Kinds of task environments

6 common properties to distinguish tasks (not exhaustive)

- **Fully observable** vs **Partially observable**
- **Single agent** vs **Multiagent**
- **Deterministic** vs **Stochastic**
- **Episodic** vs **Sequential**
- **Static** vs **Dynamic**
- **Discrete** vs **Continuous**

Col 1 – Poker
Col 2 – Self-driving taxi
Col 3 – Spam classifier
Col 4 – Pacman with ghosts
Col 5 – Oil refinery control system
Col 6 – Automatic speech transcription

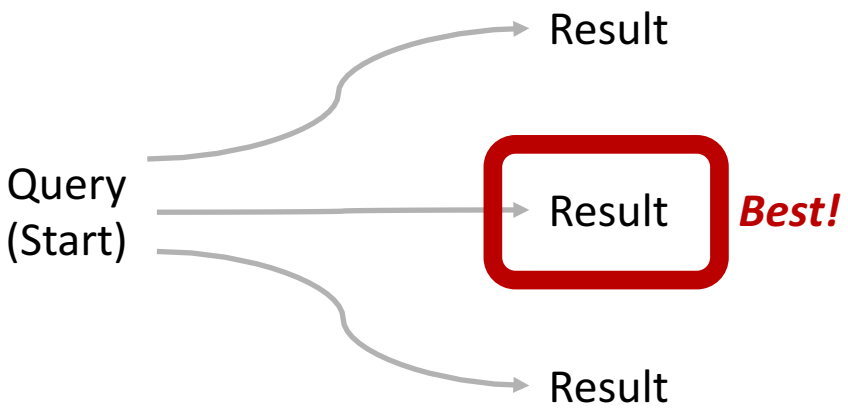
Search Problems

Search?

Information Retrieval vs Search

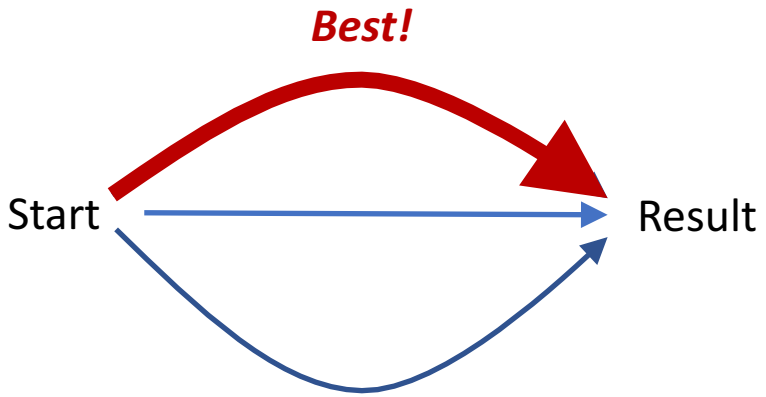
Google

(Information Retrieval)



Search

(Problem-Solving)



Definition of Search

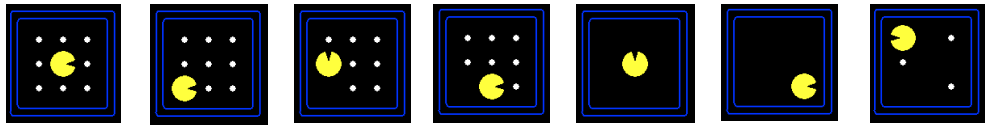
Finding a (best) sequence of actions to solve a problem

For now, assume the problem is

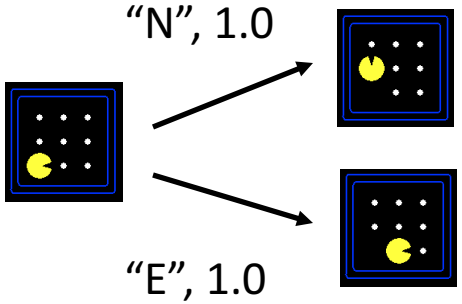
- Deterministic
- Fully observable
- Known

Search Problem Mechanics

- A search problem consists of:
  - A state space



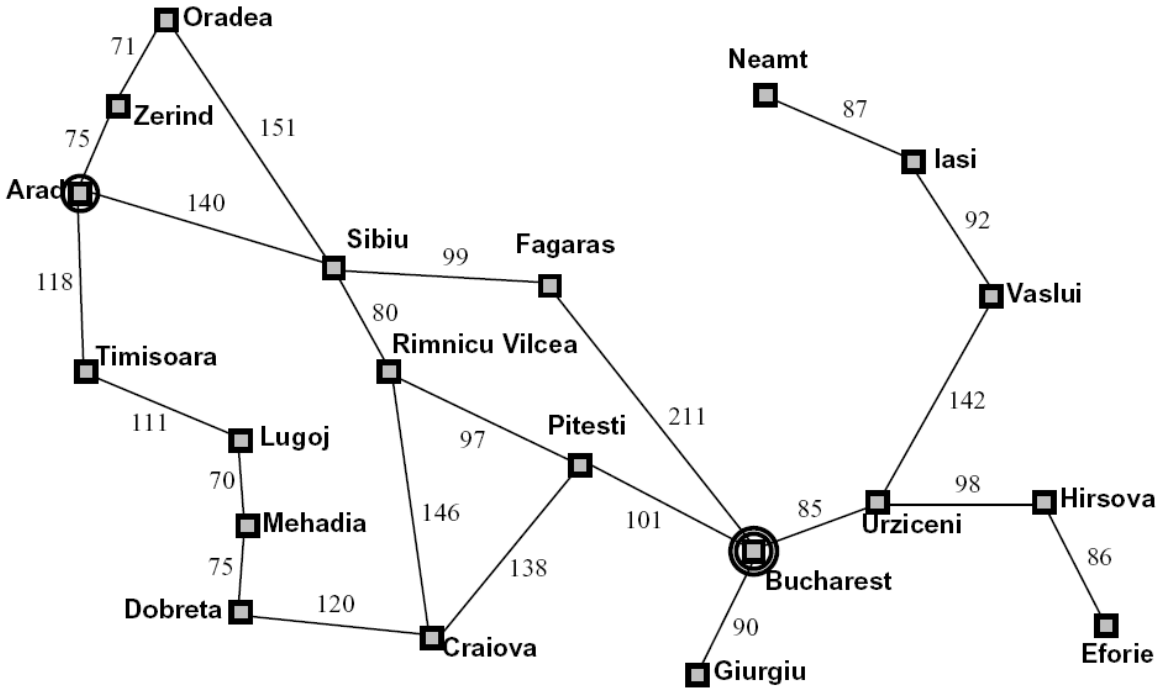
  - A successor function (with actions, costs)



