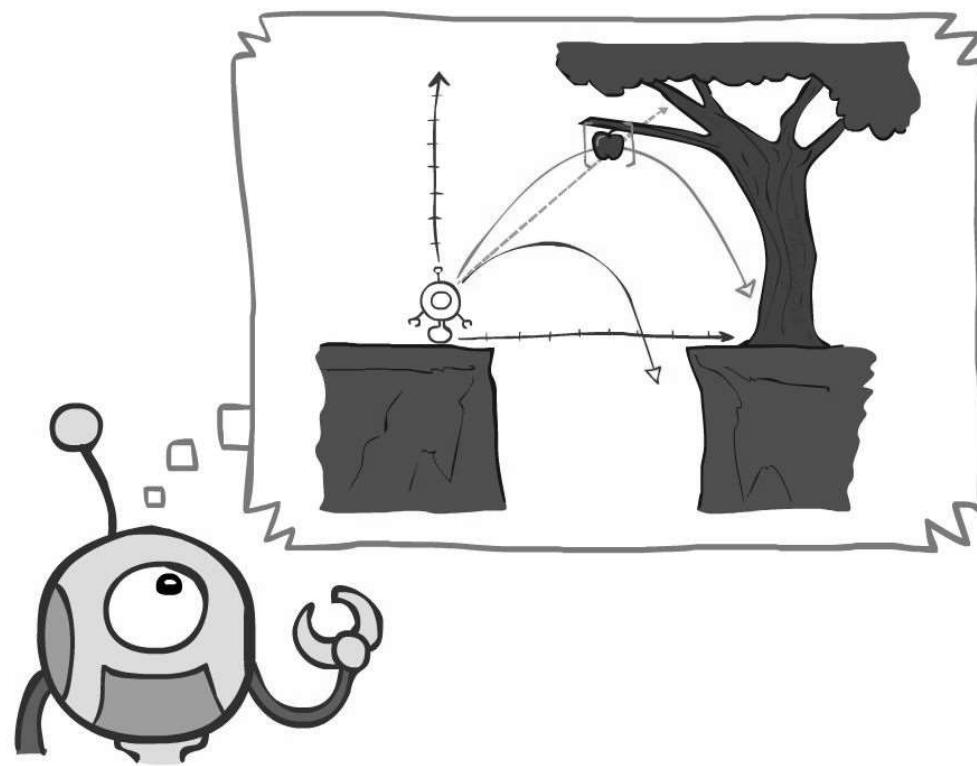
[These slides have been adapted from the slides made by Dan Klein and Pieter Abbeel for CS188
Intro to AI at UC Berkeley. All CS188 materials are available at <http://ai.berkeley.edu.>]

Today

- Agents that Plan Ahead
- Search Problems
- Uninformed Search Methods
 - Depth-First Search
 - Breadth-First Search
 - Uniform-Cost Search

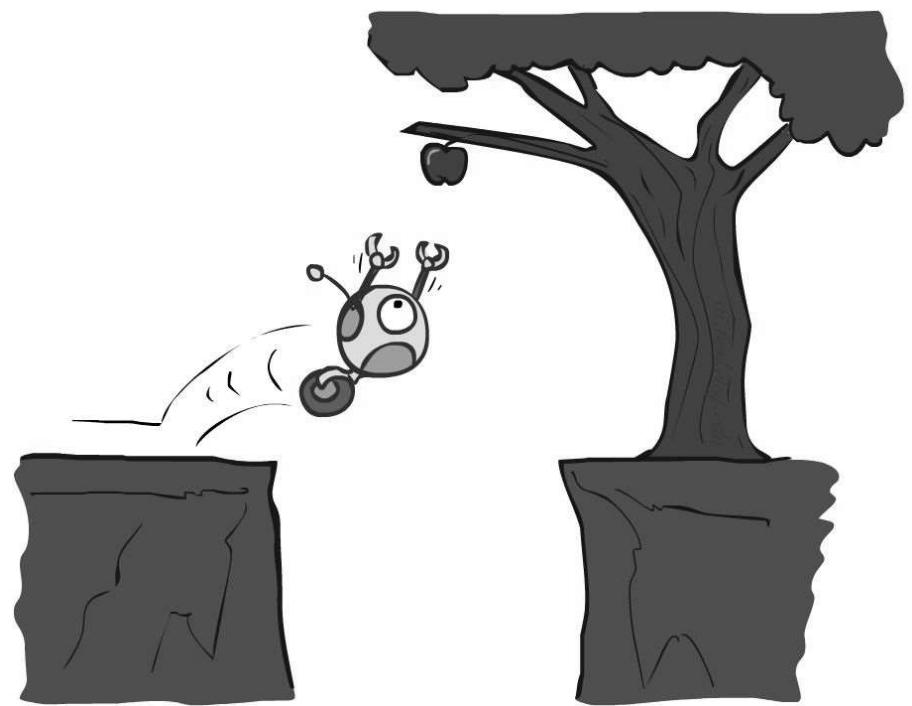


Agents that Plan

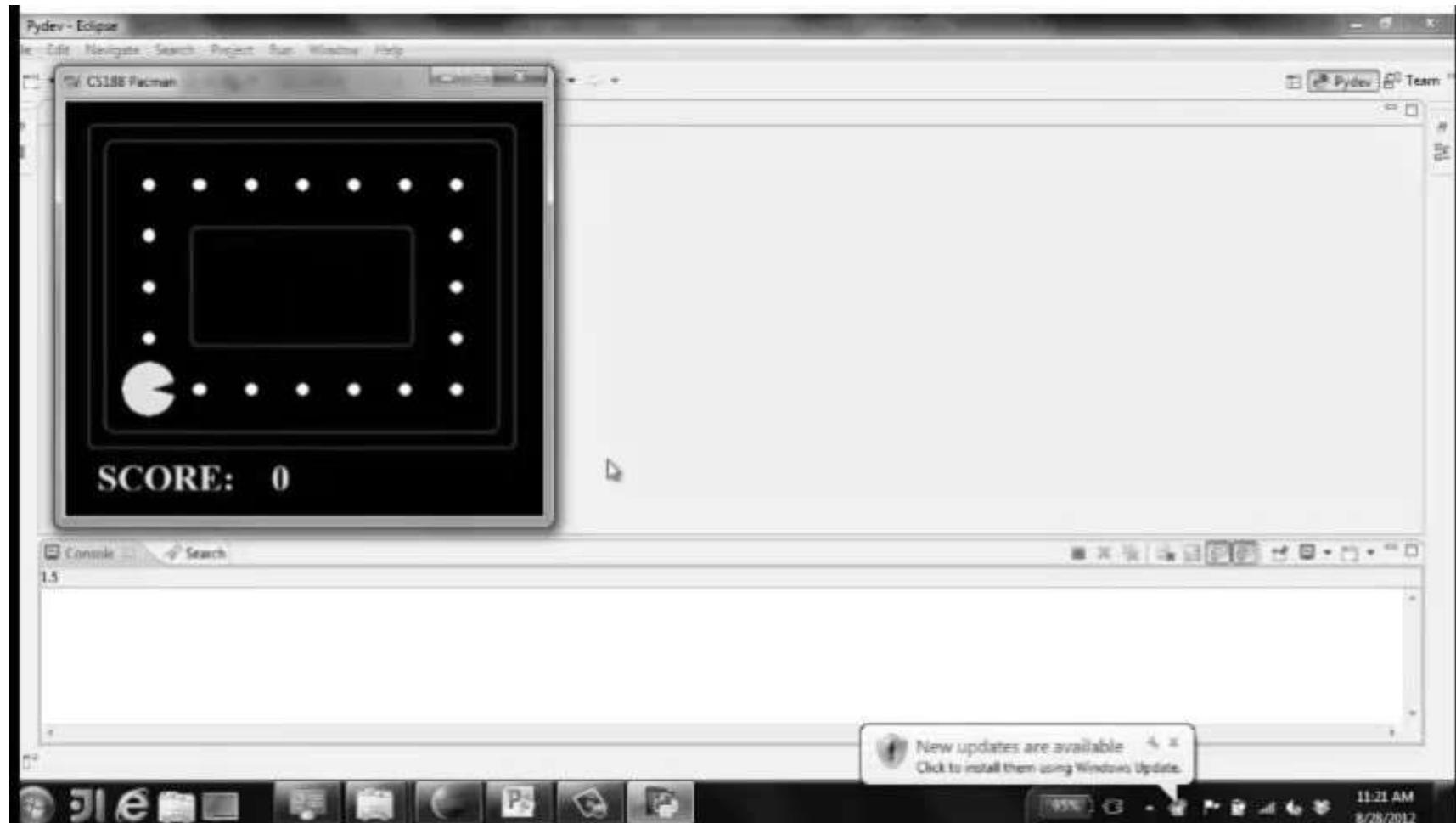


Reflex Agents

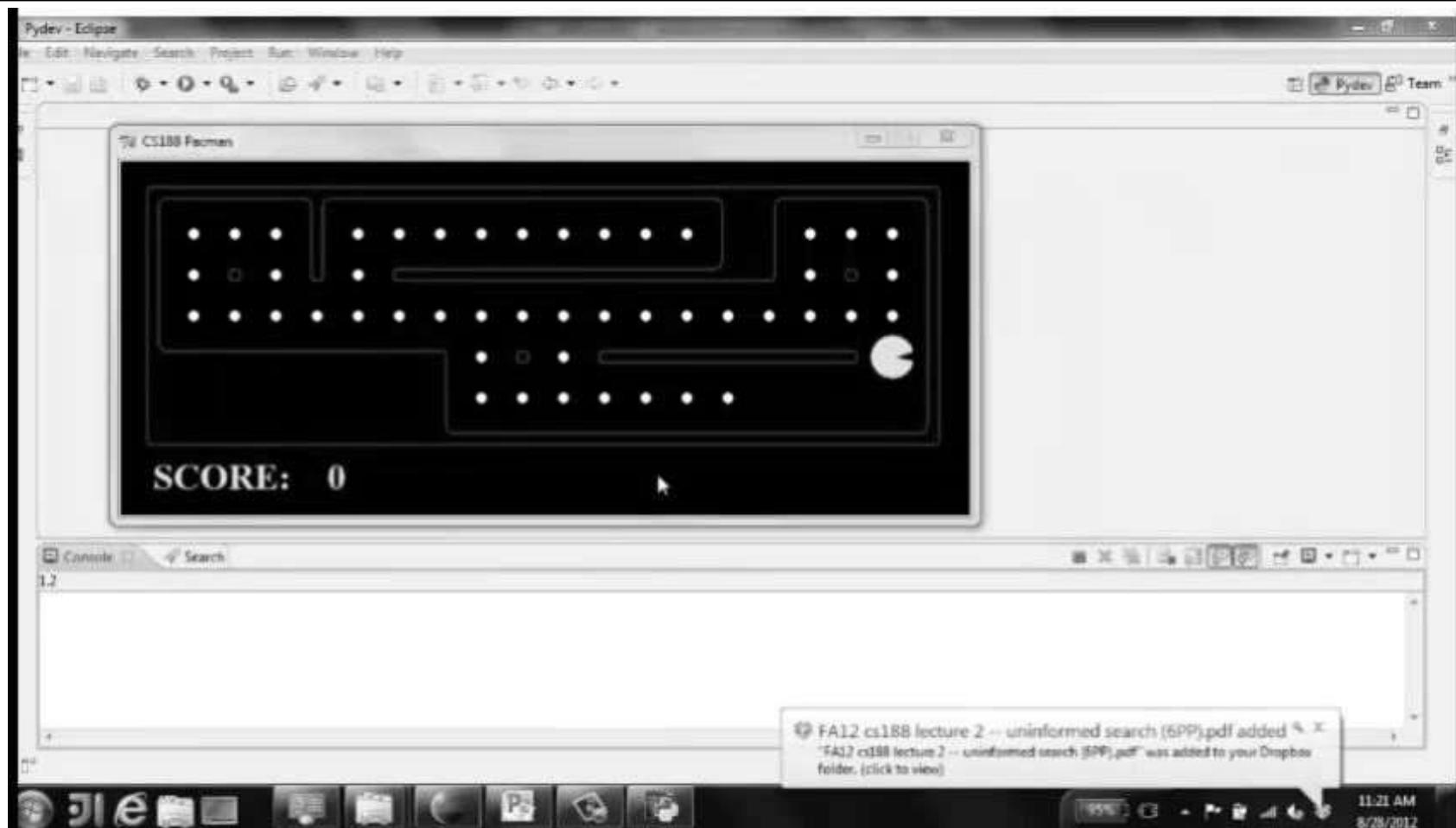
- Reflex agents:
 - Choose action based on current percept (and maybe memory)
 - May have memory or a model of the world's current state
 - Do not consider the future consequences of their actions
 - Consider how the world IS
- Can a reflex agent be rational?



