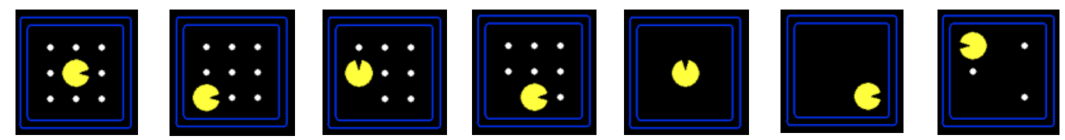
Solving Problems by Searching

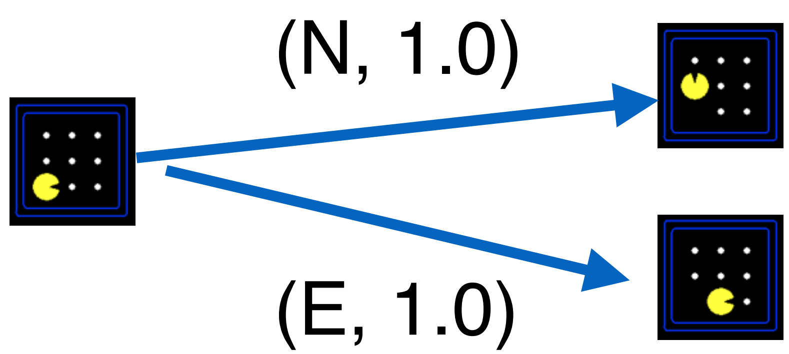
CS 486/686: Introduction to Artificial Intelligence
Winter 2016

Introduction

- Search was one of the first topics studied in AI
  - Newell and Simon (1961) *General Problem Solver*
- Central component to many AI systems
  - Automated reasoning, theorem proving, robot navigation, scheduling, game playing,...