  - 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

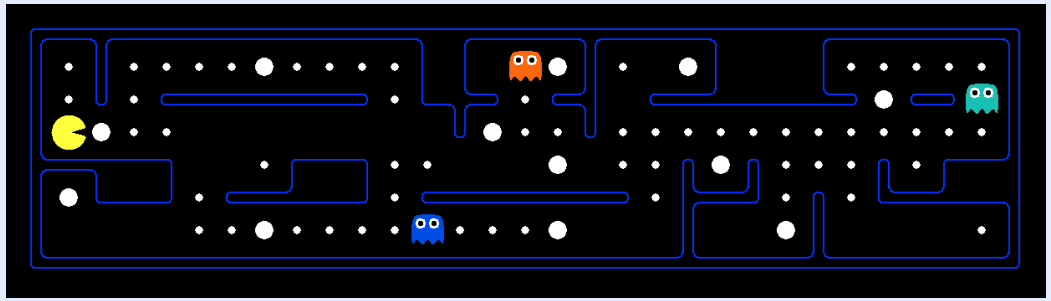
Example: Traveling in Romania



- State space:
  - Cities
- Successor function:
  - Roads: Go to adjacent city with cost = distance
- Start state:
  - Arad
- Goal test:
  - Is state == Bucharest?
- 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)

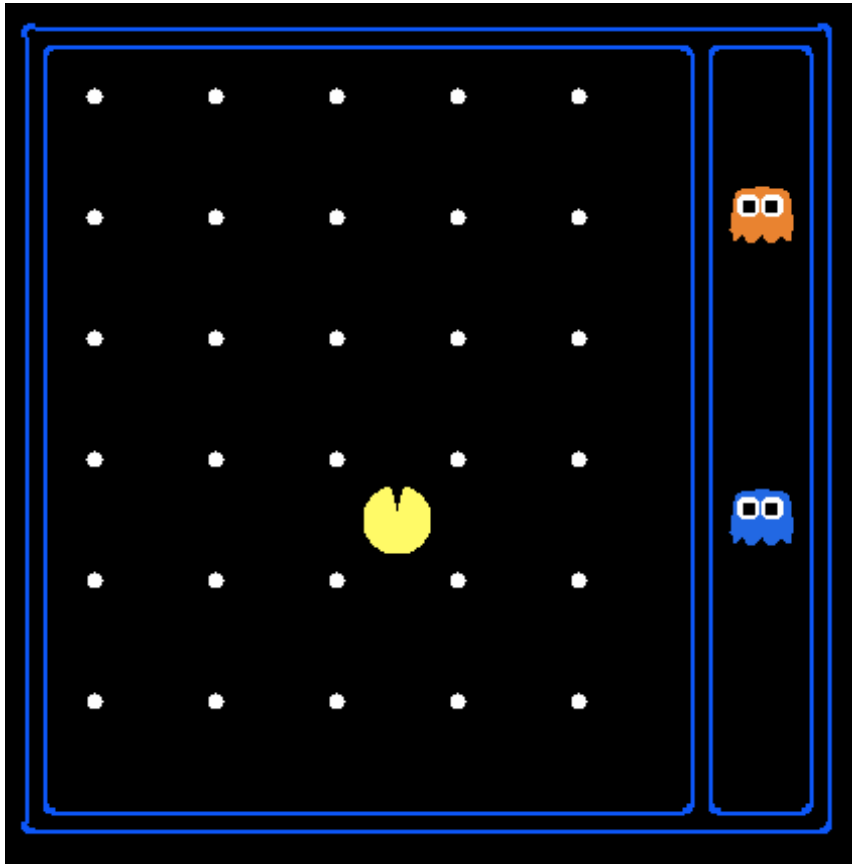
- Problem: Pathing
  - States: (x,y) location
  - Actions: NSEW
  - Successor: update location only
  - Goal test: is (x,y)=END

- 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?
    $120x(2^{30})x(12^2)x4$
  - States for pathing?
    120
  - States for eat-all-dots?
    $120x(2^{30})$



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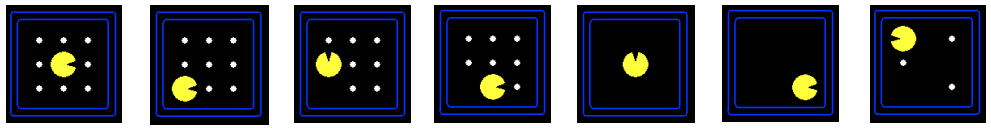
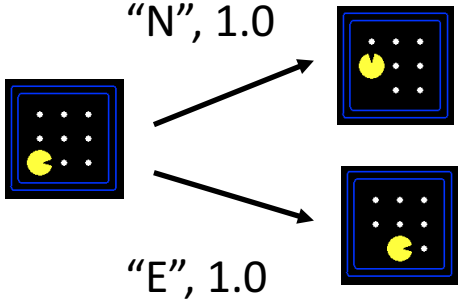