Video of Demo Reflex Optimal

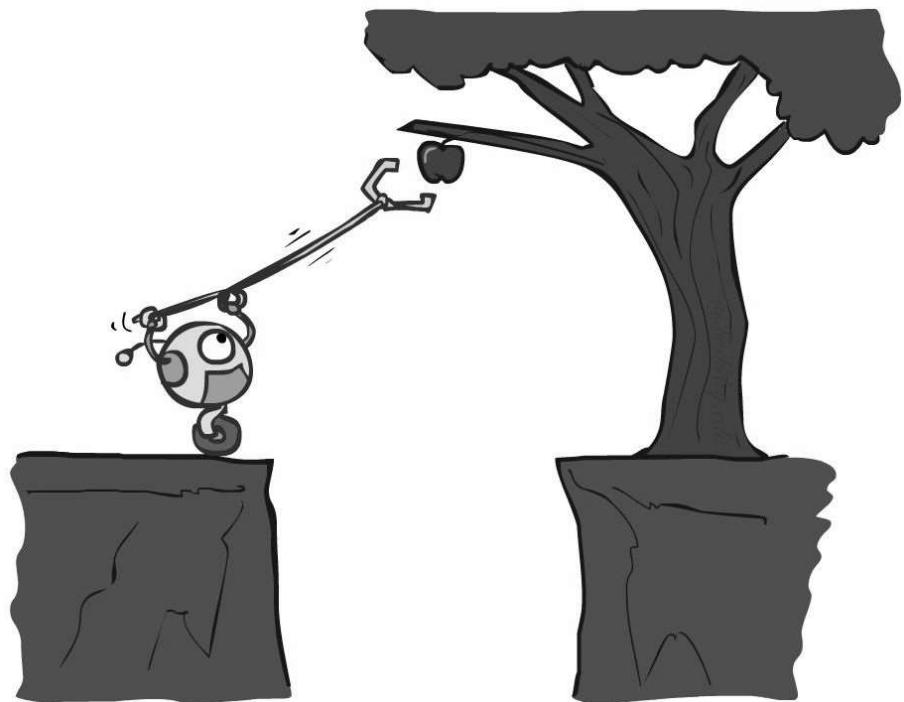


Video of Demo Reflex Odd

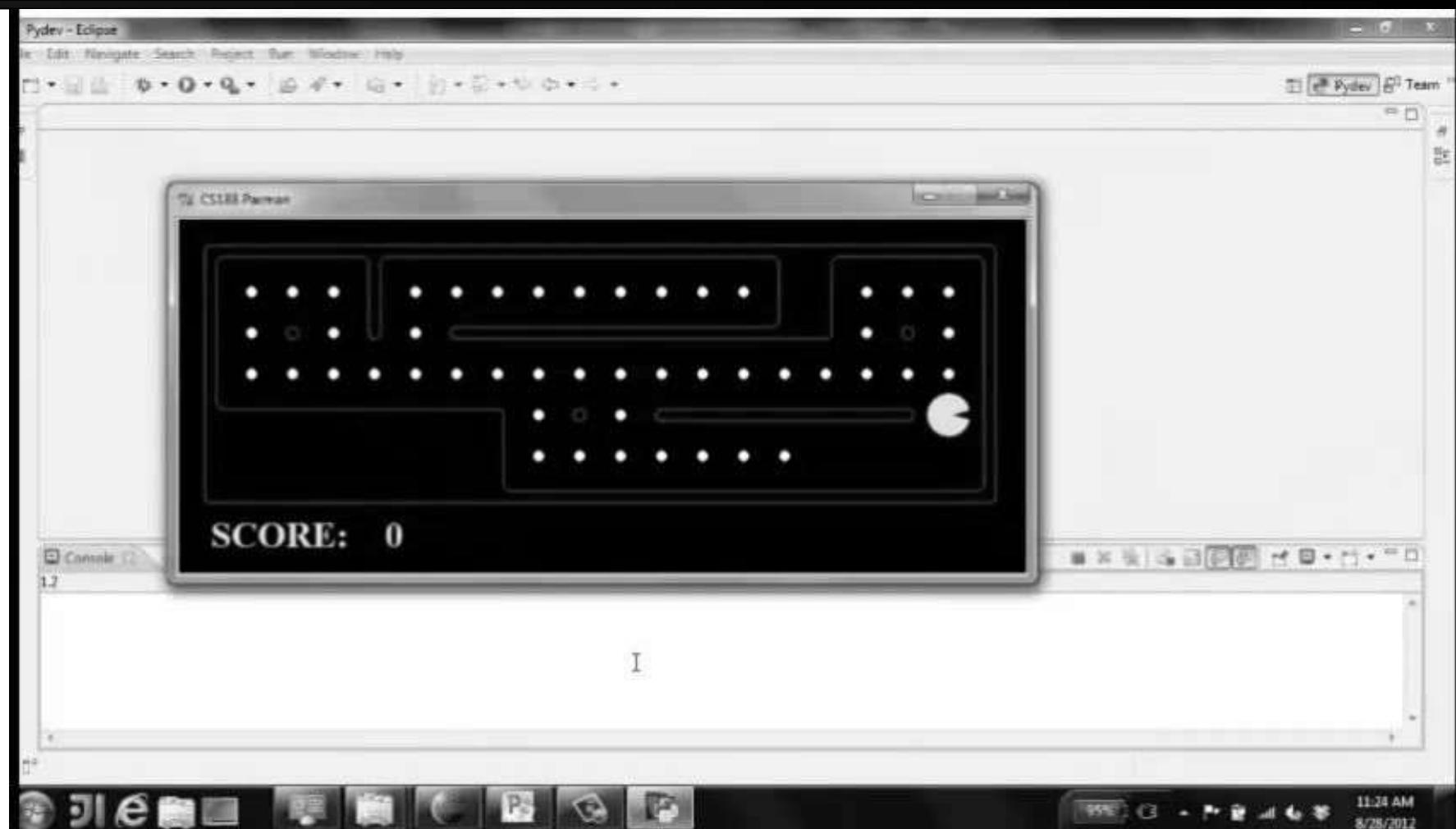


Planning Agents

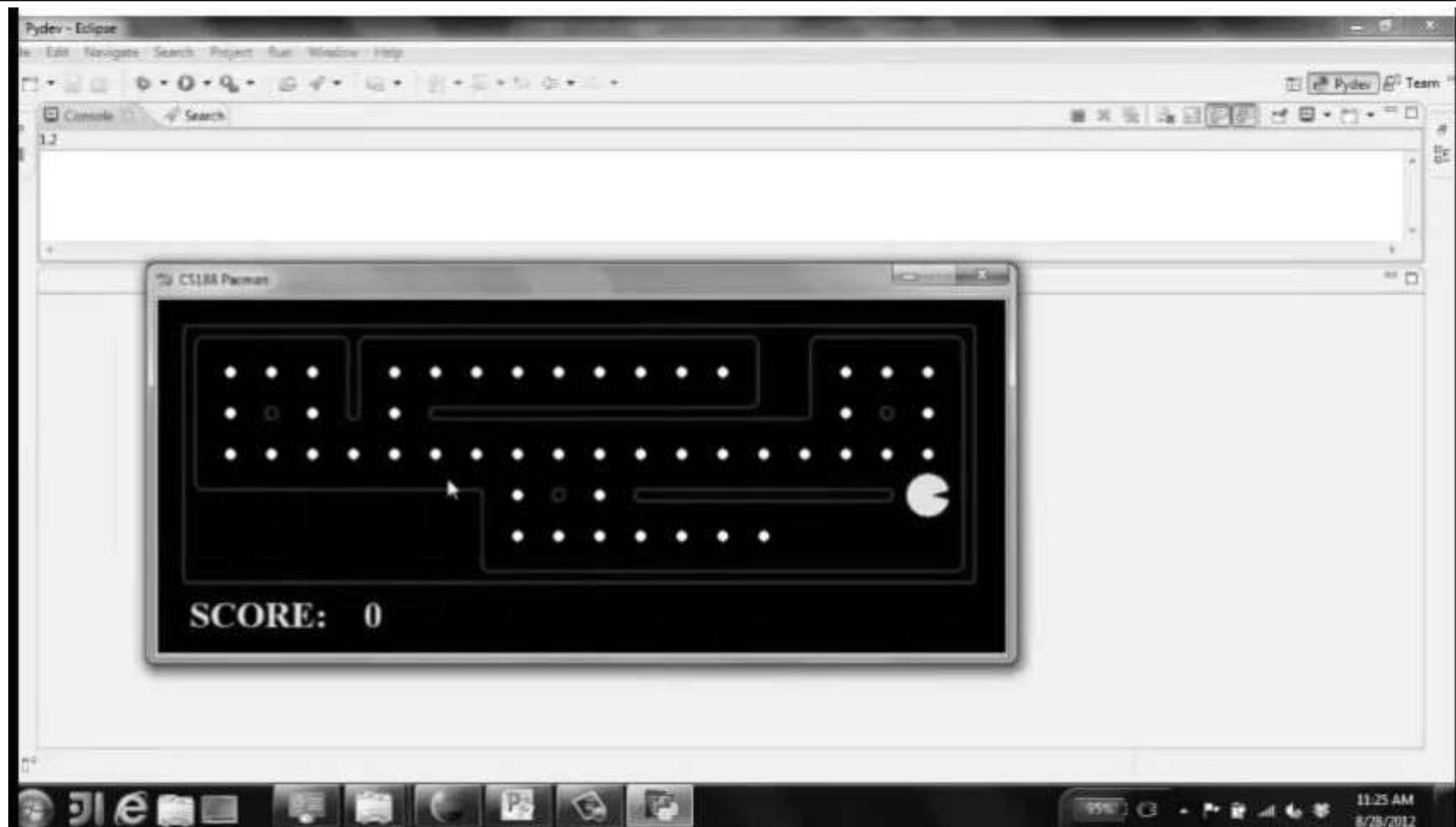
- Planning agents:
 - Ask “what if”
 - Decisions based on (hypothesized) consequences of actions
 - Must have a model of how the world evolves in response to actions
 - Must formulate a goal (test)
 - Consider how the world WOULD BE
- Optimal vs. complete planning
- Planning vs. replanning



Video of Demo Replanning



Video of Demo Mastermind



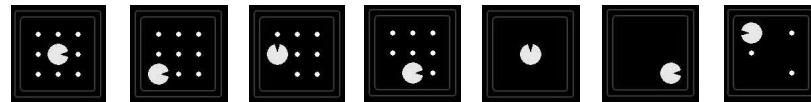
Search Problems



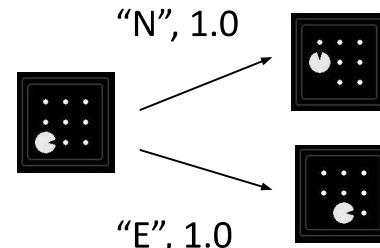
Search Problems

- A search problem consists of:

- A state space



- A successor function
(with actions, costs)

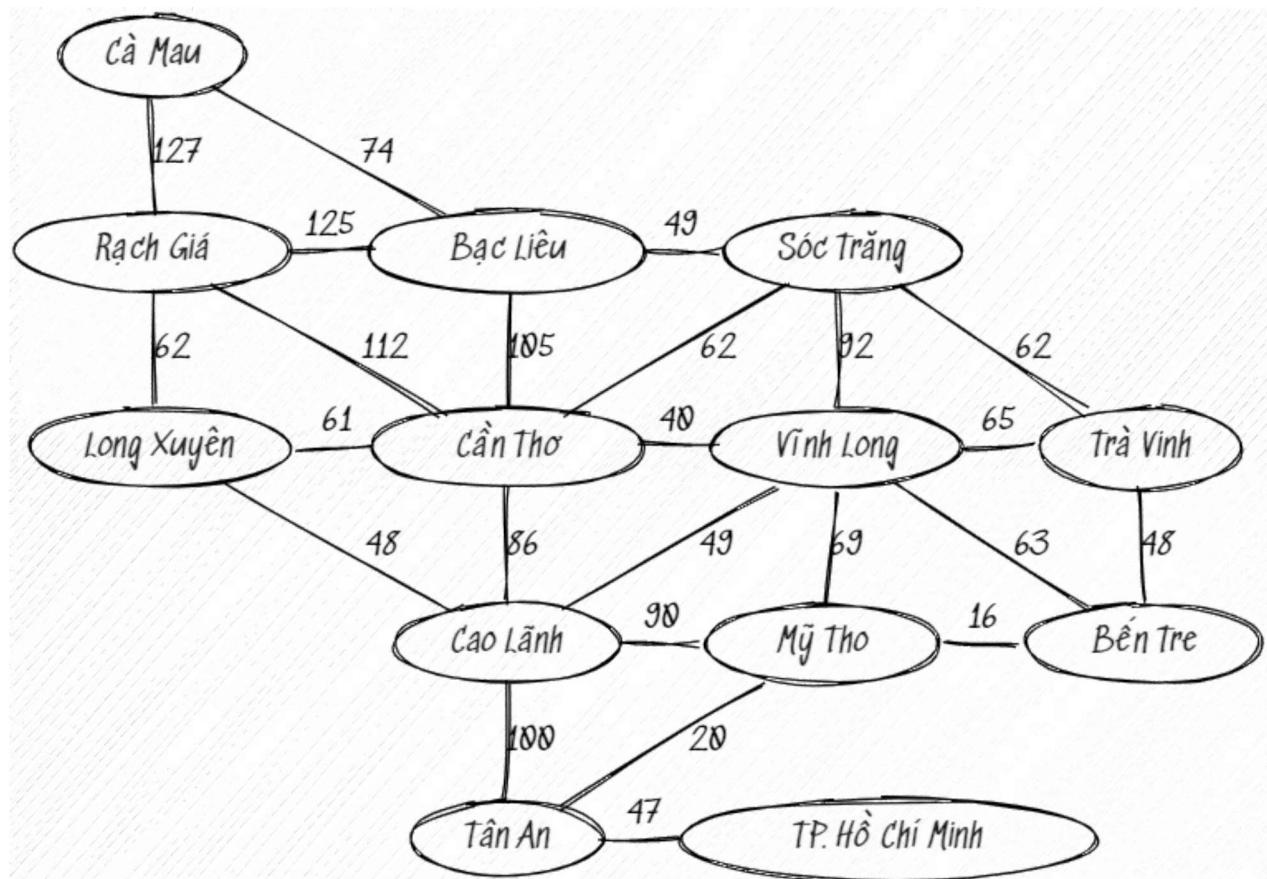


- A start state and a goal test
- A solution is a sequence of actions (a plan) which transforms the start state to a goal state

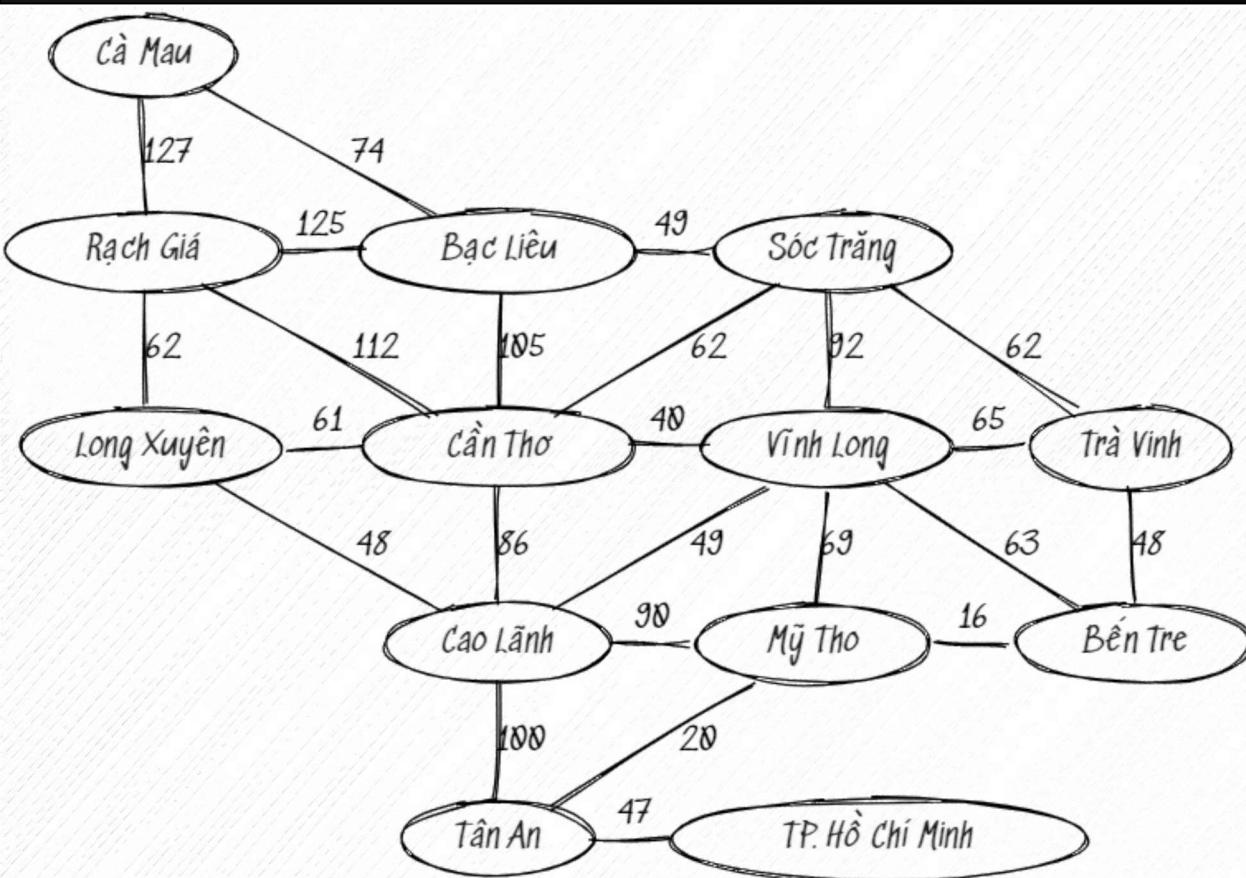
Search Problems Are Models



Example: Traveling in Mekong River Delta (Miền Tây)



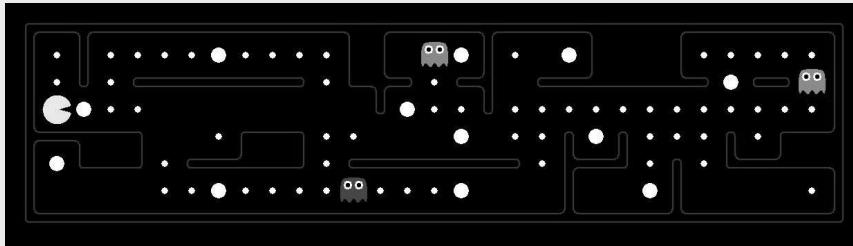
Example: Traveling in Mekong River Delta (Miền Tây)



- State space:
 - Cities
- Successor function:
 - Roads: Go to adjacent city with cost = distance
- Start state:
 - Cà Mau
- Goal test:
 - Is state == TP. Hồ Chí Minh?
- Solution?

What's in a State Space?