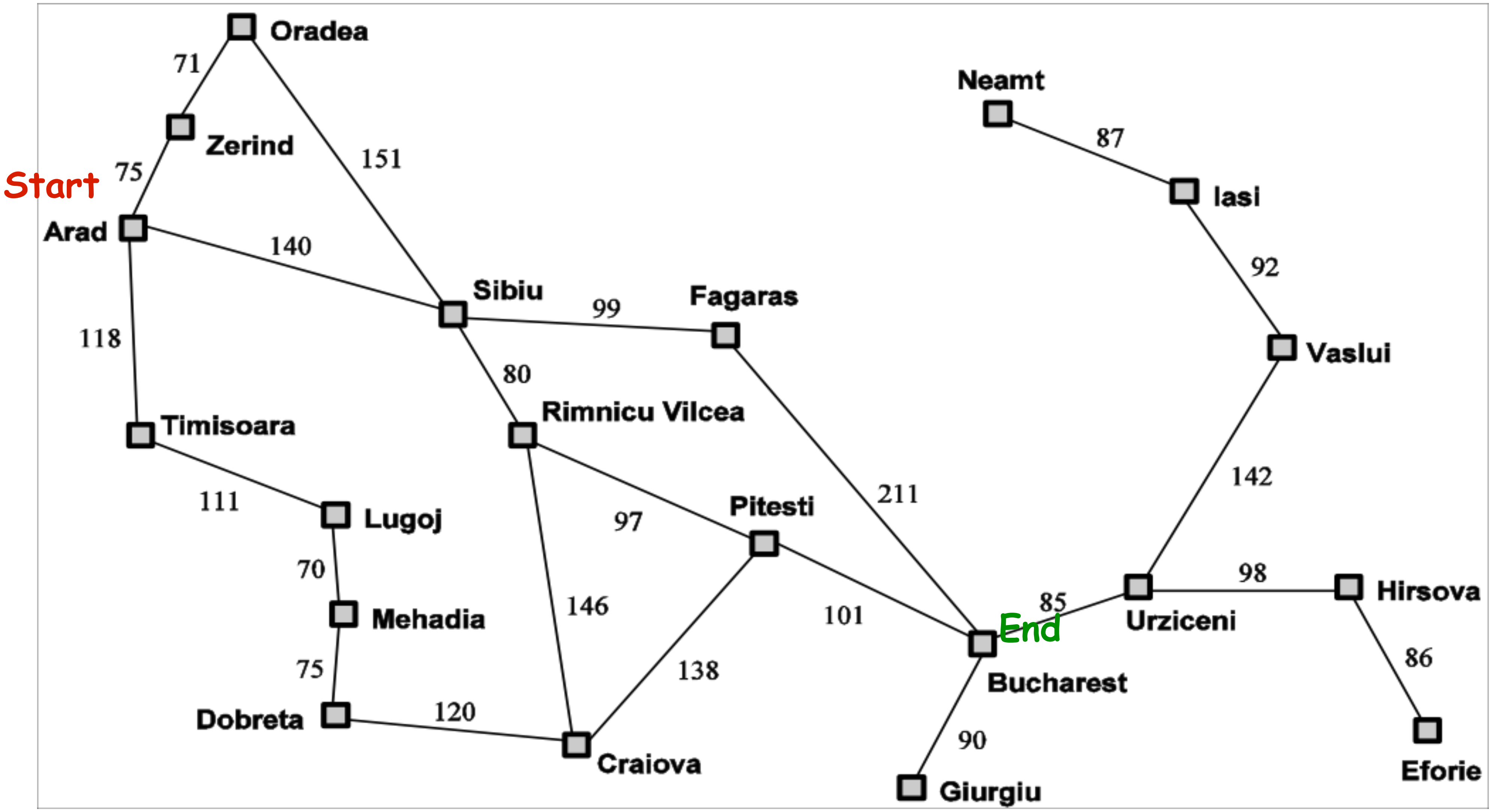
Search Problems

- A **search problem** consists of
  - a state space 
  - a successor function (actions, cost)



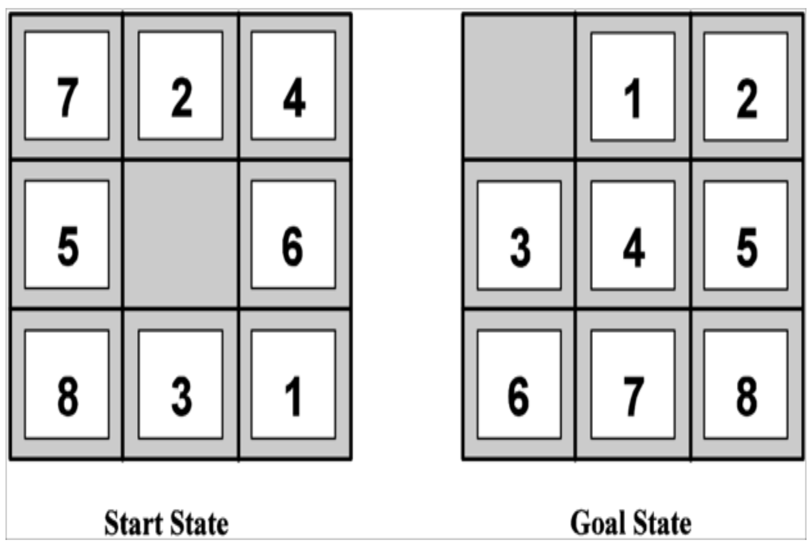
  - a start state and a goal test
- A **solution** is a sequence of actions (plan) from the start state to a goal state

Example: Traveling in Romania

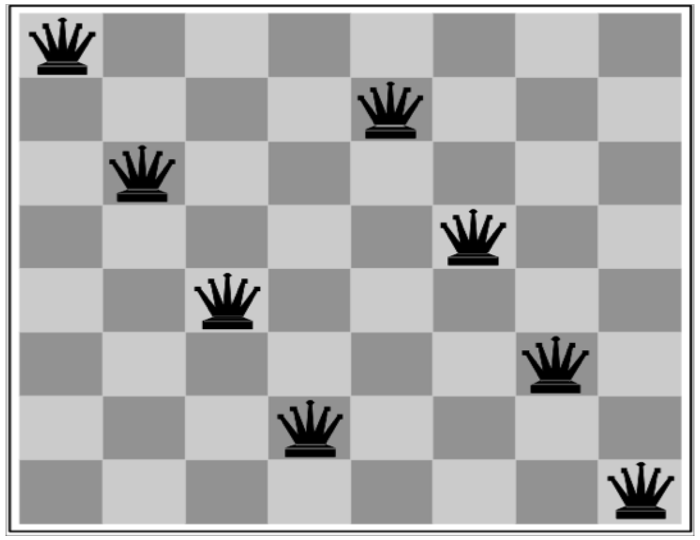


- States:
- Initial State:
- Successor Function:
- Goal test:
- Solution:

Examples of Search Problems

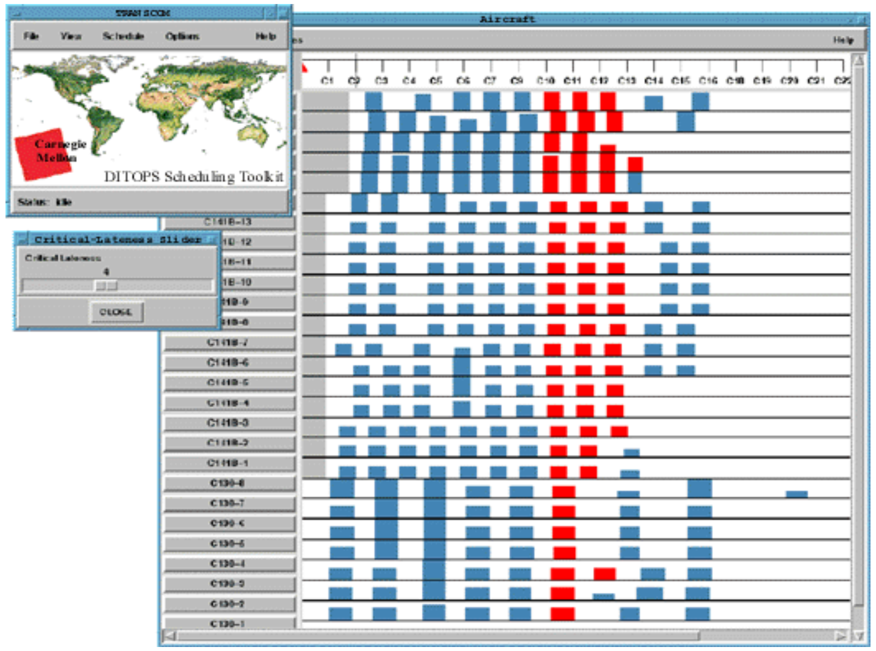


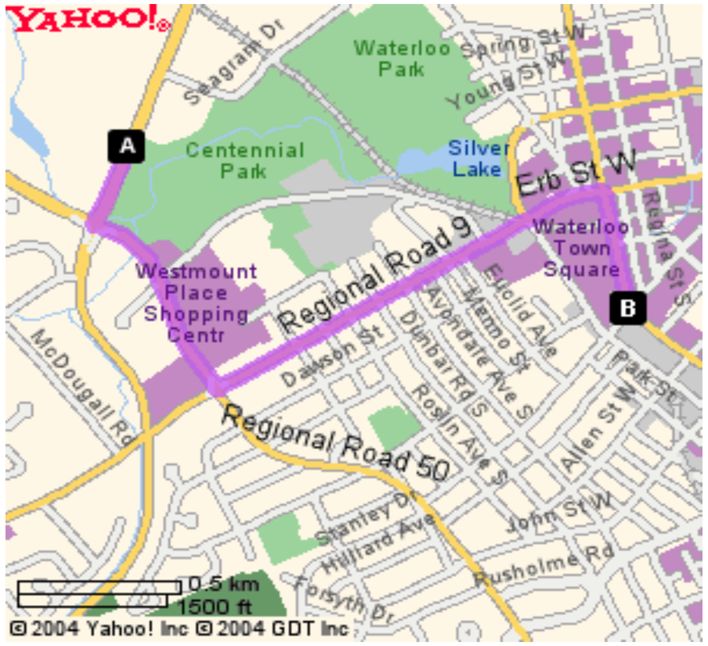
- States:
- Initial State:
- Successor Function:
- Goal test:
- Solution:



- States:
- Initial State:
- Successor Function:
- Goal test:
- Solution:

Examples of Search Problems





Our Definition Excludes...

Chance

Adversaries

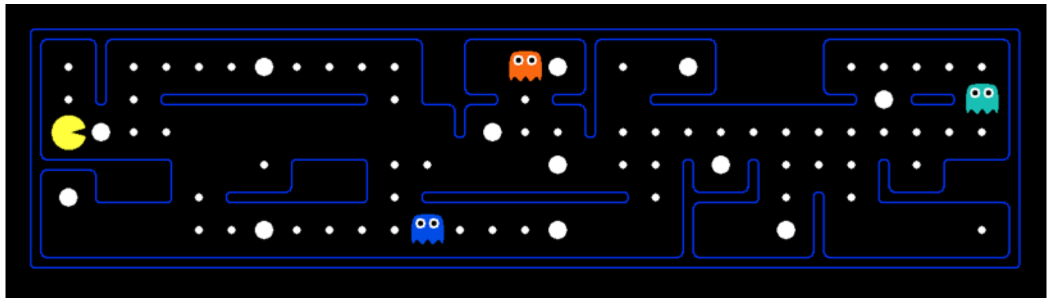
Continuous states

Partial Observability

All of the above

What is is a state space?