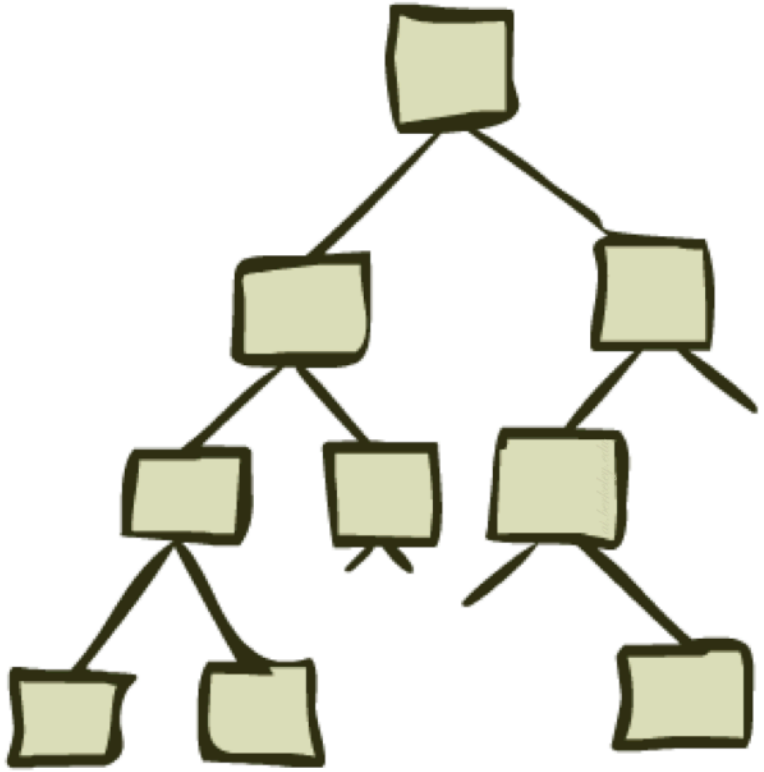
  - A successor function (with actions, costs)
  - A start state and a goal test



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

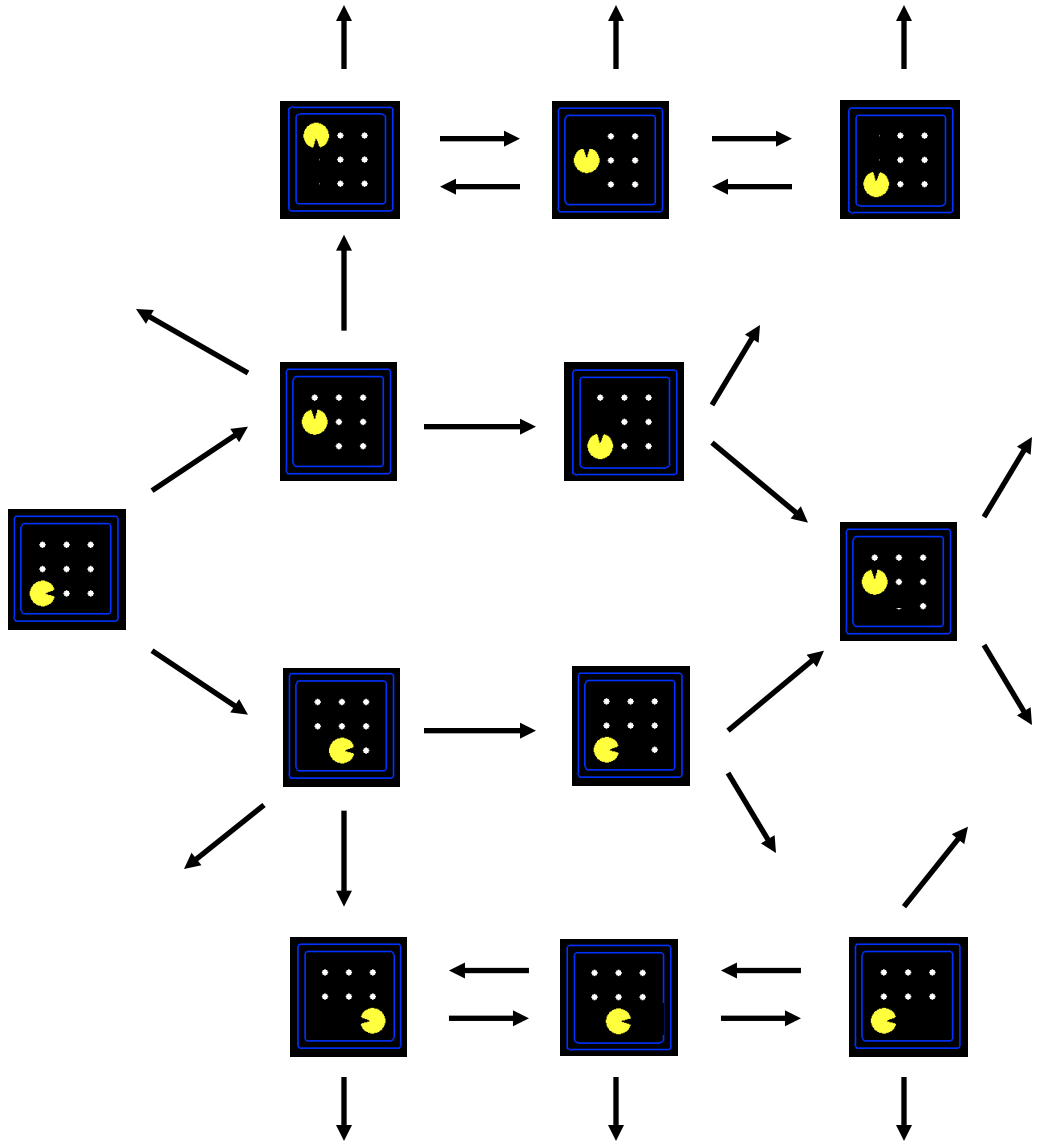
What are some problems that <u>can't</u> be formulated as search?