The world state includes every last detail of the environment

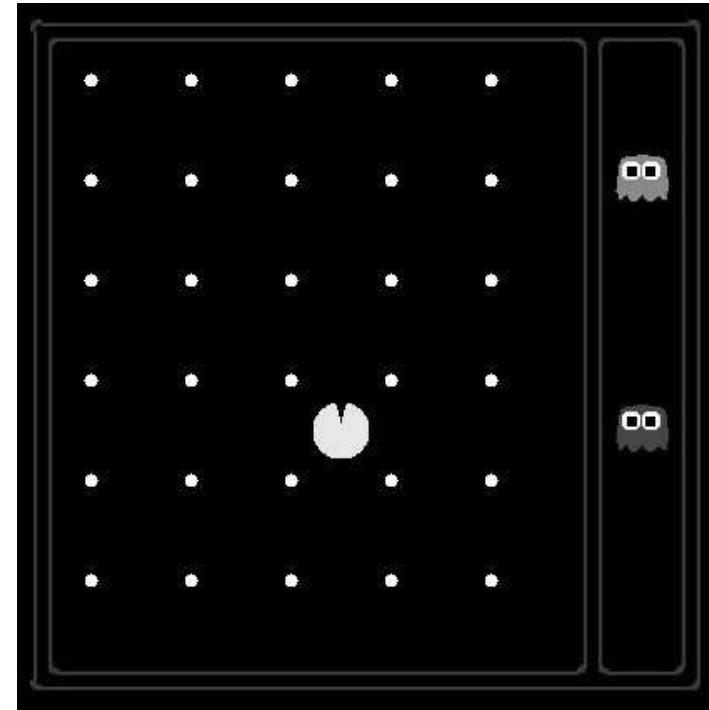


A search state keeps only the details needed for planning (abstraction)

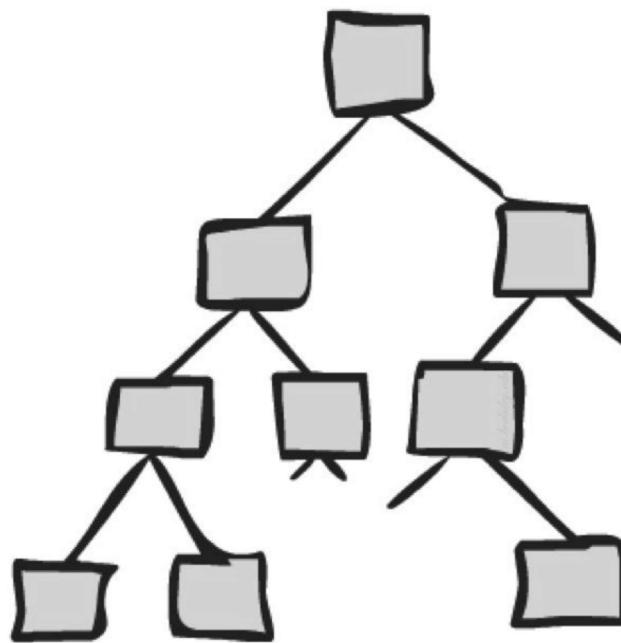
- Problem: Pathing
 - States: (x,y) location
 - Actions: NSEW
 - Successor: update location only
 - Goal test: is (x,y)=END
- Problem: Eat-All-Dots
 - States: {(x,y), dot booleans}
 - Actions: NSEW
 - Successor: update location and possibly a dot boolean
 - Goal test: dots all false

State Space Sizes?

- World state:
 - Agent positions: 120
 - Food count: 30
 - Ghost positions: 12
 - Agent facing: NSEW
- How many
 - World states?
 $120 \times (2^{30}) \times (12^2) \times 4$
 - States for pathing?
120
 - States for eat-all-dots?
 $120 \times (2^{30})$

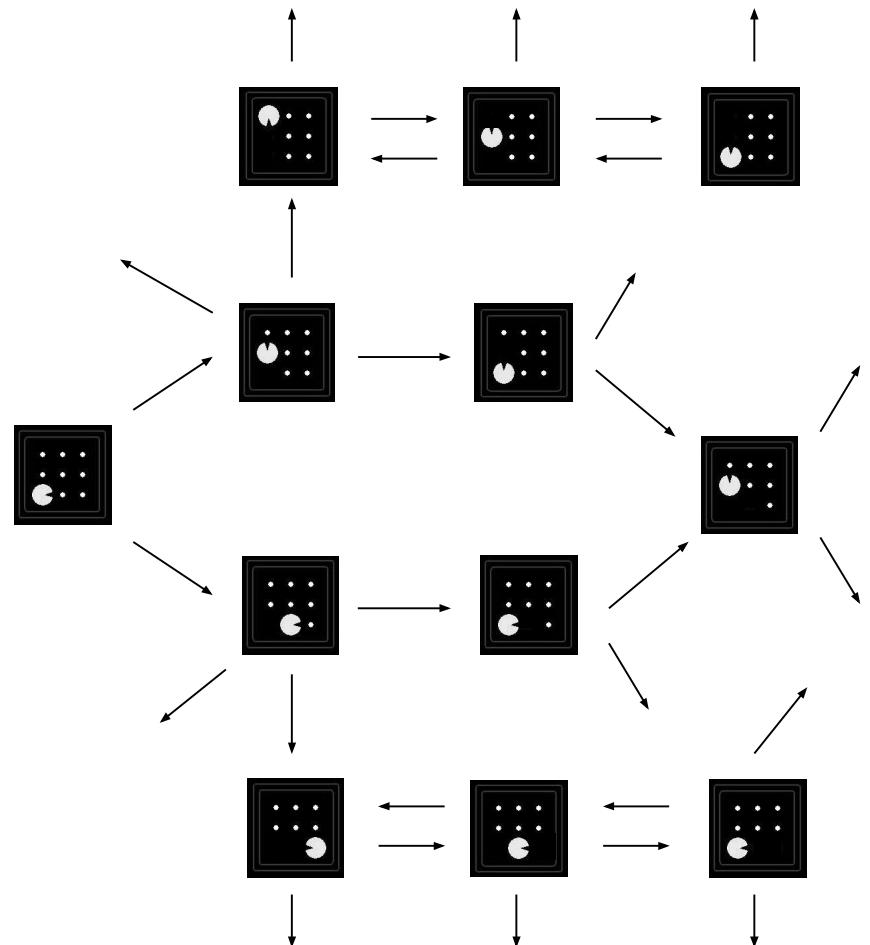


State Space Graphs and Search Trees



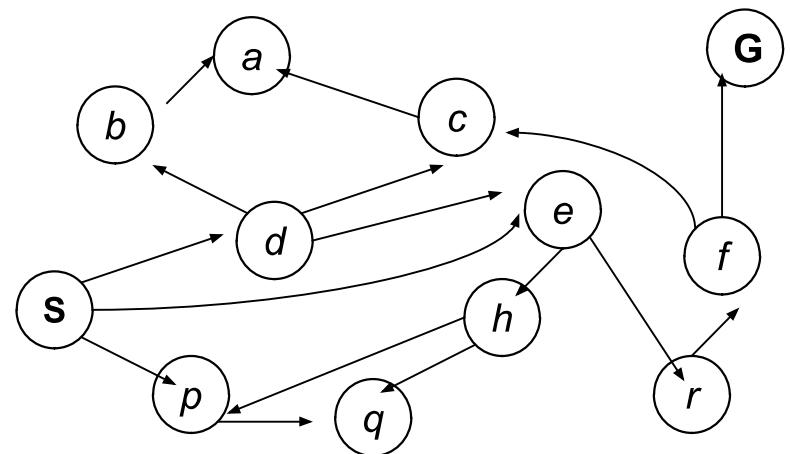
State Space Graphs

- State space graph: A mathematical representation of a search problem
 - Nodes are (abstracted) world configurations
 - Arcs represent successors (action results)
 - The goal test is a set of goal nodes (maybe only one)
- In a state space graph, each state occurs only once!
- We can rarely build this full graph in memory (it's too big), but it's a useful idea



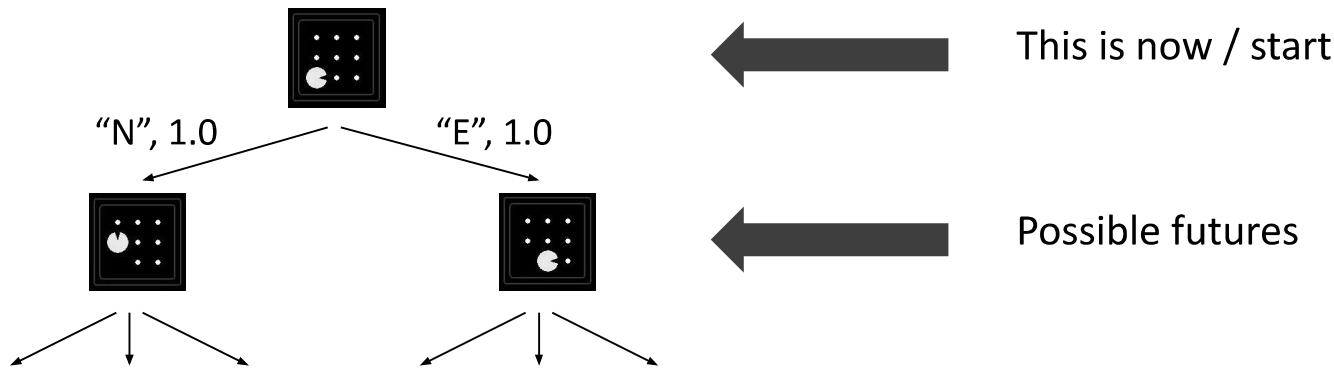
State Space Graphs

- State space graph: A mathematical representation of a search problem
 - Nodes are (abstracted) world configurations
 - Arcs represent successors (action results)
 - The goal test is a set of goal nodes (maybe only one)
- In a search graph, each state occurs only once!
- We can rarely build this full graph in memory (it's too big), but it's a useful idea



Tiny search graph for a tiny search problem

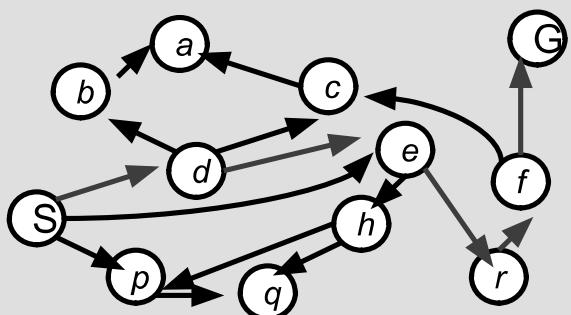
Search Trees



- A search tree:
 - A “what if” tree of plans and their outcomes
 - The start state is the root node
 - Children correspond to successors
 - Nodes show states, but correspond to PLANS that achieve those states
 - For most problems, we can never actually build the whole tree

State Space Graphs vs. Search Trees

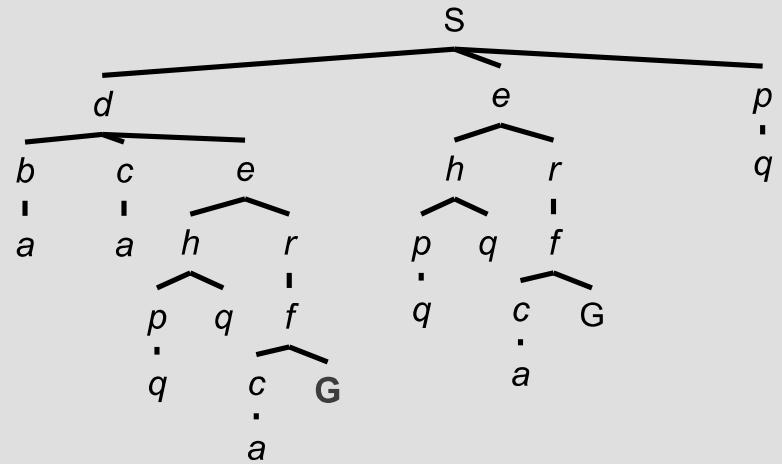
State Space Graph



Each NODE in in the search tree is an entire PATH in the state space graph.

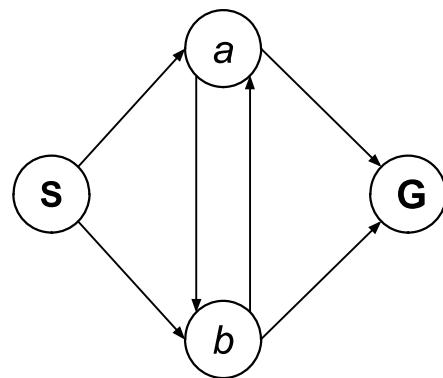
We construct both on demand – and we construct as little as possible.

Search Tree



Quiz: State Space Graphs vs. Search Trees

Consider this 4-state graph:

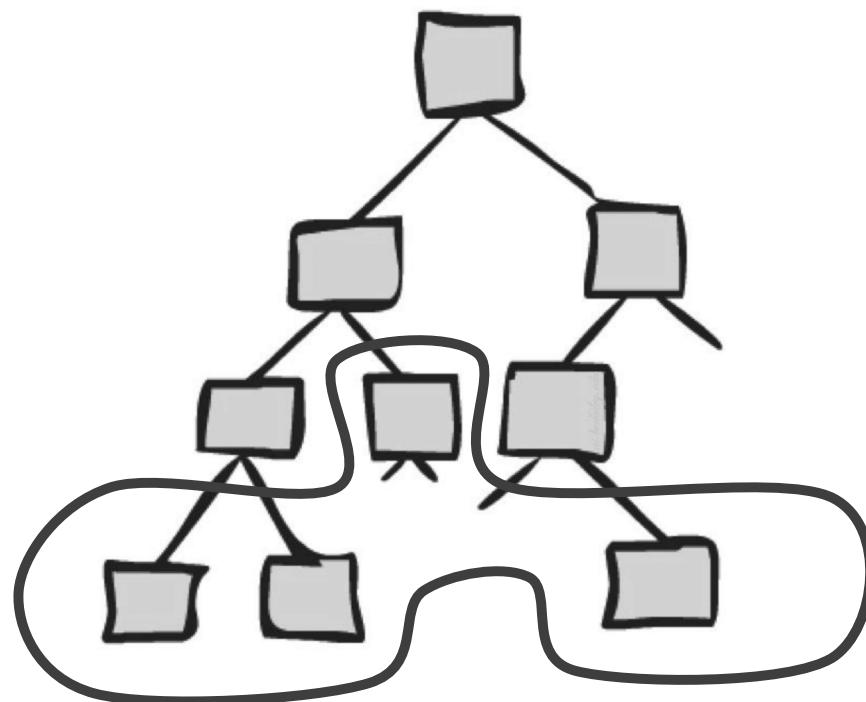


How big is its search tree (from S)?



Important: Lots of repeated structure in the search tree!