The **world state** includes every last detail of the environment



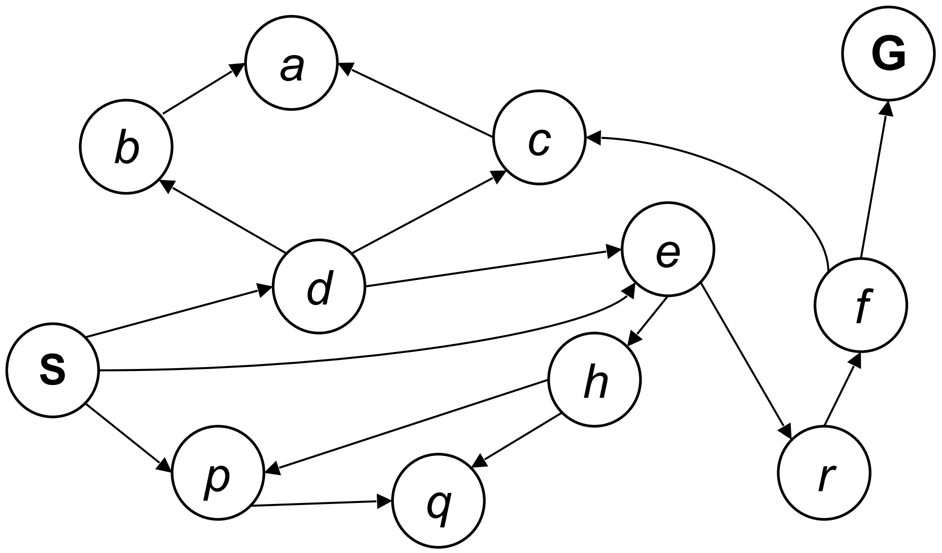
A **search state** keeps only the details needed for planning (abstraction)