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



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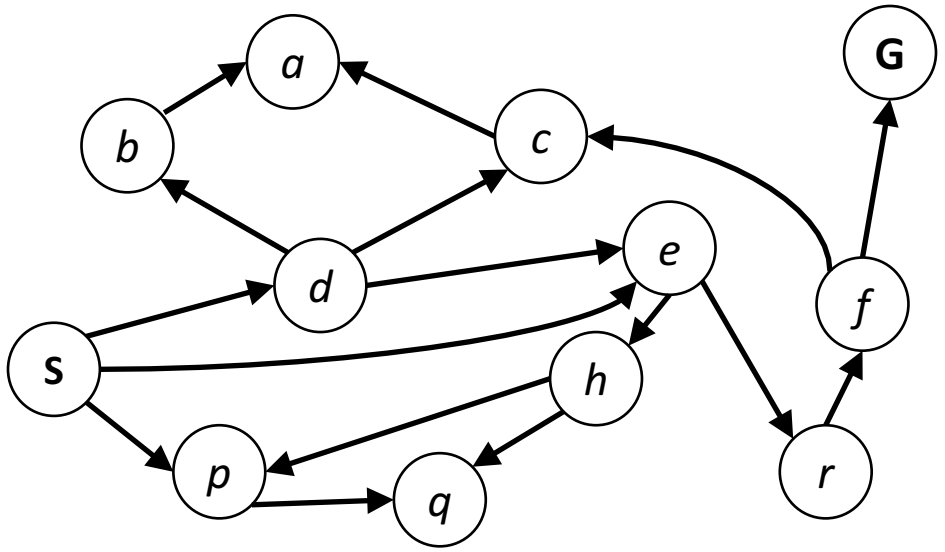
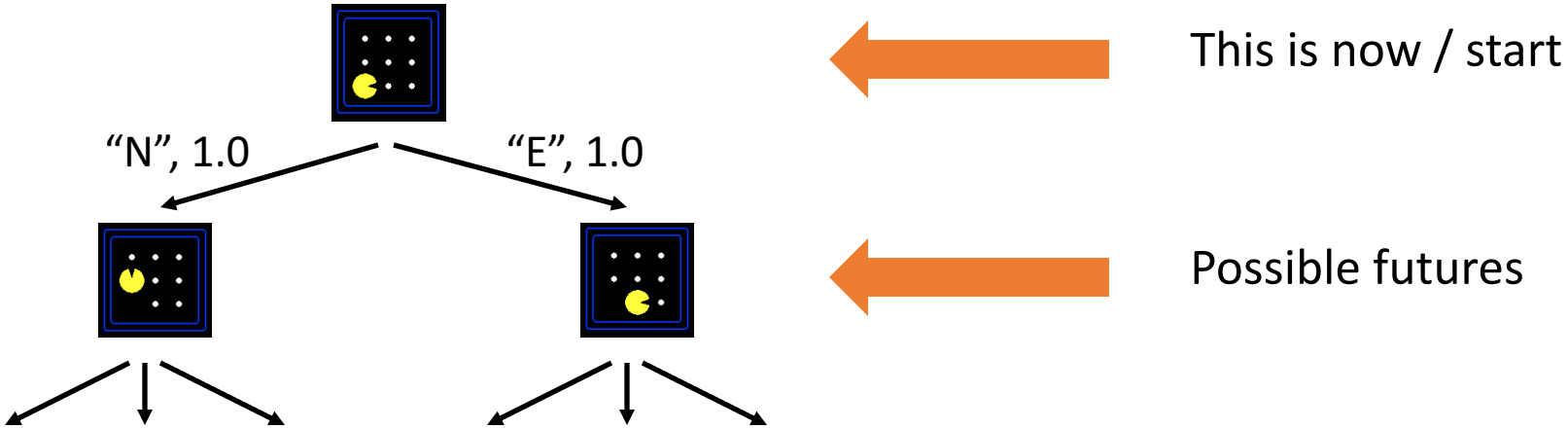


Tiny search graph for a tiny search problem

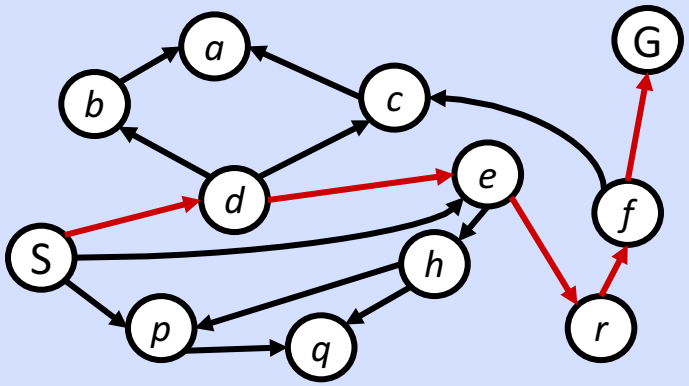
Search Trees



- 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 ACTION SEQUENCES that achieve those states
  - For most problems, we can never actually build the whole tree