Tree Search

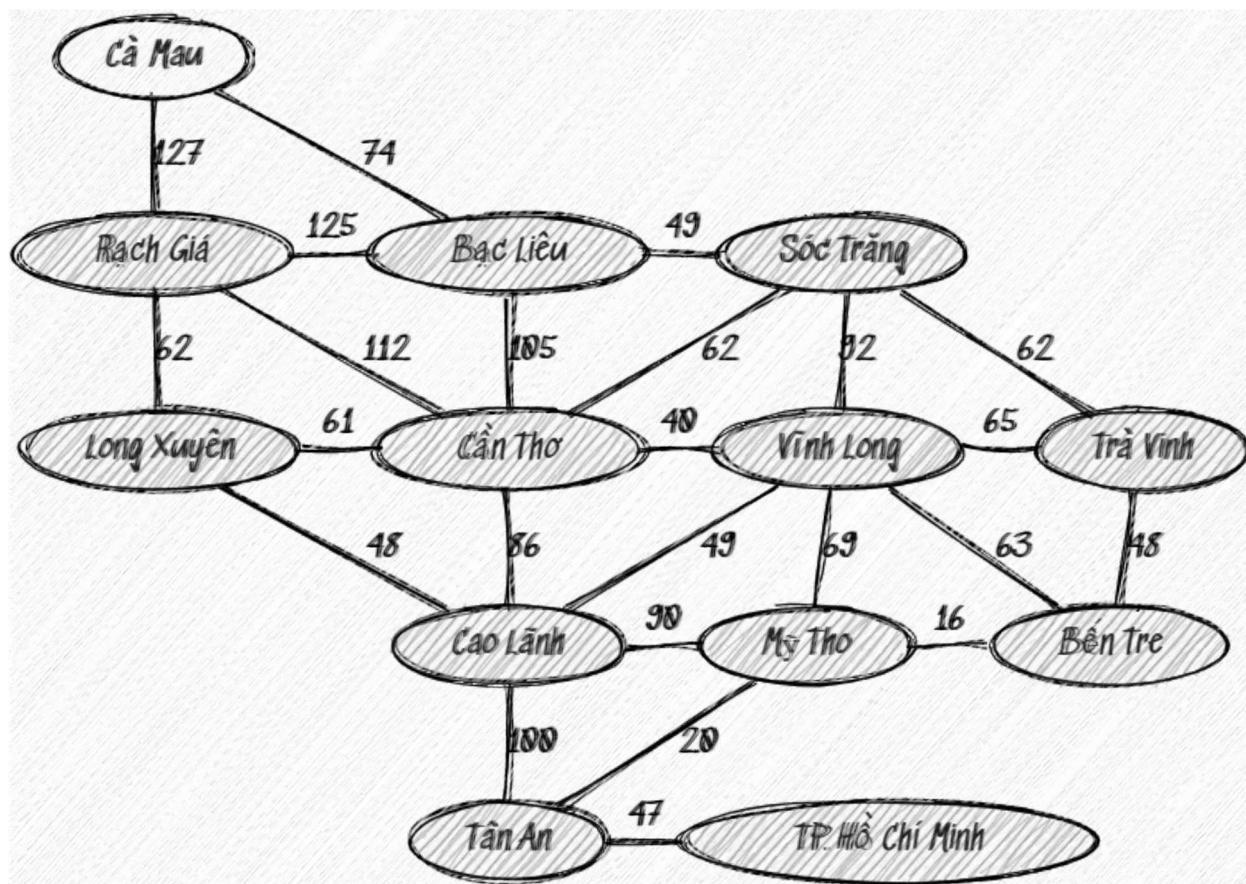


General Tree Search

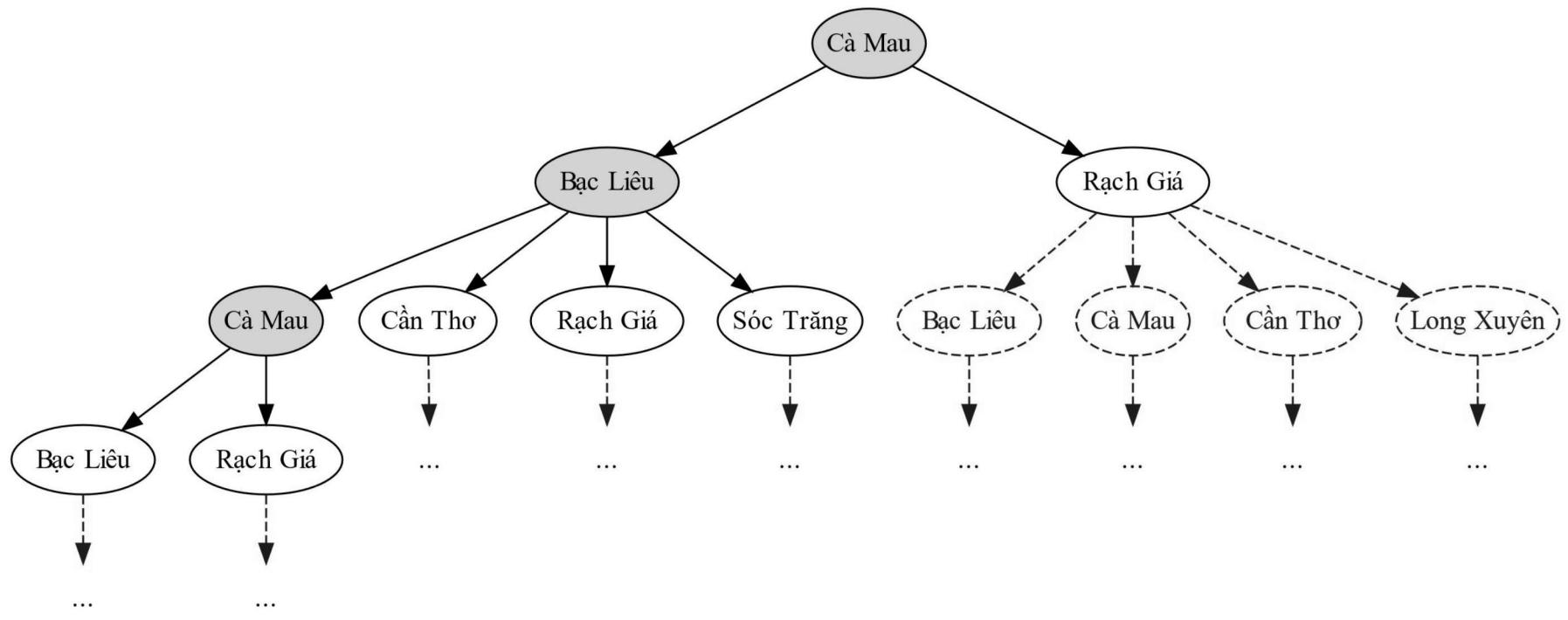
```
function TREE-SEARCH(problem, strategy) returns a solution, or failure
    initialize the search tree using the initial state of problem
    loop do
        if there are no candidates for expansion then return failure
        choose a leaf node for expansion according to strategy
        if the node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

- Important ideas:
 - Fringe/Frontier
 - Expansion
 - Exploration strategy
- Main question: which fringe/frontier nodes to explore?

Search Example: Mekong River Delta

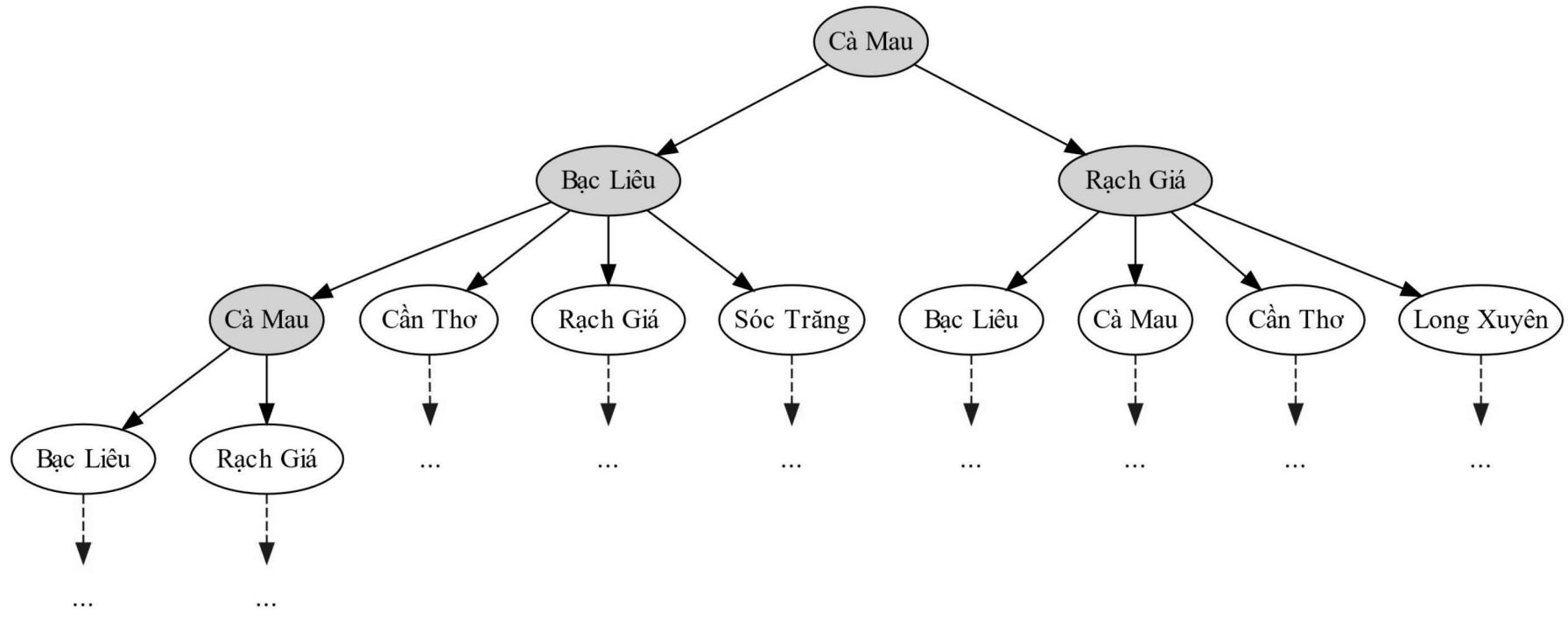


Searching with a Search Tree



- Expand out potential plans (tree nodes)
- Maintain a fringe of partial plans under consideration

Searching with a Search Tree



- Expand out potential plans (tree nodes)
- Maintain a fringe of partial plans under consideration
- Try to expand as few tree nodes as possible

Tree Search Pseudo-Code

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

Graph Search Pseudo-Code