- 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

Adapted from UC Berkeley's CS188 Course

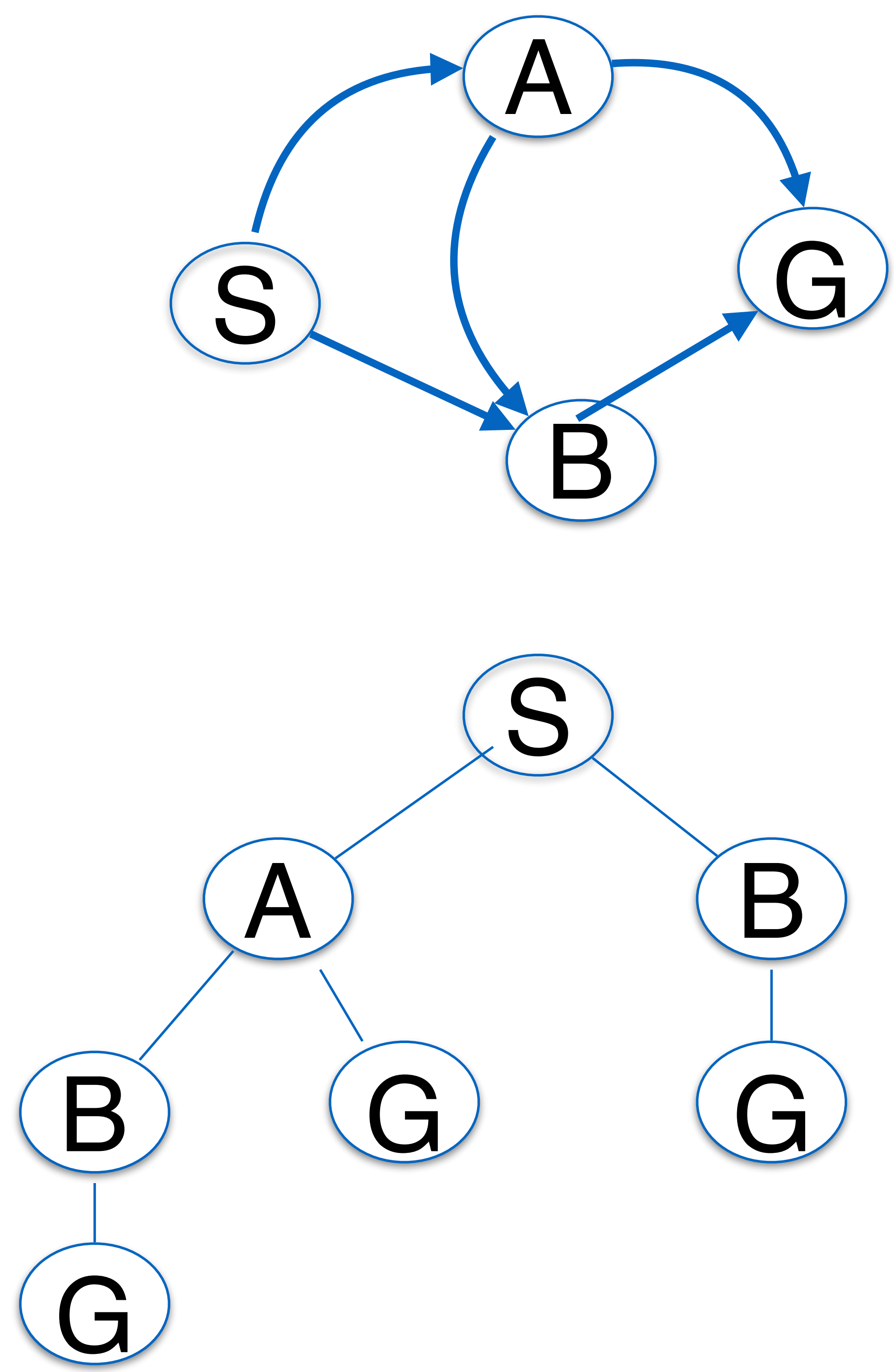
Representing Search

- State space graph
  - Vertices correspond to states (one vertex for each state)
  - Edges correspond to successors
  - Goal test is a set of goal nodes
- We search for a solution by building a search tree and traversing it to find a goal state