State Space Graphs vs. Search Trees

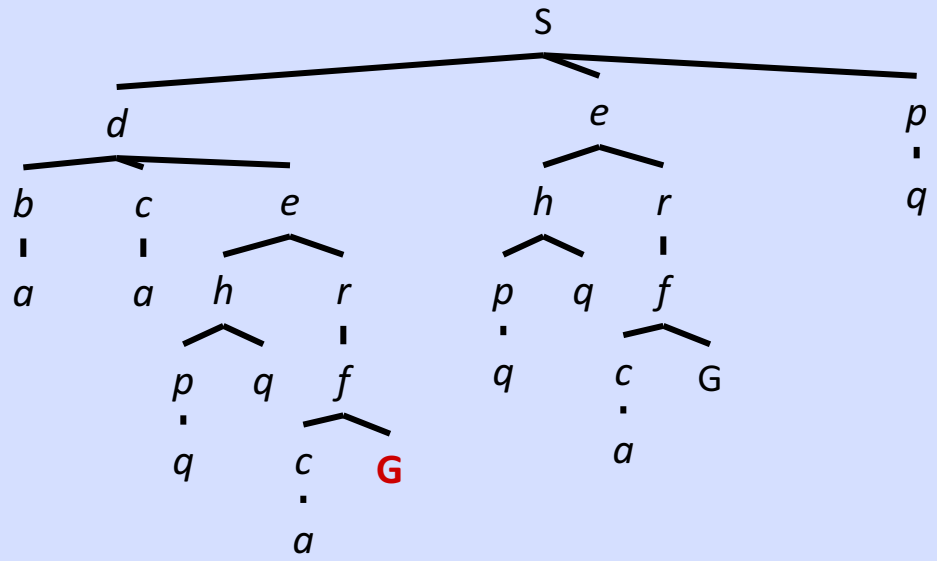
State Space Graph



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

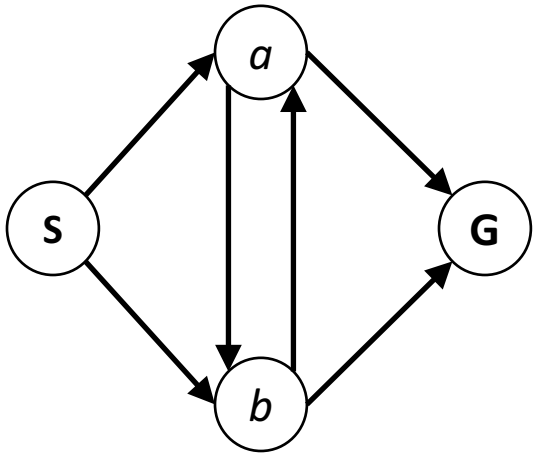
We construct both on demand – and we construct as little as possible.

Search Tree



Quiz: State Space Graphs vs. Search Trees

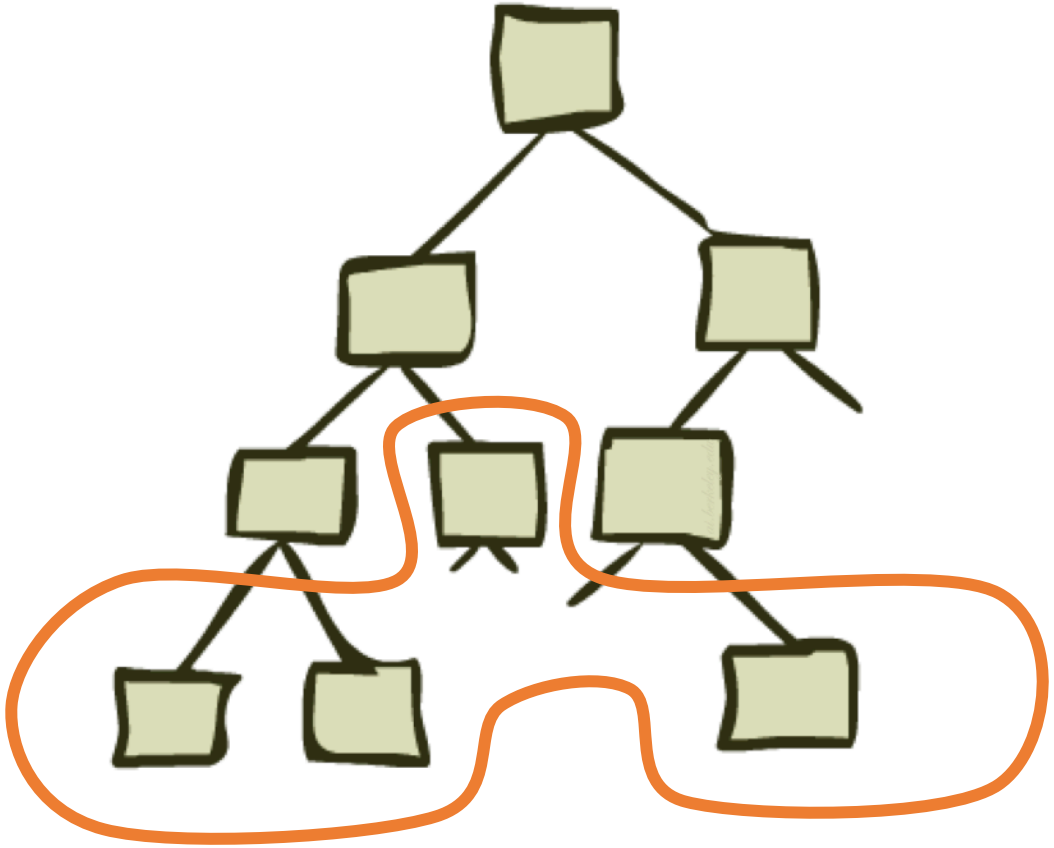
Consider this 4-state graph:



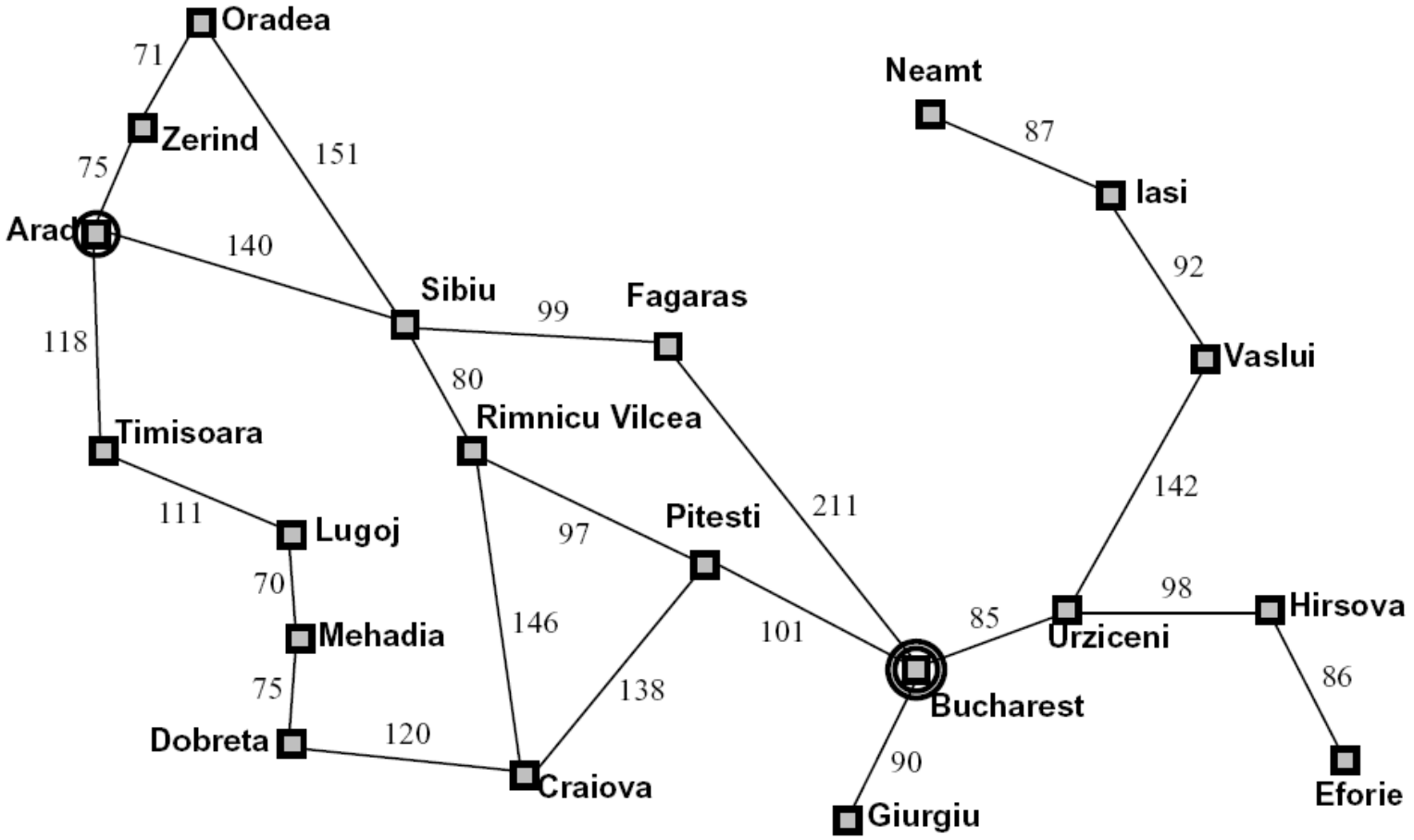
How big is its search tree (from S)?

Important: Lots of repeated structure in the search tree!