```
function GRAPH-SEARCH(problem, fringe) return a solution, or failure
  closed  $\leftarrow$  an empty set
  fringe  $\leftarrow$  INSERT(MAKE-NODE(INITIAL-STATE[problem]), fringe)
  loop do
    if fringe is empty then return failure
    node  $\leftarrow$  REMOVE-FRONT(fringe)
    if GOAL-TEST(problem, STATE[node]) then return node
    if STATE[node] is not in closed then
      add STATE[node] to closed
      for child-node in EXPAND(STATE[node], problem) do
        fringe  $\leftarrow$  INSERT(child-node, fringe)
    end
  end
```

Depth-First Search

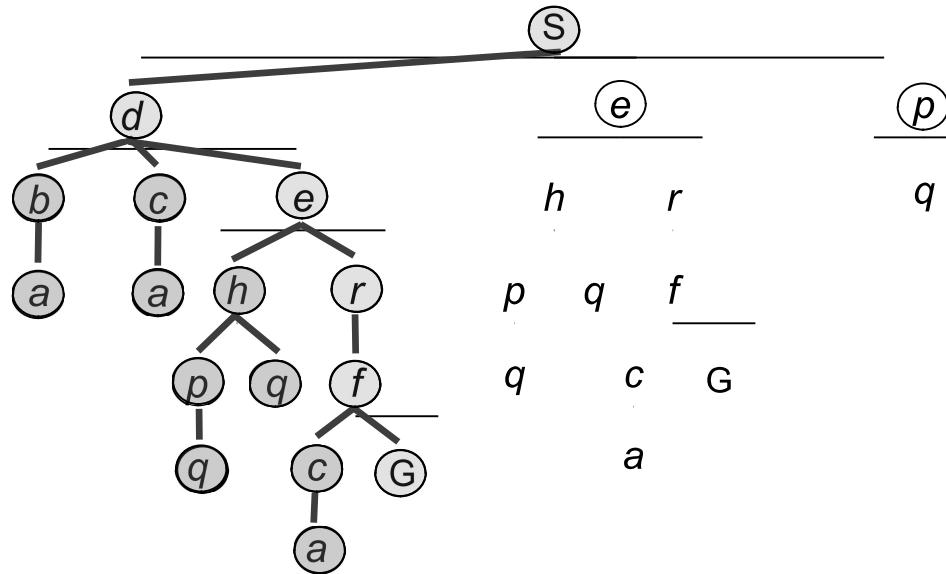
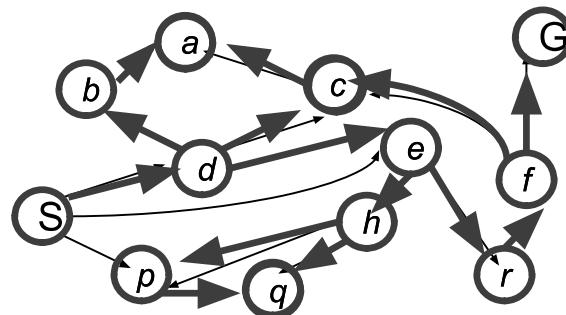
Strategy: expand a deepest node first



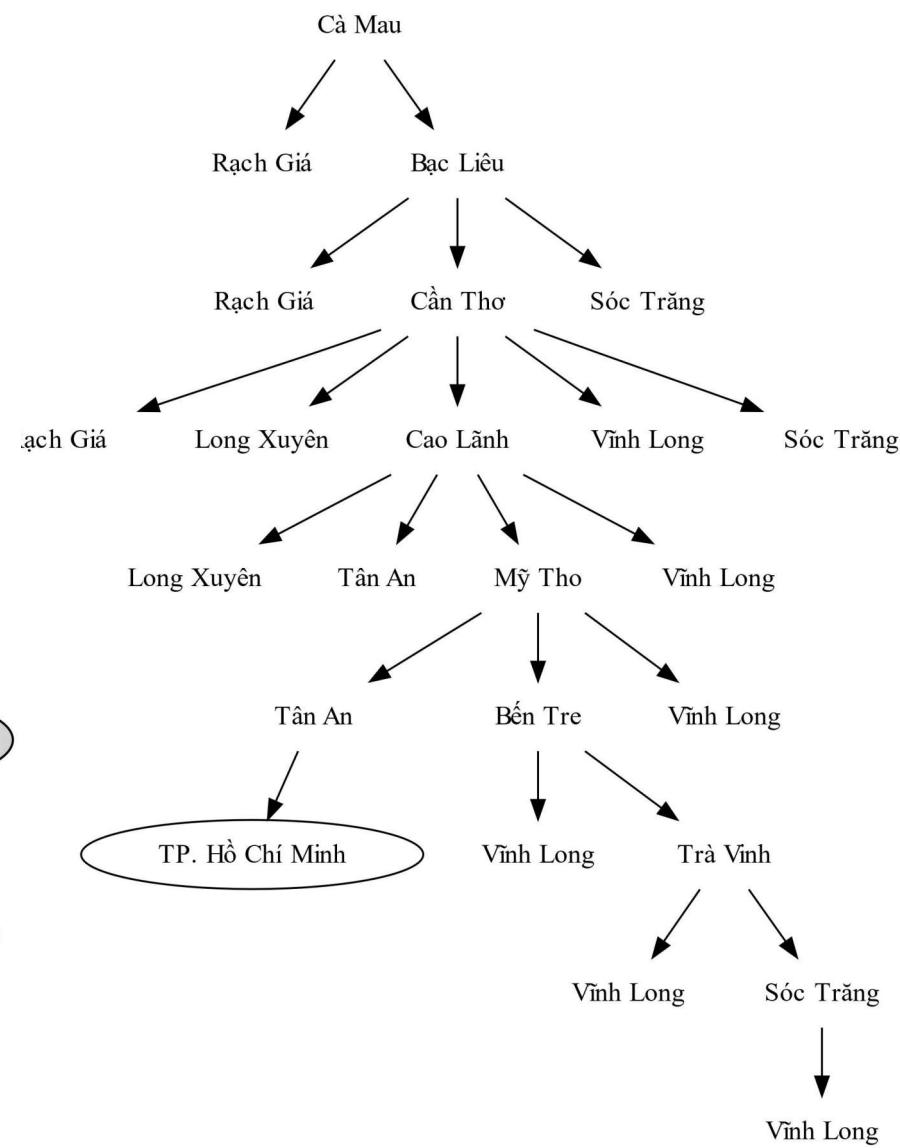
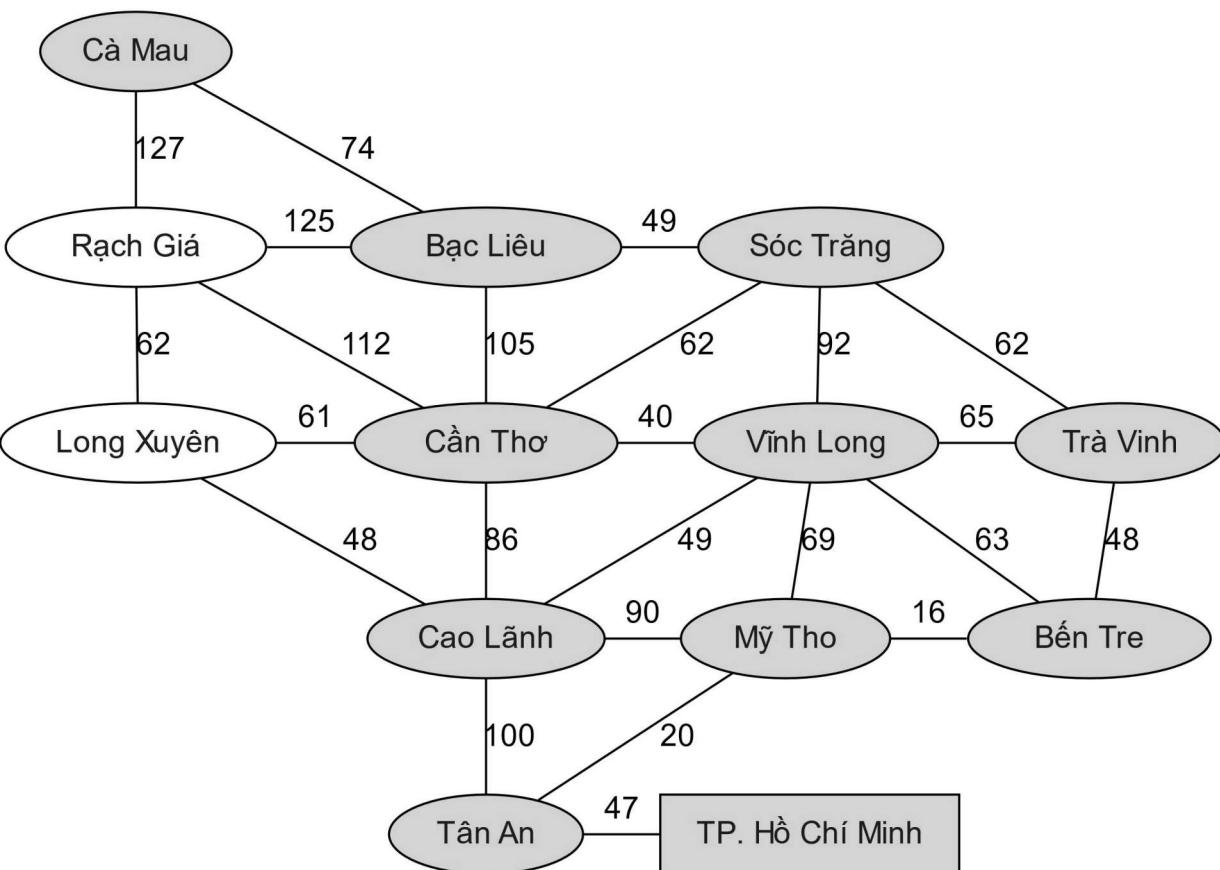
Depth-First Search

Strategy: expand a deepest node first

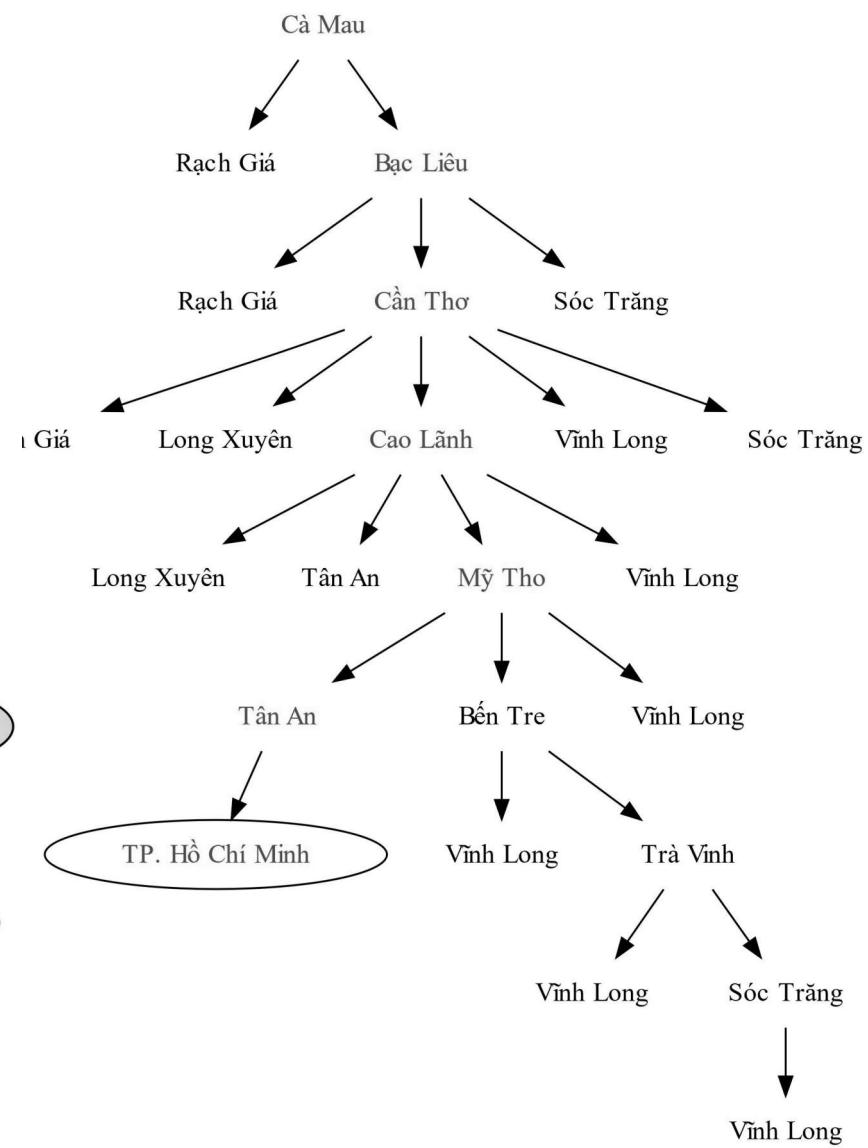
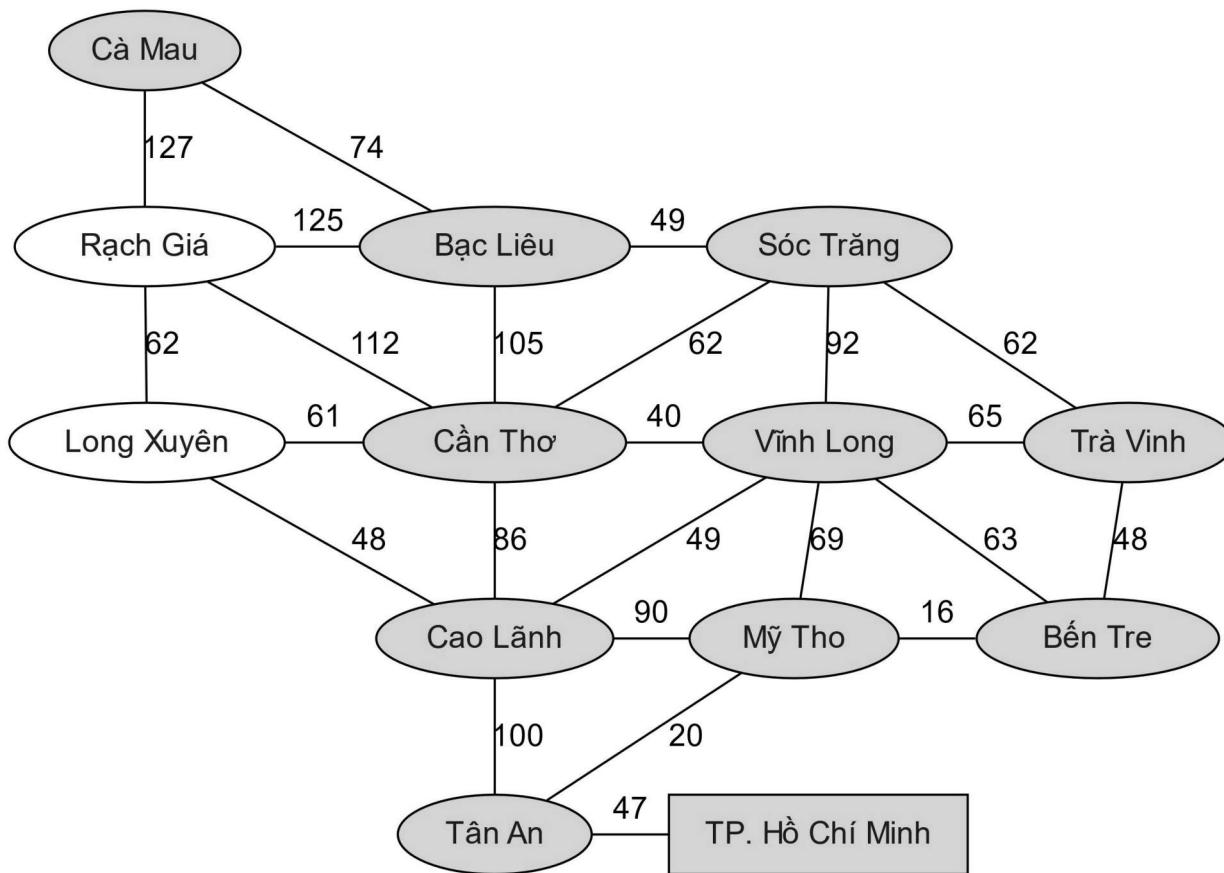
Implementation:
Fringe is a LIFO stack



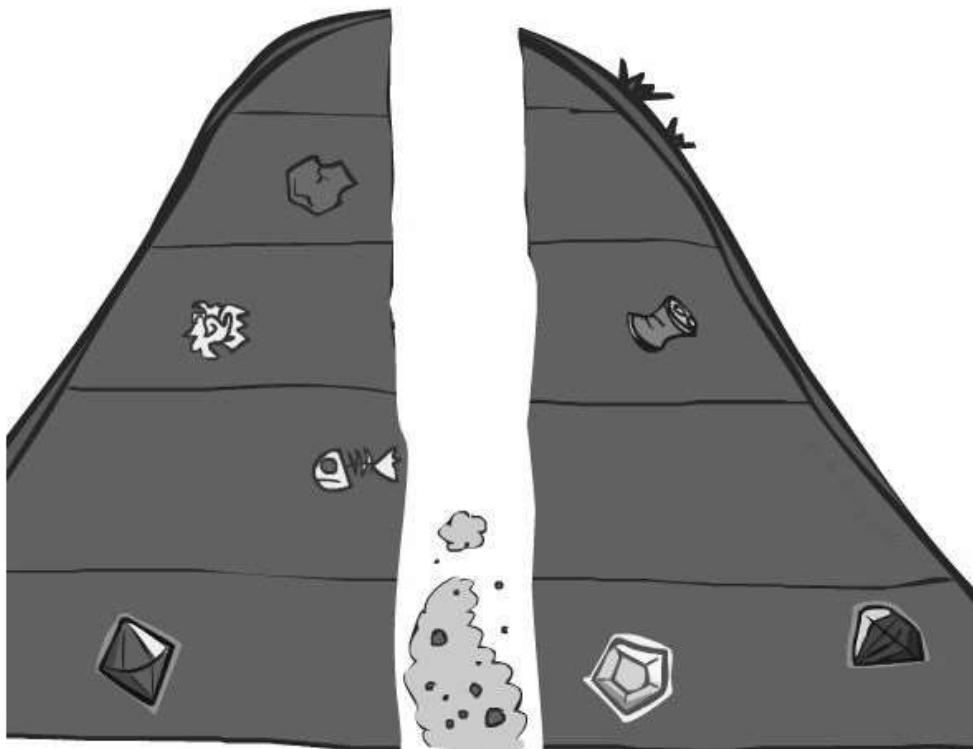
Depth-First Search



DFS: Is it optimal?

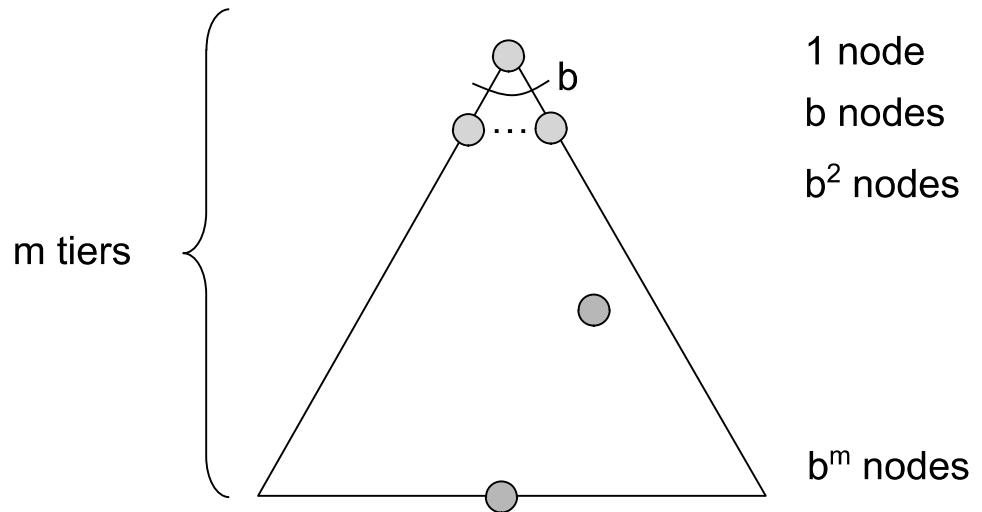


Search Algorithm Properties



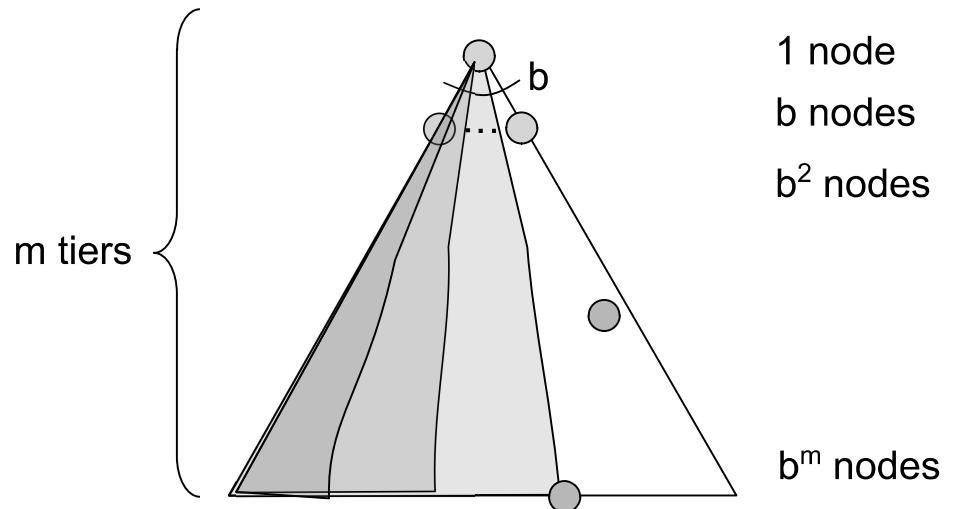
Search Algorithm Properties

- Complete: Guaranteed to find a solution if one exists?
- Optimal: Guaranteed to find the least cost path?
- Time complexity?