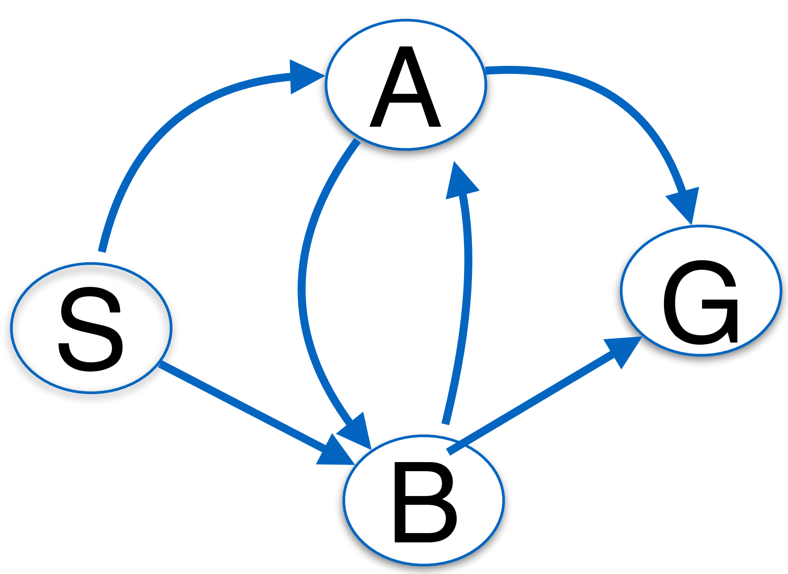
Search Tree

- A search tree:
  - Start state is the root of the tree
  - Children are successors
  - A plan is a path in the tree. A solution is a path from the root to a goal node.
  - For most problems we do not actually generate the entire tree



Quiz

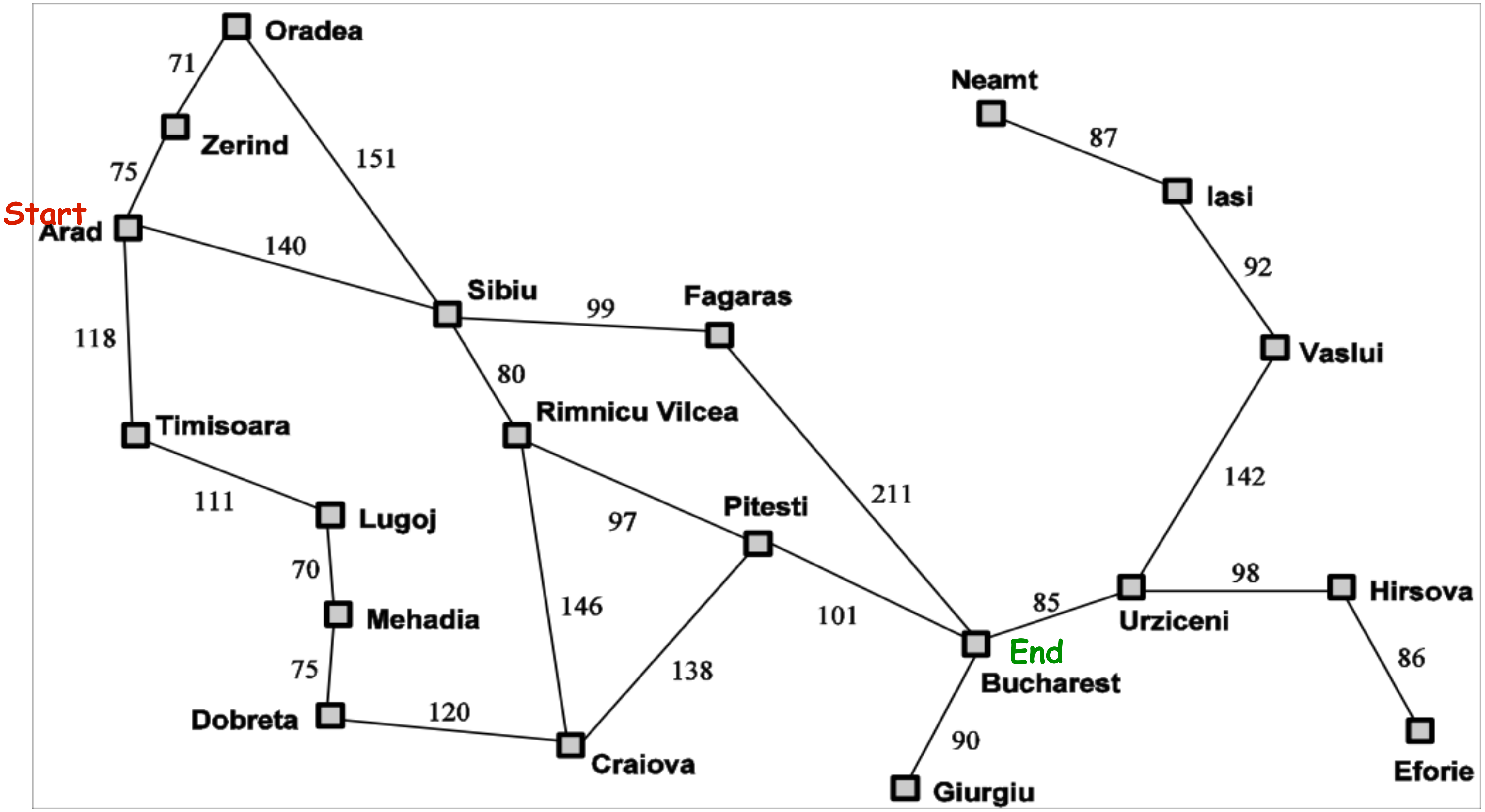
- Given this state graph, how large is the search tree?