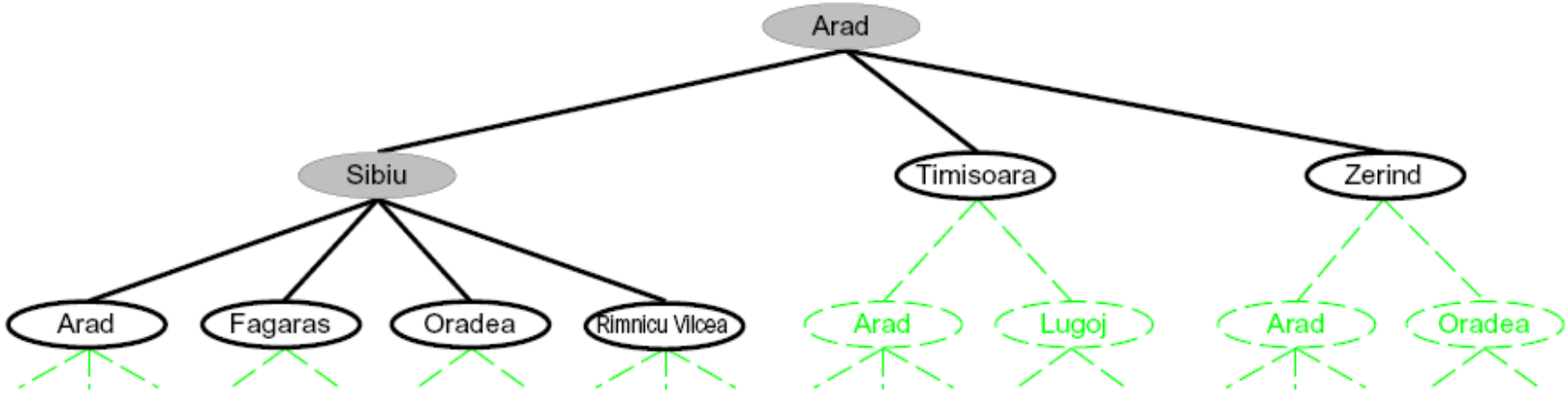
Tree Search



Search Example: Romania



Searching with a Search Tree



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

General Tree Search

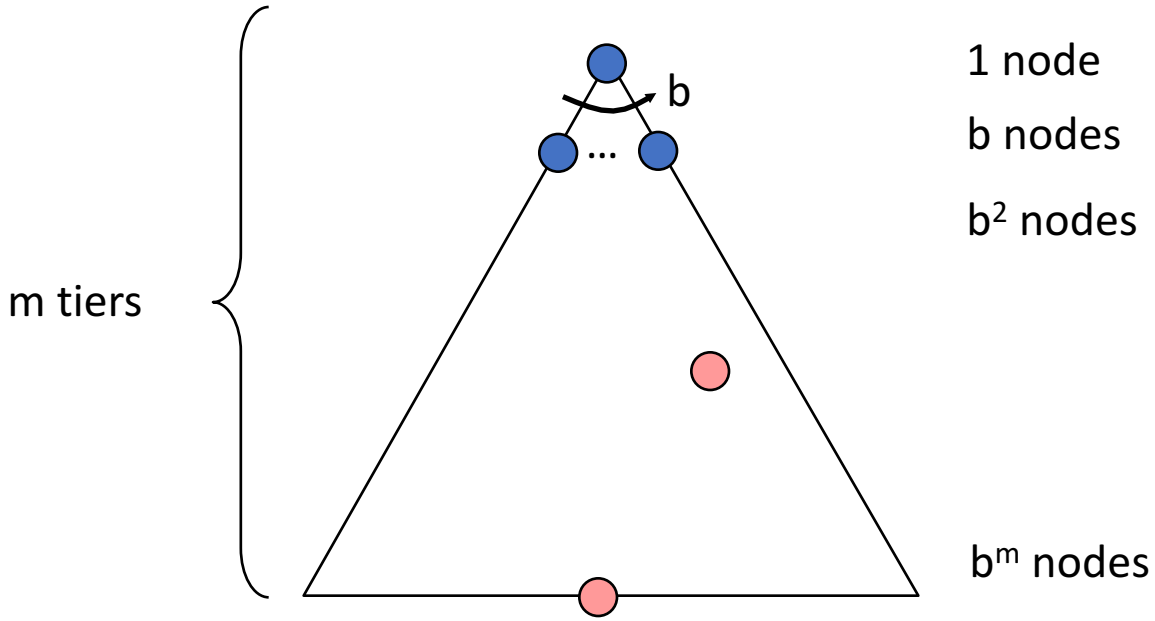
```
function TREE-SEARCH( problem, strategy) returns a solution, or failure
    initialize the search tree using the initial state of problem
    loop do
        if there are no candidates for expansion then return failure
        choose a leaf node for expansion according to strategy
        if the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

Search Algorithm Properties

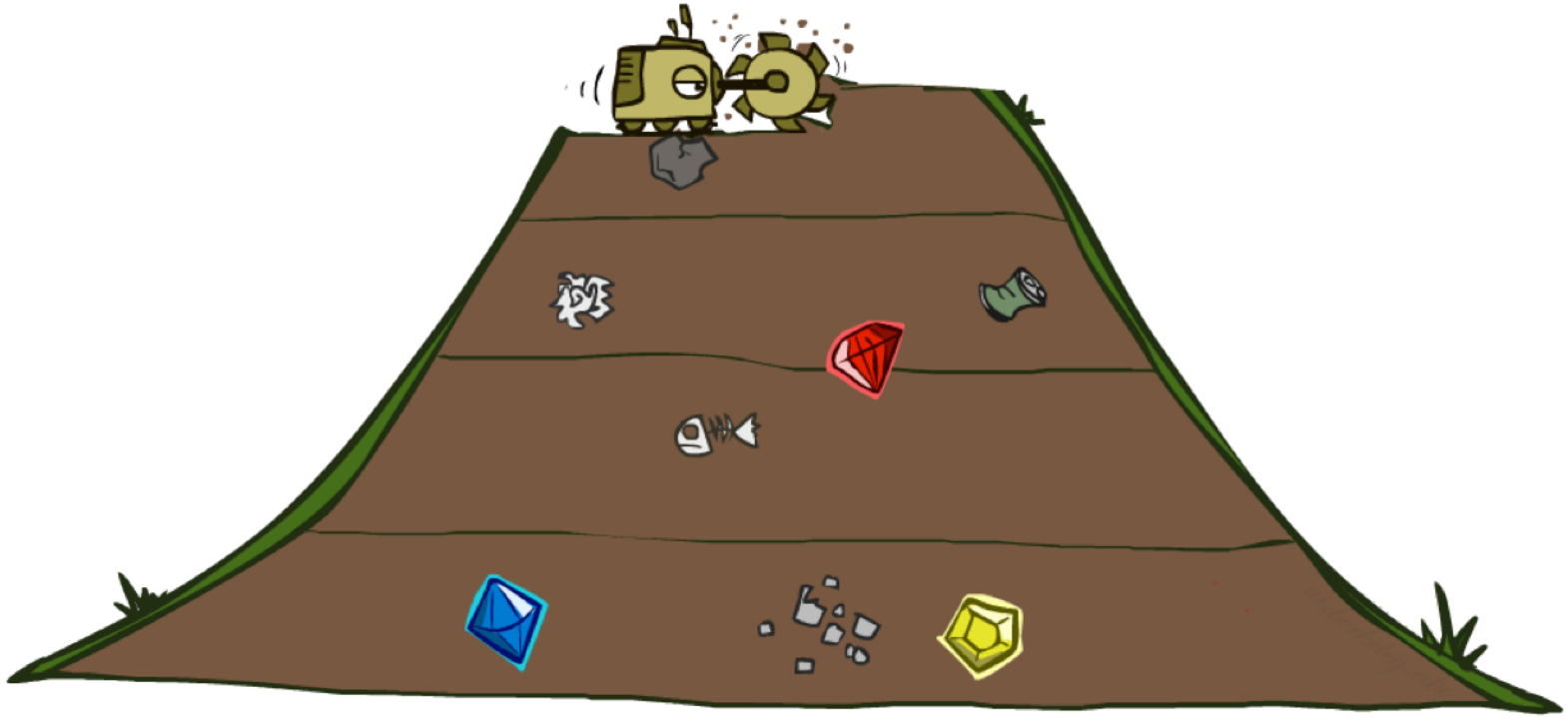
- Complete: Guaranteed to find a solution if one exists?
- Optimal: Guaranteed to find the least cost path?
- Time complexity?
- Space complexity?

- Cartoon of search tree:
  - b is the branching factor
  - m is the maximum depth
  - solutions at various depths