- Space complexity?
- Cartoon of search tree:
 - b is the branching factor
 - m is the maximum depth
 - solutions at various depths
- Number of nodes in entire tree?
 - $1 + b + b^2 + \dots + b^m = O(b^m)$



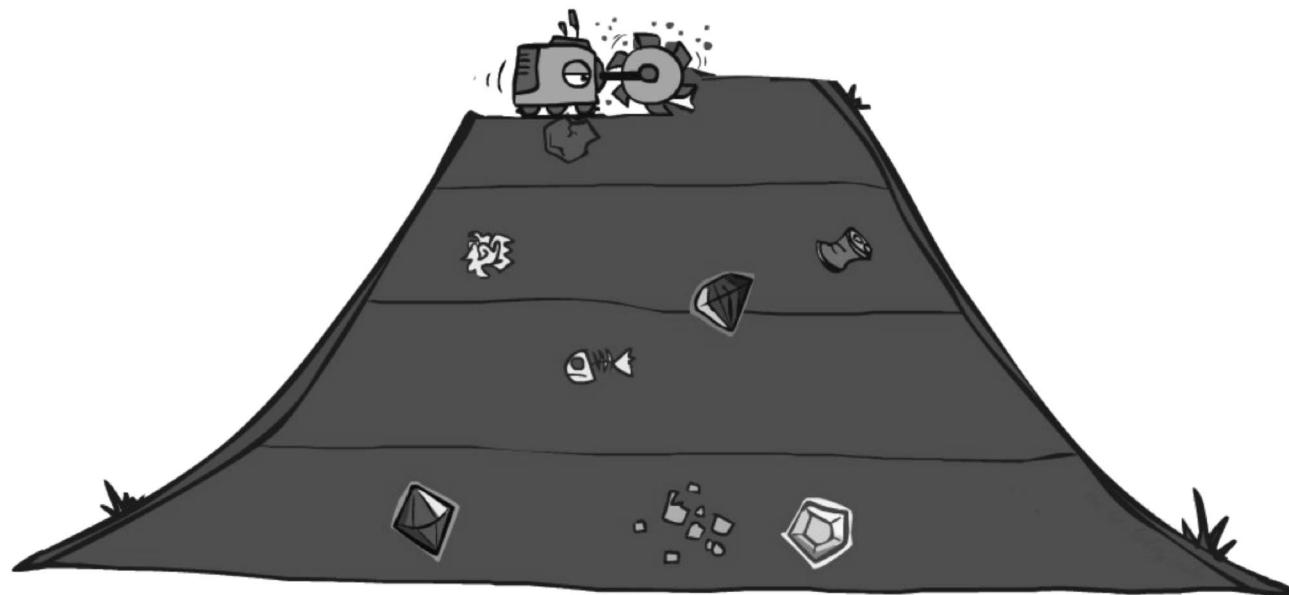
Depth-First Search (DFS) Properties

- What nodes DFS expand?
 - Some left prefix of the tree.
 - Could process the whole tree!
 - If m is finite, takes time $O(b^m)$
- How much space does the fringe take?
 - Only has siblings on path to root, so $O(bm)$
- Is it complete?
 - m could be infinite, so only if we prevent cycles.
- Is it optimal?
 - No, it finds the “leftmost” solution, regardless of depth or cost



Breadth-First Search

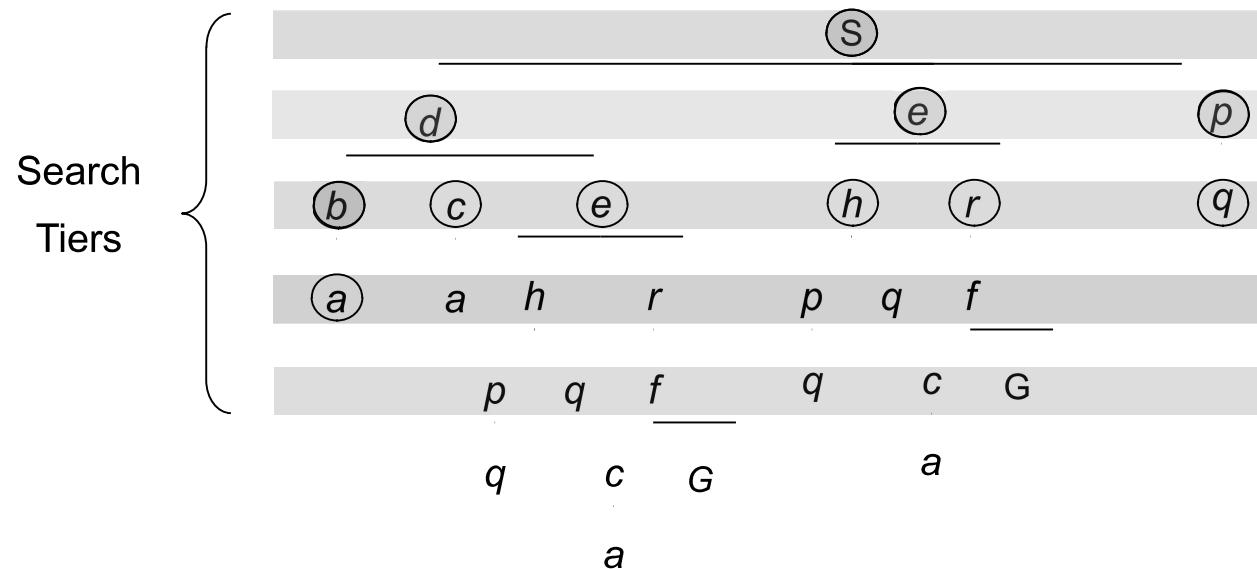
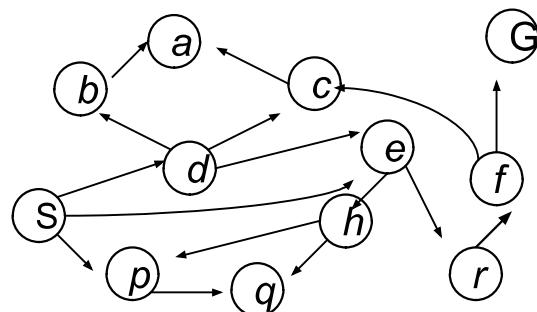
Strategy: expand a shallowest node first



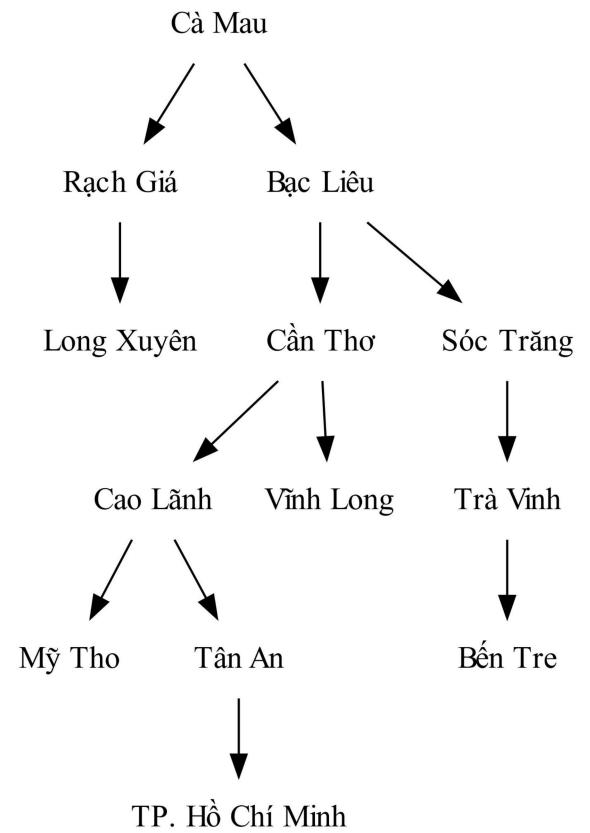
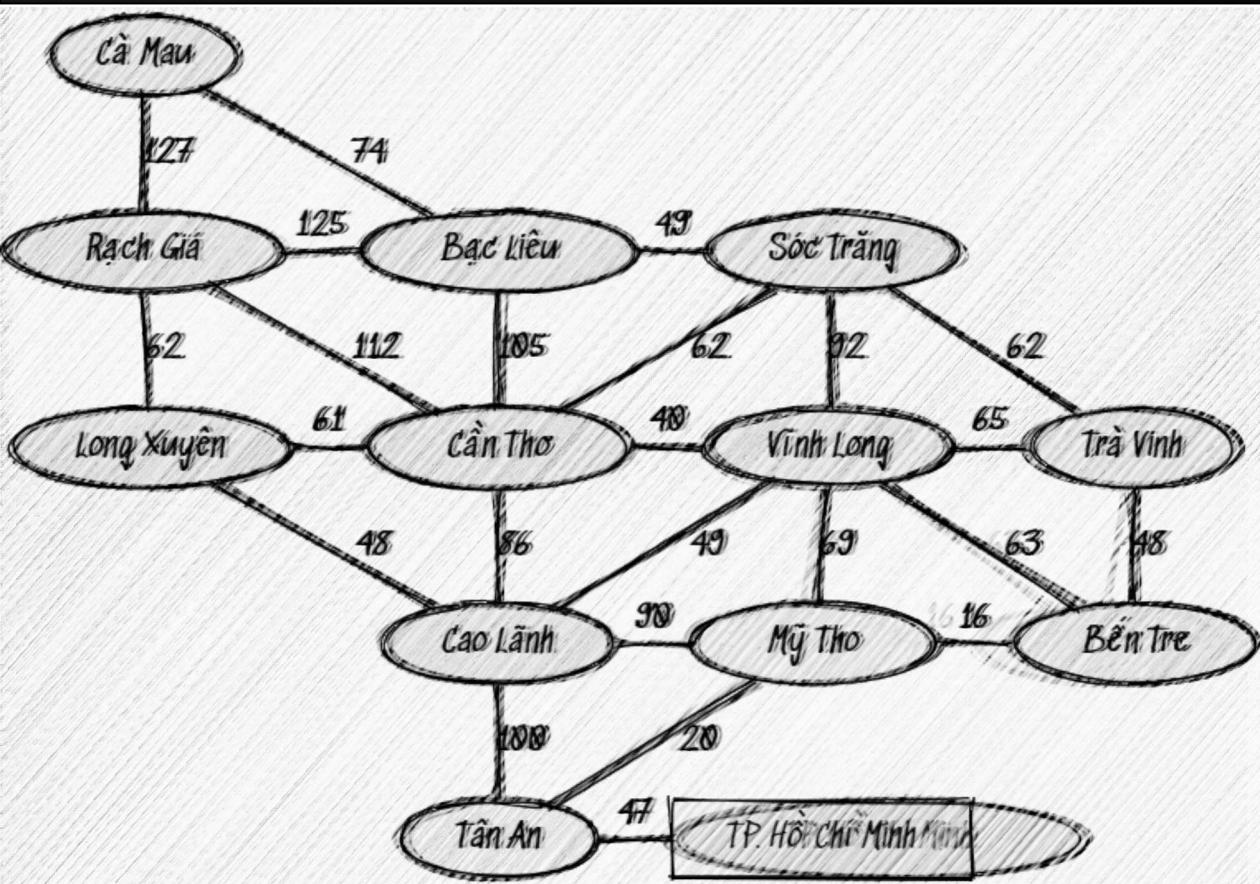
Breadth-First Search

Strategy: expand a shallowest node first

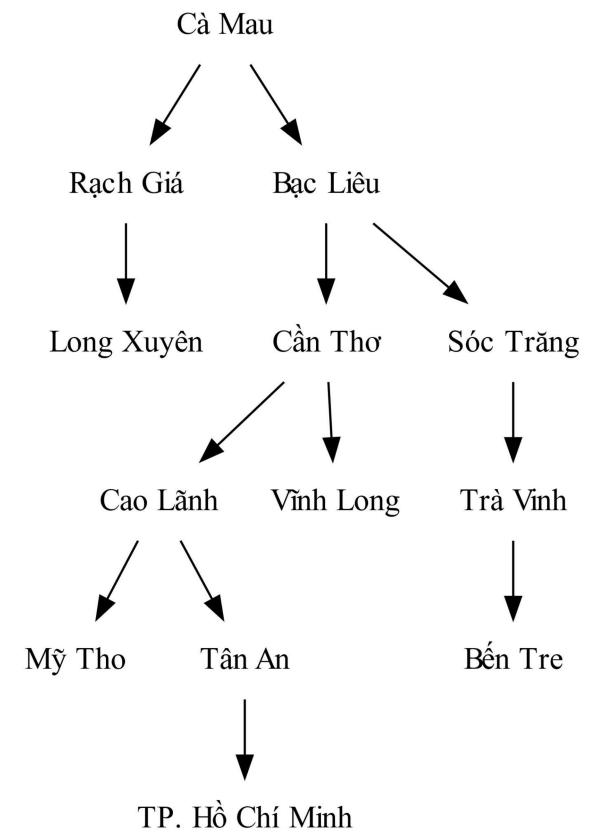
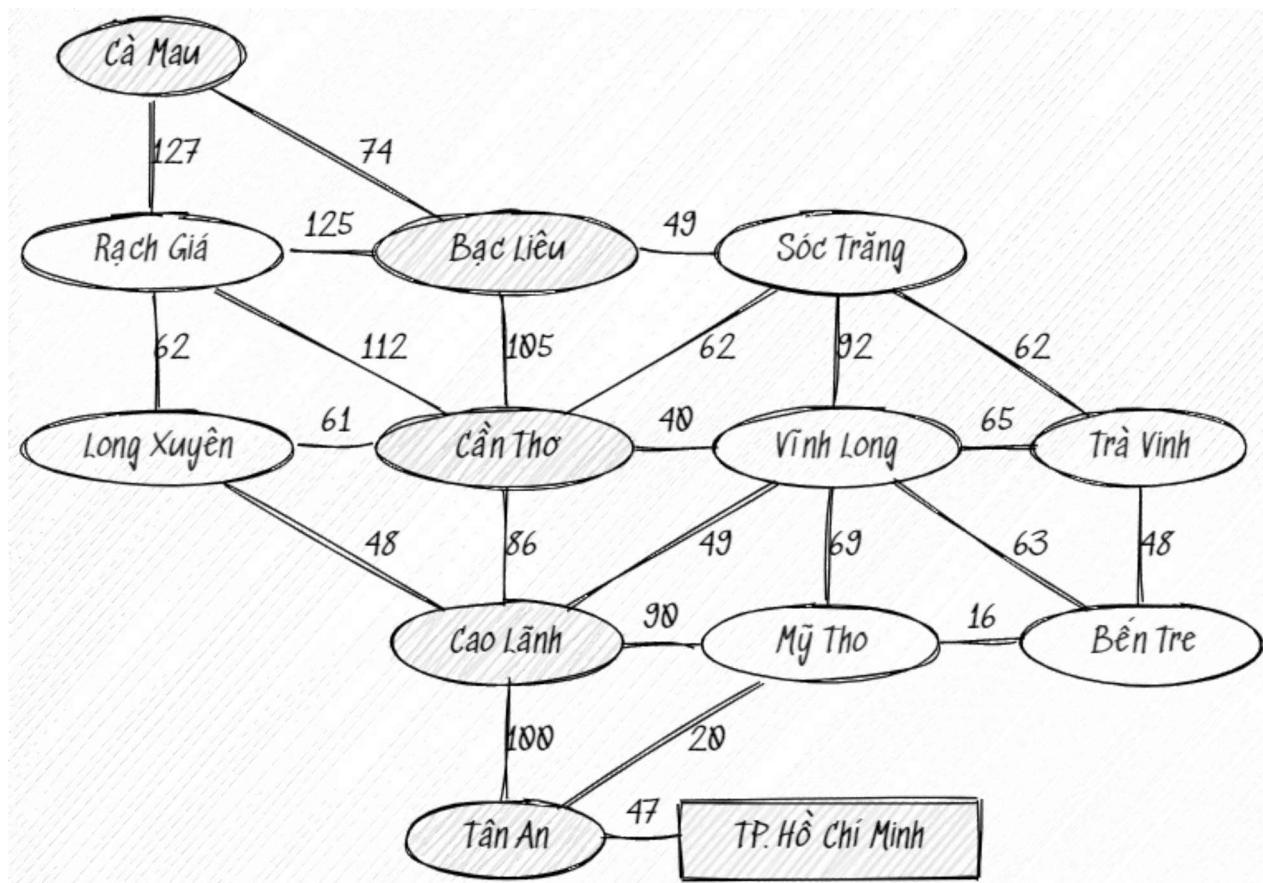
*Implementation: Fringe
is a FIFO queue*



Breadth-First Search

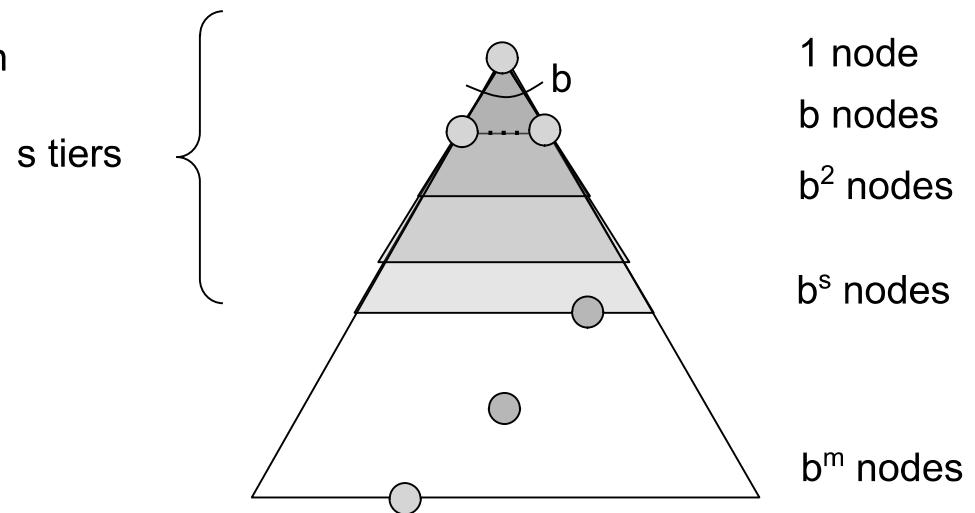


Breadth-First Search: Is it optimal?



Breadth-First Search (BFS) Properties

- What nodes does BFS expand?
 - Processes all nodes above shallowest solution