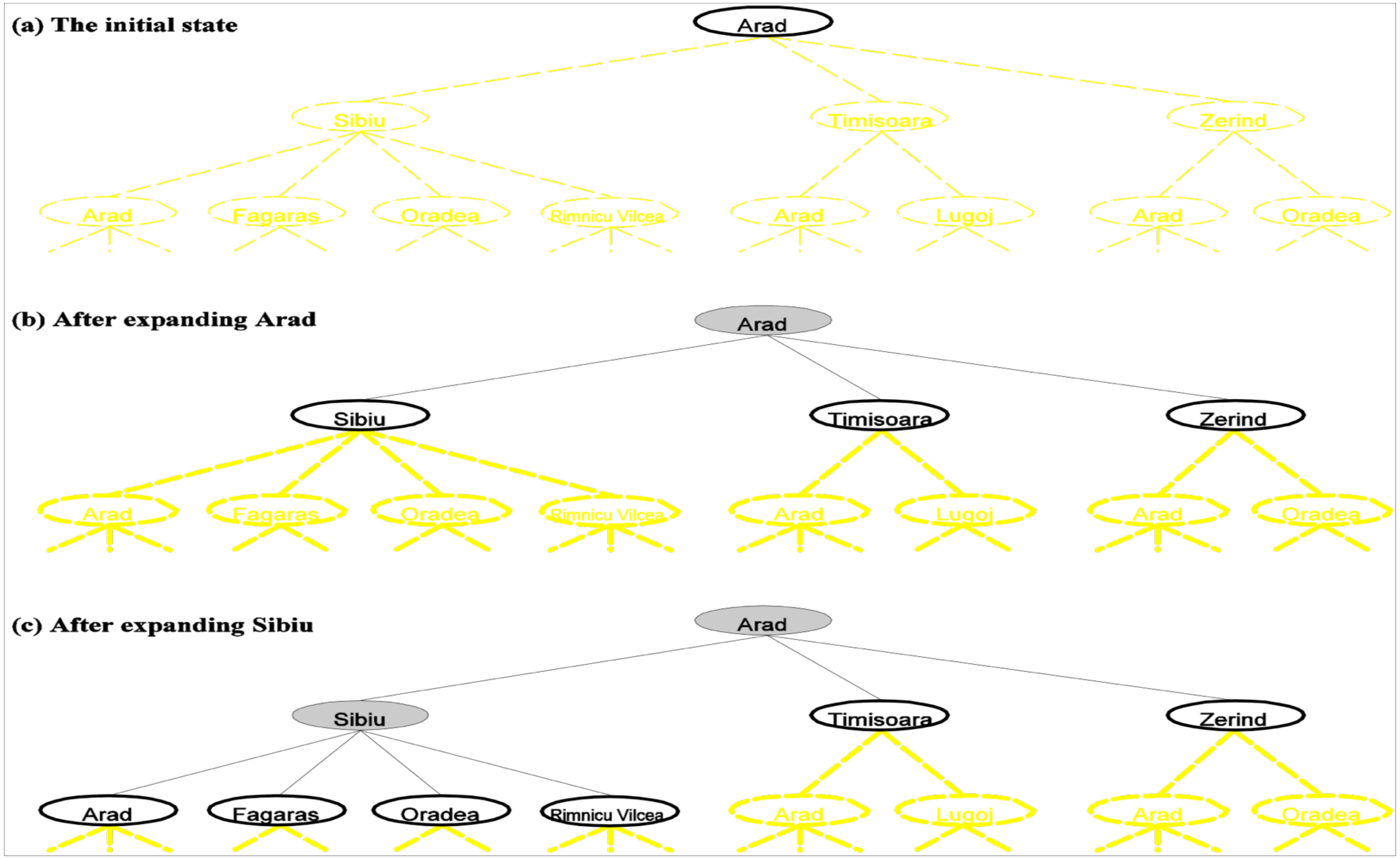
Expanding Nodes

- Expanding a node
  - Applying all legal operators to the state contained in the node
  - Generating nodes for all corresponding successor states

Example: Traveling in Romania



Expanding Nodes



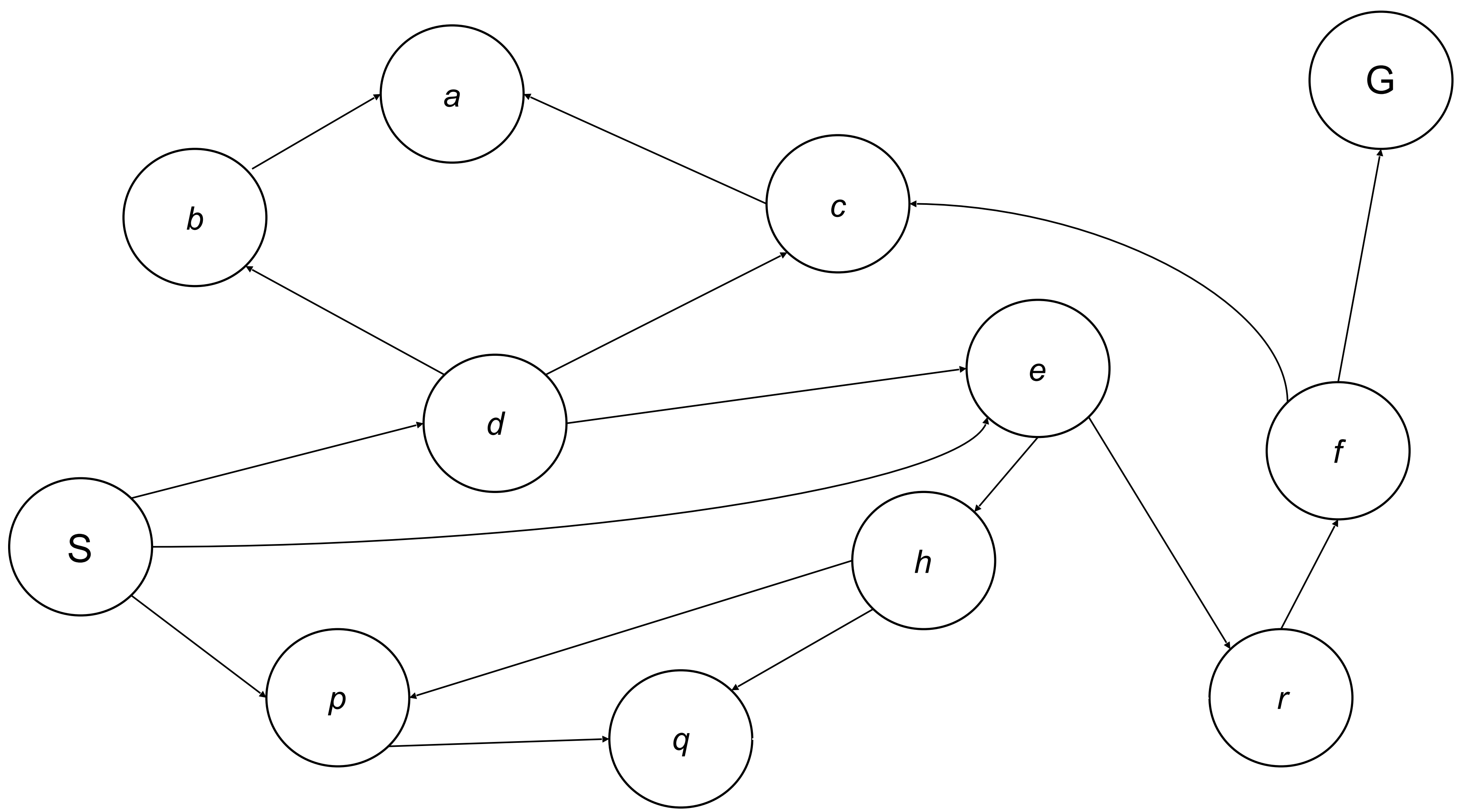
Generic Search Algorithm

- Initialize with initial state of the problem
- Repeat
  - If no candidate nodes can be expanded **return failure**
  - Choose leaf node for expansion, according to **search strategy**
  - If node contains goal state, **return solution**
  - Otherwise, expand the node. Add resulting nodes to the tree