- Number of nodes in entire tree?
  - $1 + b + b^2 + \ldots. b^m = O(b^m)$



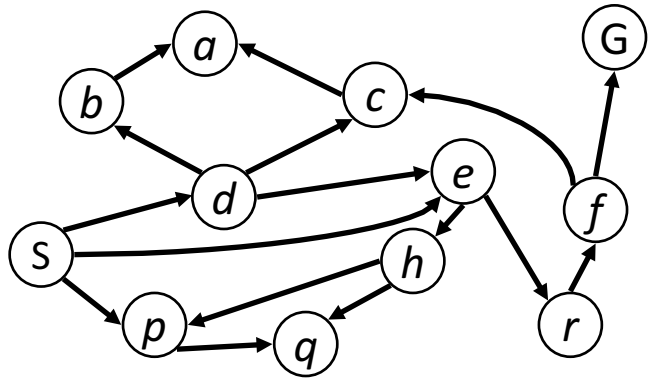
Breadth-First Search



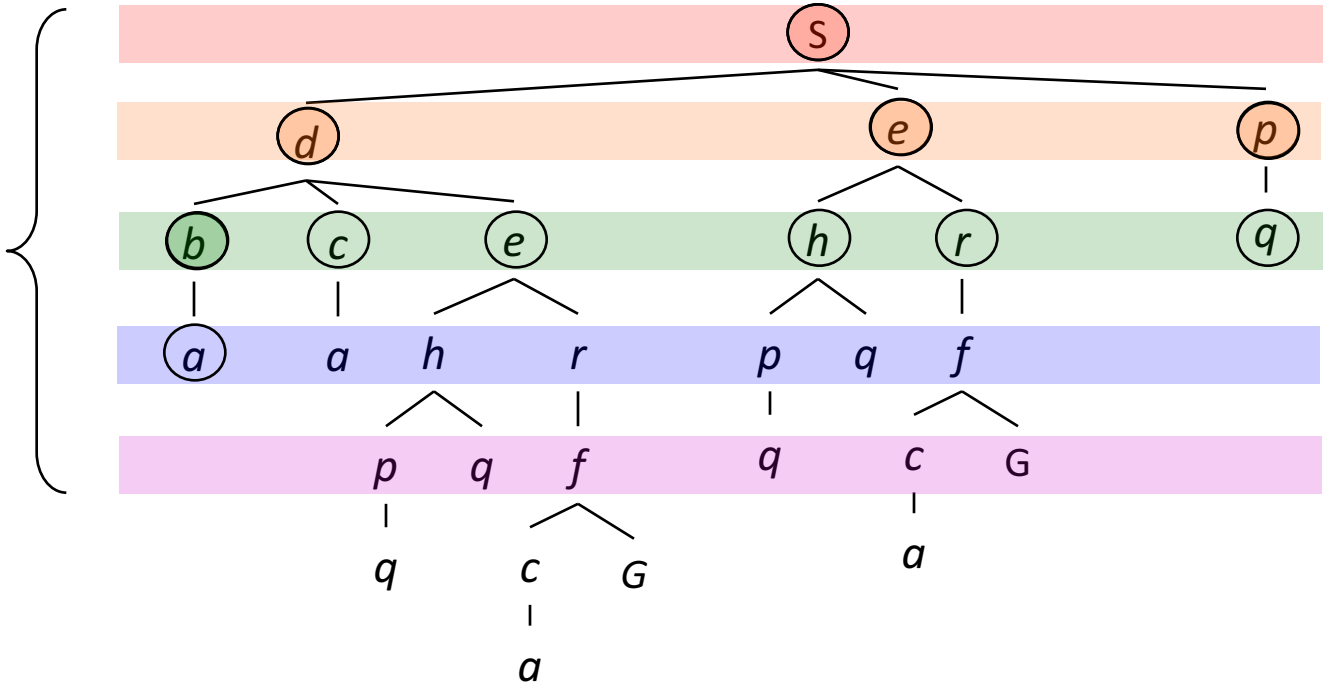
Breadth-First Search

Strategy: expand a shallowest node first

Implementation: Fringe is a FIFO queue

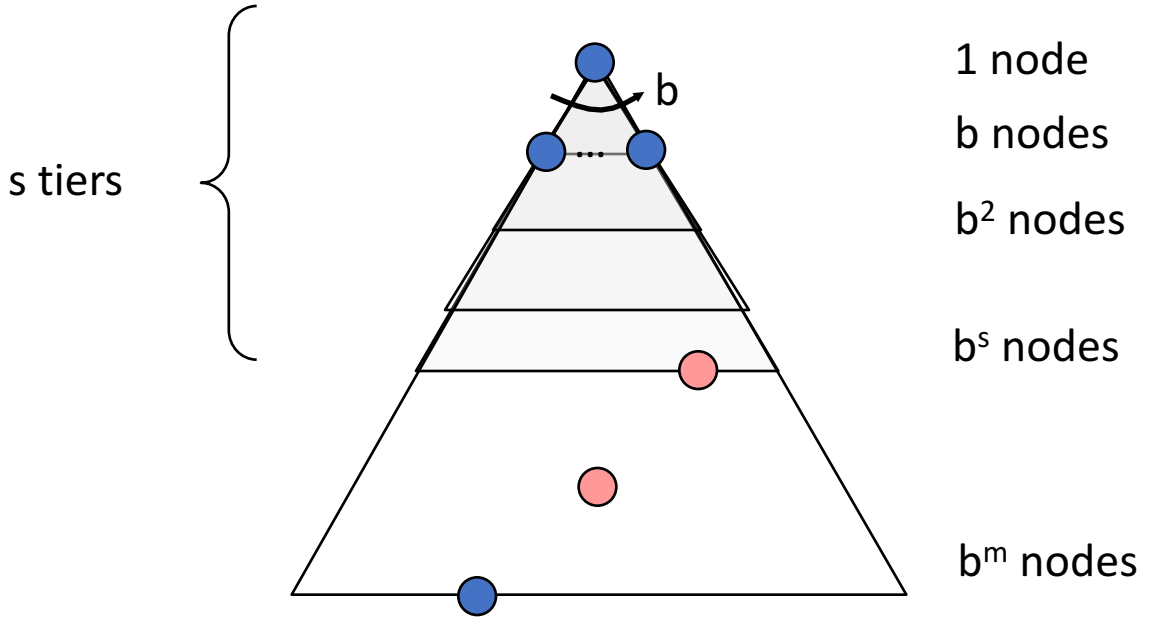


Search Tiers



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)



Python code for BFS

```
import collections

def bfs(graph, root):
    seen, queue = set([root]), collections.deque([root])
    while queue:
        vertex = queue.popleft()
        visit(vertex)
        for node in graph[vertex]:
            if node not in seen:
                seen.add(node)
                queue.append(node)

def visit(n):
    print(n)

if __name__ == '__main__':
    graph = {0: [1, 2], 1: [2, 0], 2: []}
    bfs(graph, 0)
```

Next time

Other search strategies