 - Let depth of shallowest solution be s
 - Search takes time $O(b^s)$
- How much space does the fringe take?
 - Has roughly the last tier, so $O(b^s)$
- Is it complete?
 - s must be finite if a solution exists, so yes!
- Is it optimal?
 - Only if costs are all 1 (more on costs later)

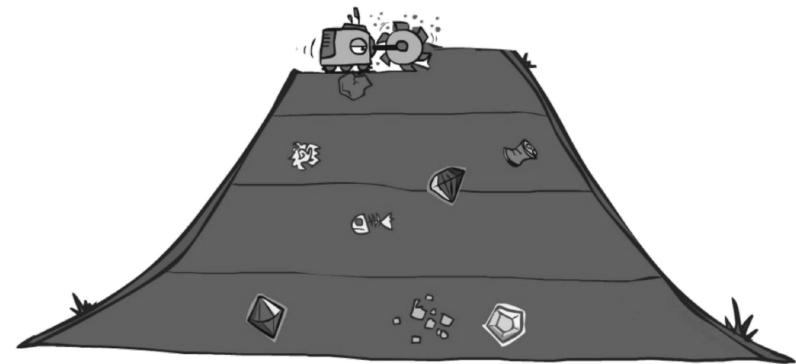
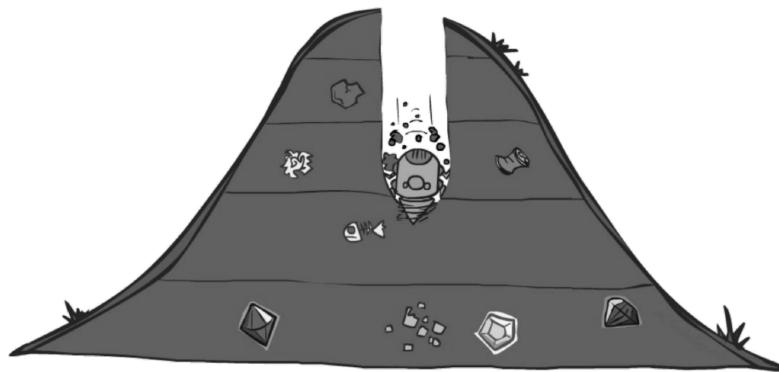


Breadth-First Search (BFS) Properties

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.

Quiz: DFS vs BFS

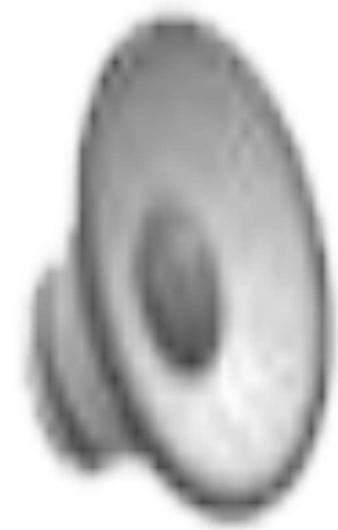


DFS vs BFS

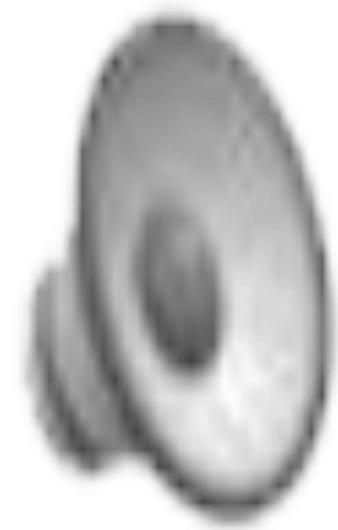
- When will BFS outperform DFS?
- When will DFS outperform BFS?

[Demo: dfs/bfs maze water (L2D6)]

Video of Demo Maze Water DFS/BFS (part 1)

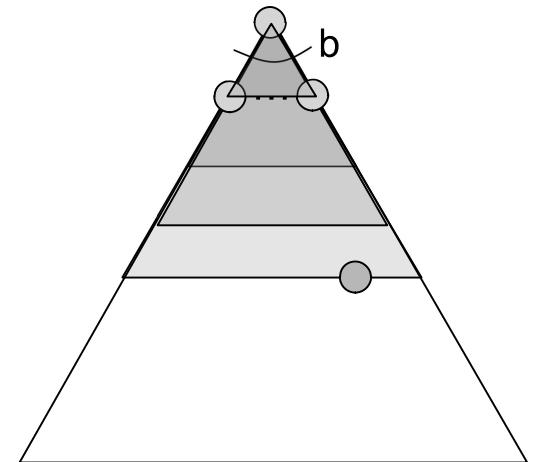


Video of Demo Maze Water DFS/BFS (part 2)

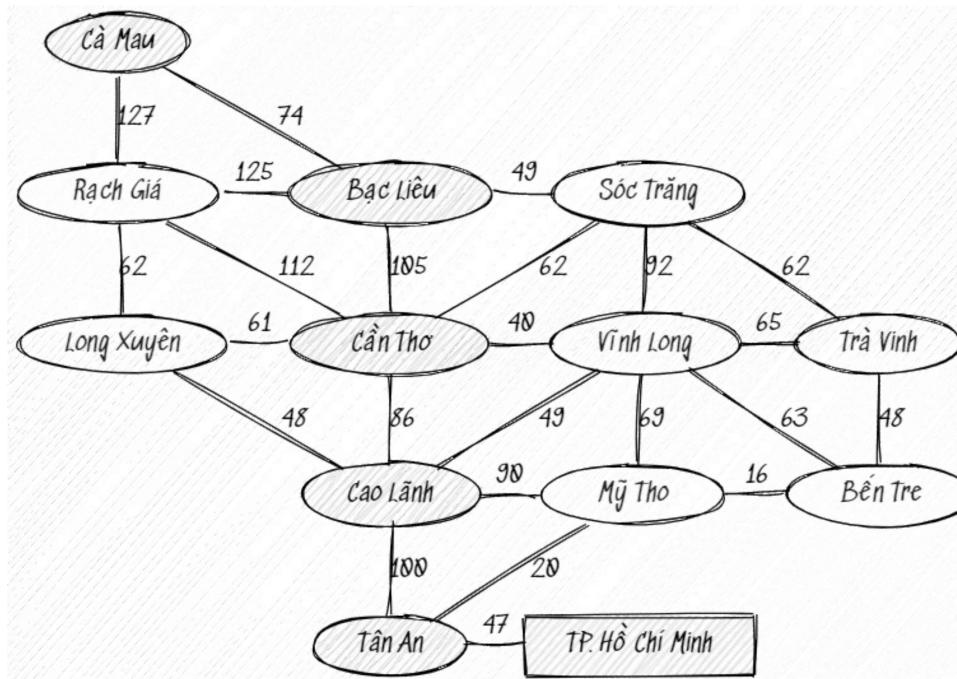


Iterative Deepening

- 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



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.

Uniform Cost Search

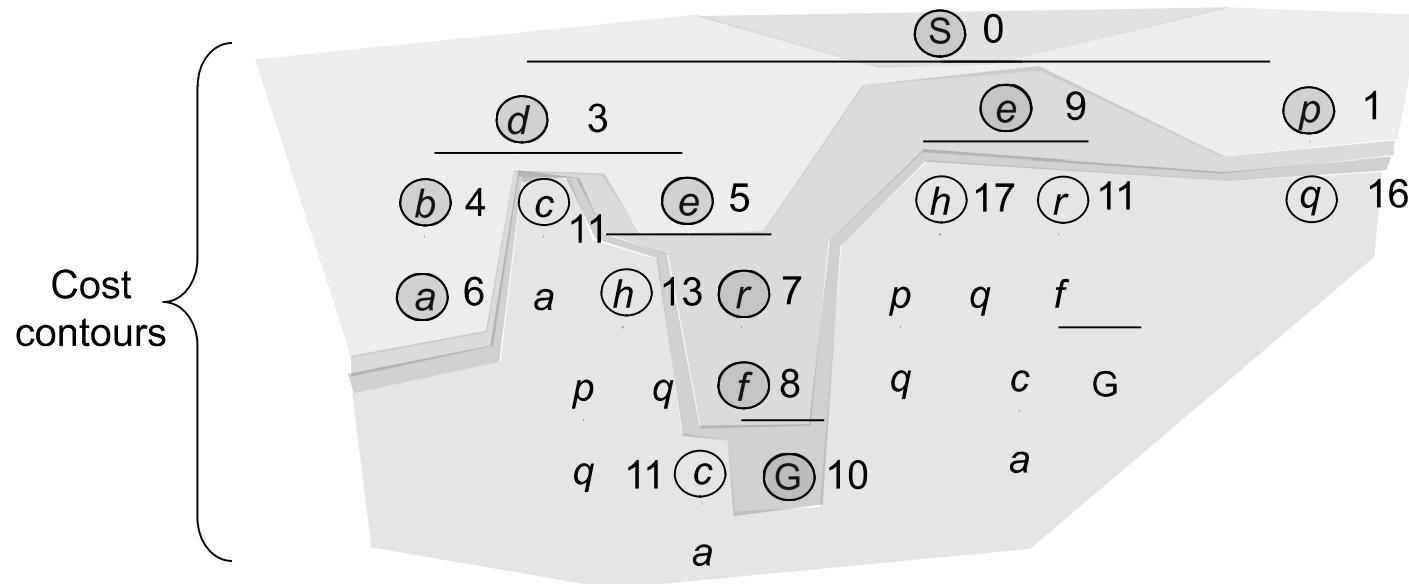
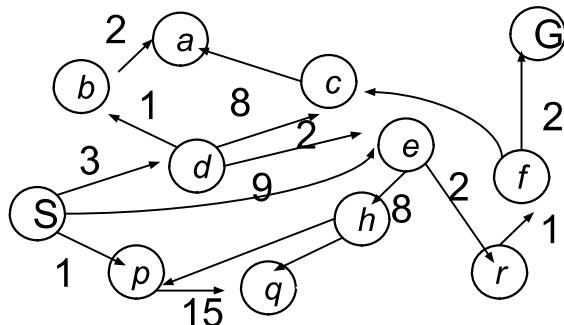
Strategy: expand a cheapest node first.



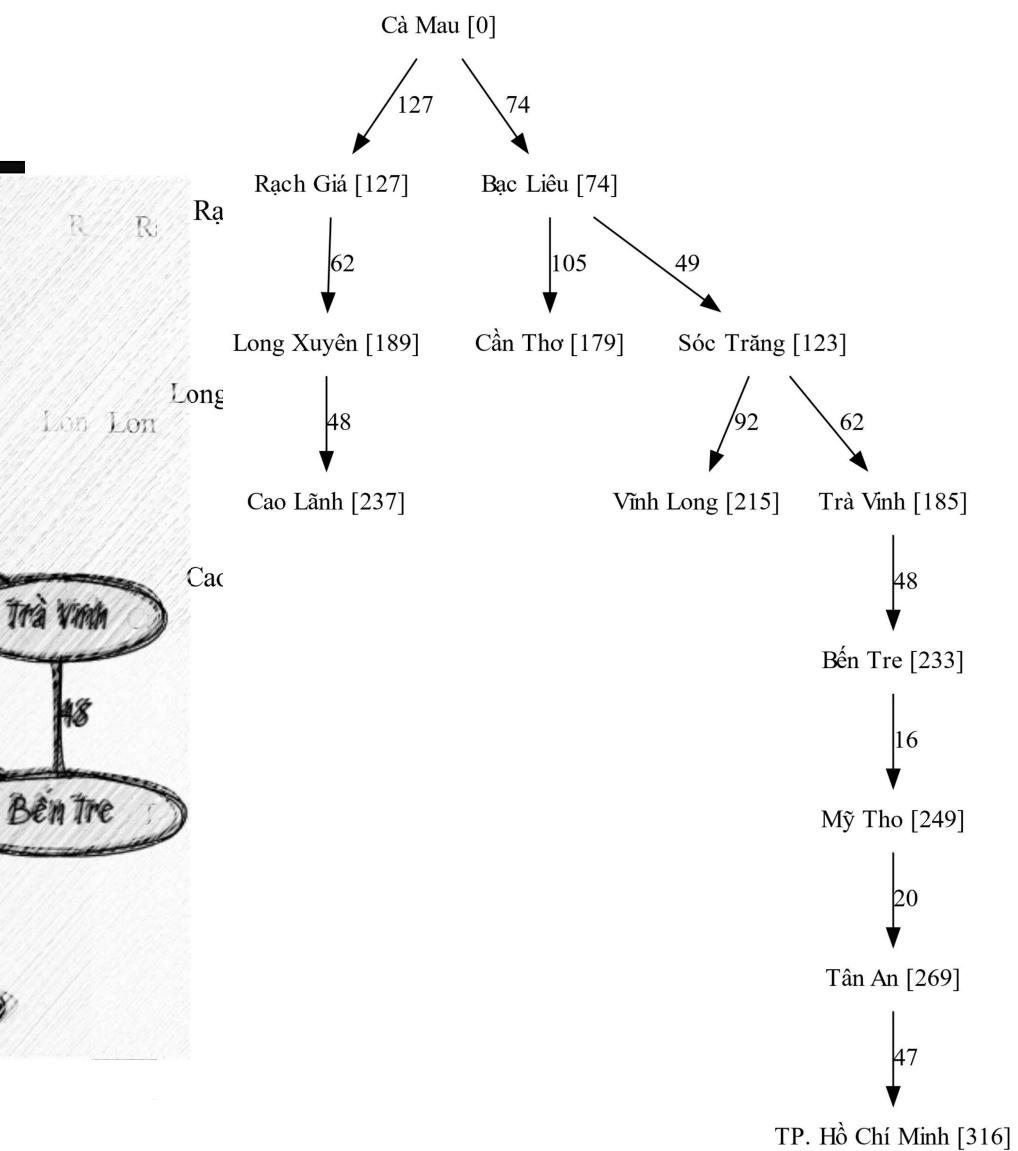
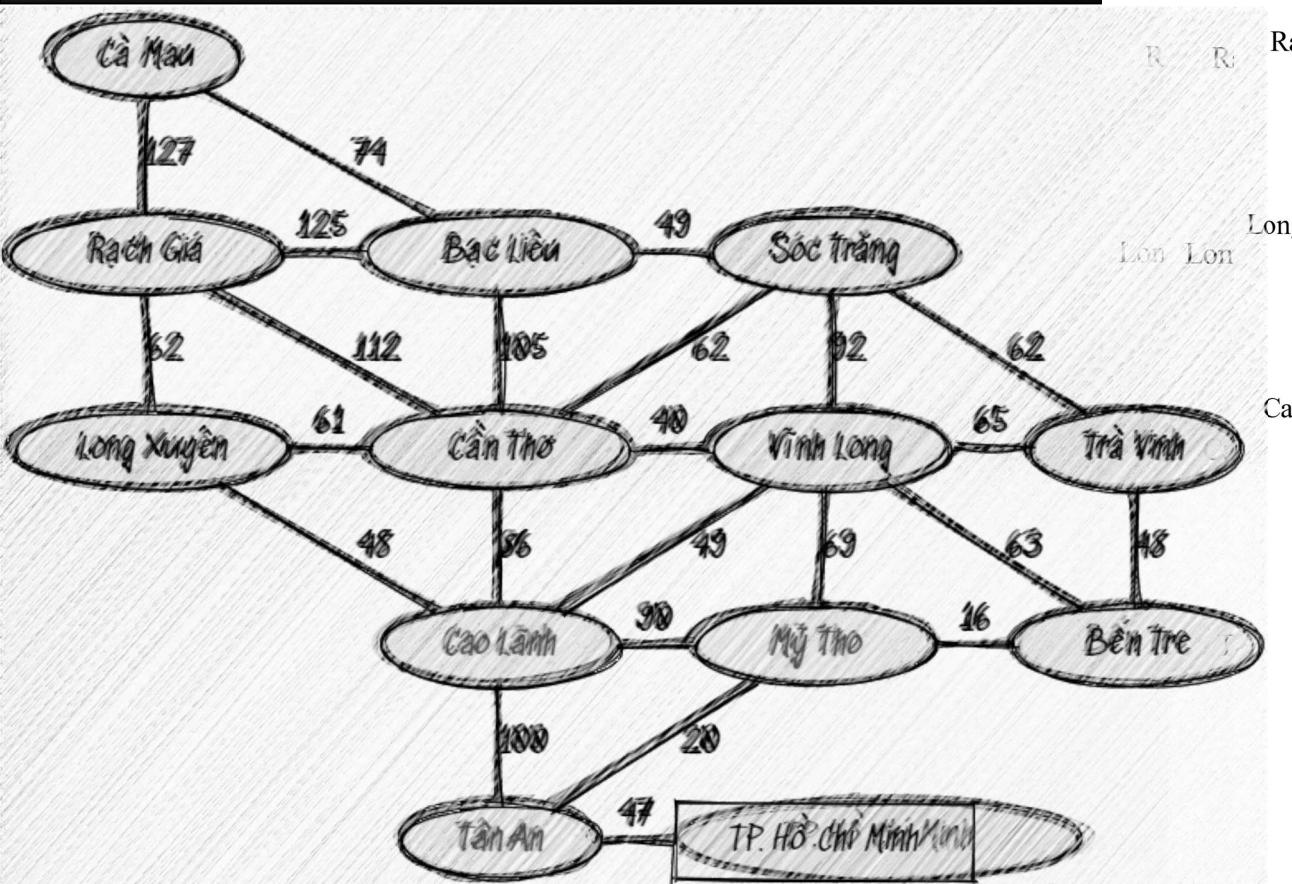
Uniform Cost Search

Strategy: expand a cheapest node first:

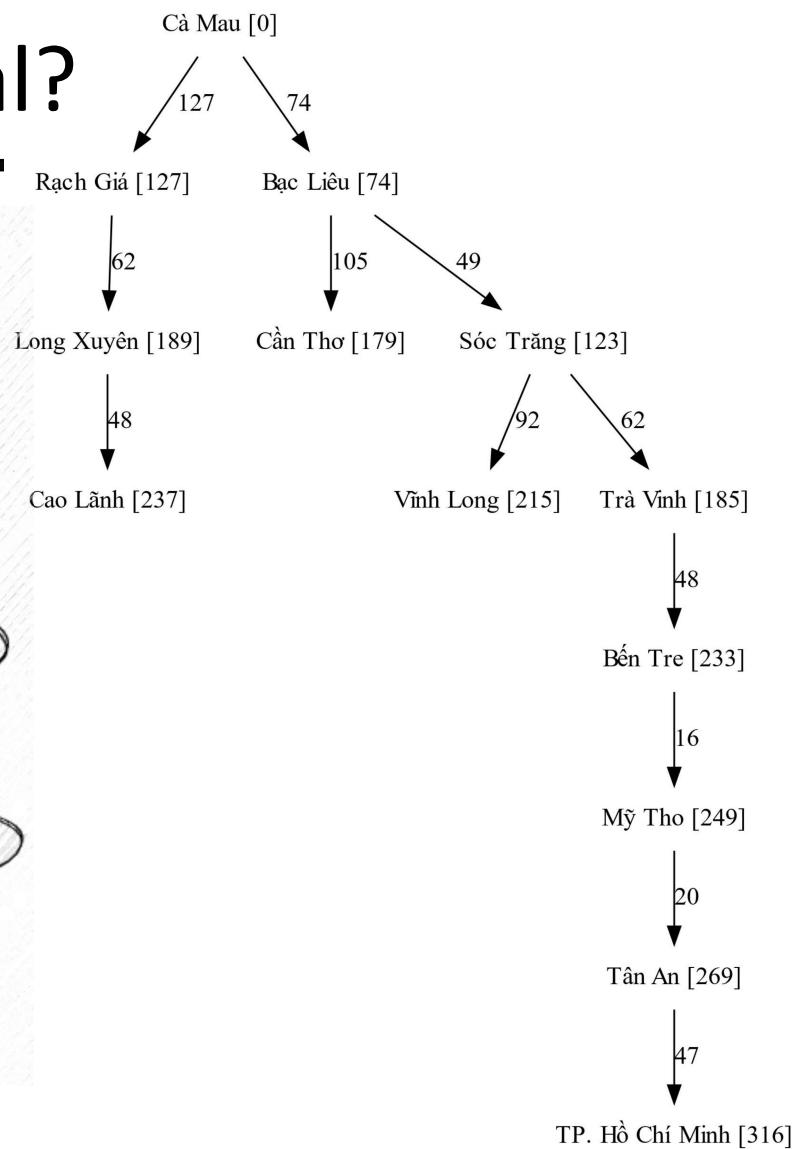
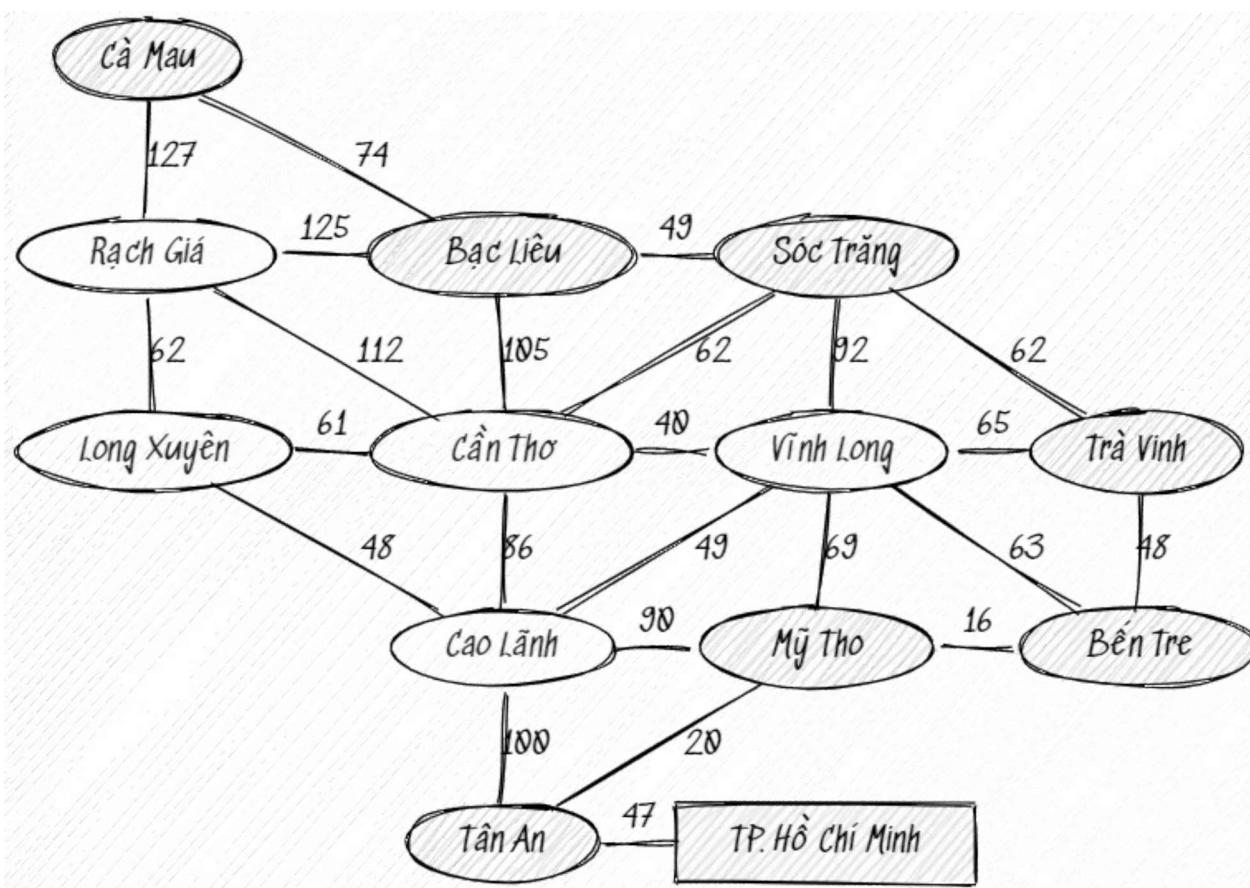
Fringe is a priority queue
(priority: cumulative cost)



Uniform Cost Search

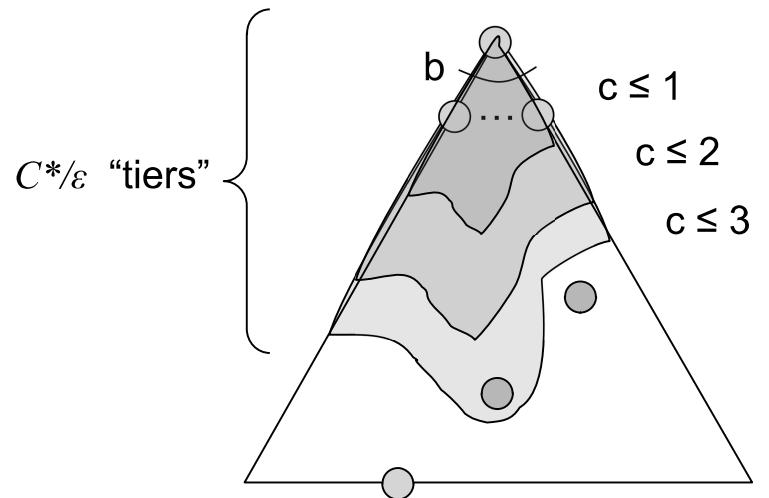


Uniform Cost Search: Is it optimal?



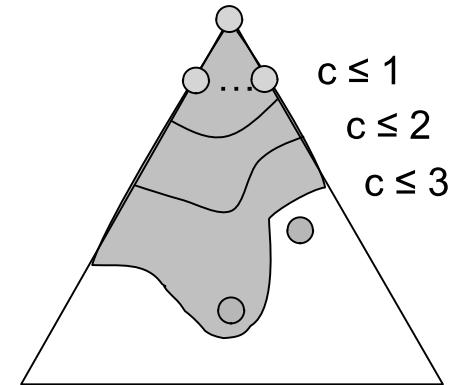
Uniform Cost Search (UCS) Properties

- 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!
- Is it optimal?
 - Yes!



Uniform Cost Issues

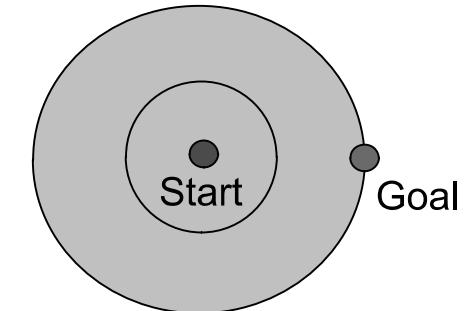
- Remember: UCS explores increasing cost contours



- The good: UCS is complete and optimal!

- The bad:

- Explores options in every “direction”
 - No information about goal location



- We'll fix that soon!

Video of Demo Empty UCS



Video of Demo Maze with Deep/Shallow Water --- DFS, BFS, or UCS? (part 1)



Video of Demo Maze with Deep/Shallow Water --- DFS, BFS, or UCS? (part 2)

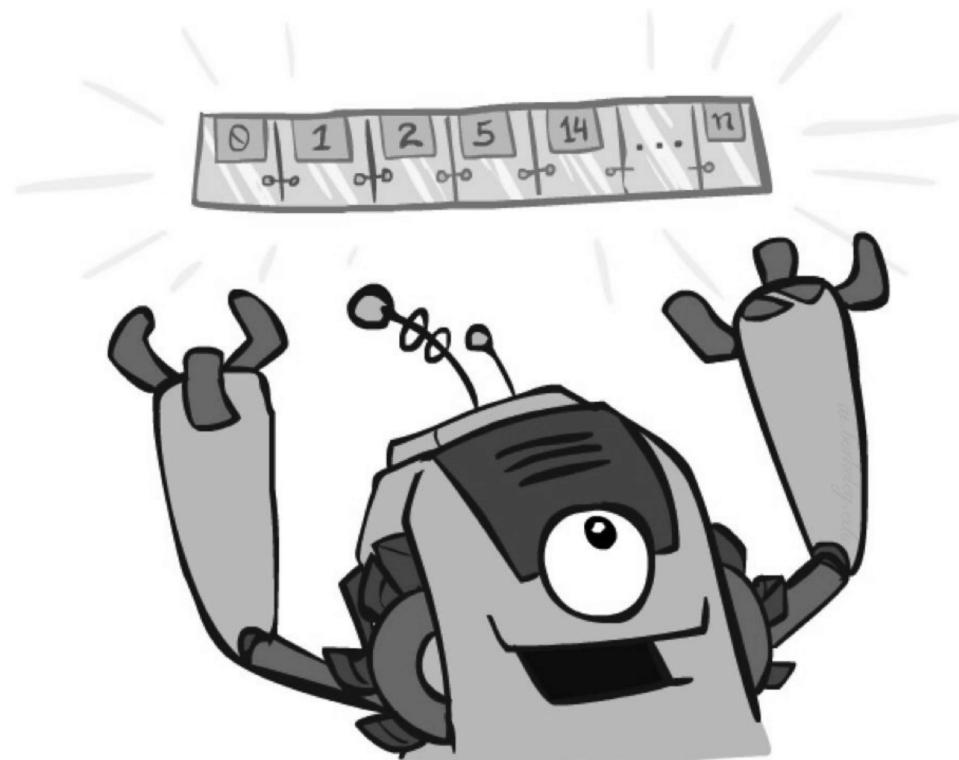


Video of Demo Maze with Deep/Shallow Water --- DFS, BFS, or UCS? (part 3)



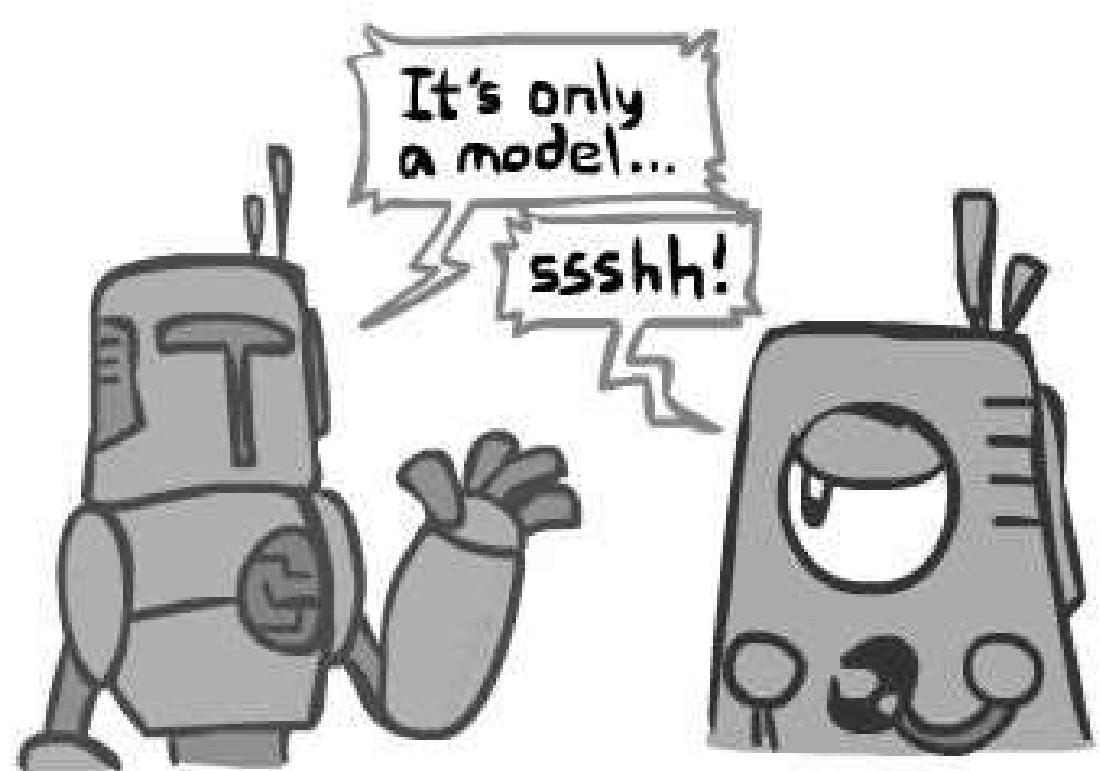
The One Queue

- 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



Search and Models

- Search operates over models of the world
 - The agent doesn't actually try all the plans out in the real world!
 - Planning is all “in simulation”
 - Your search is only as good as your models...



Search Gone Wrong?