Implementation Details

- Need to keep track of nodes to be expanded (**fringe**)
- Implement using a queue:
  - Insert node for initial state
  - Repeat
    - If queue is empty, return failure
    - **Dequeue a node**
    - If node contains goal state, return solution
    - Expand node
- Search algorithms differ in their queuing function!

Search Strategies



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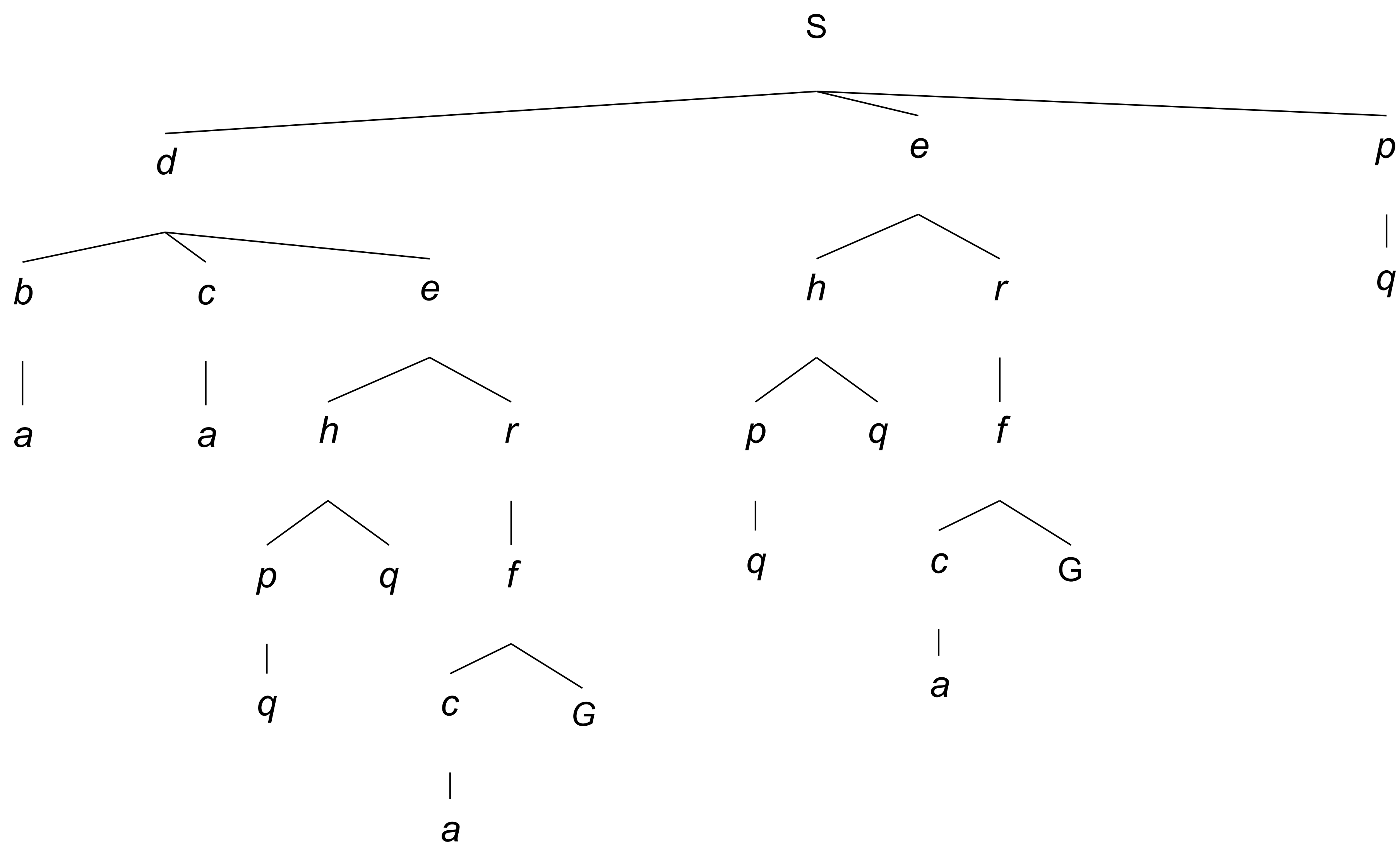
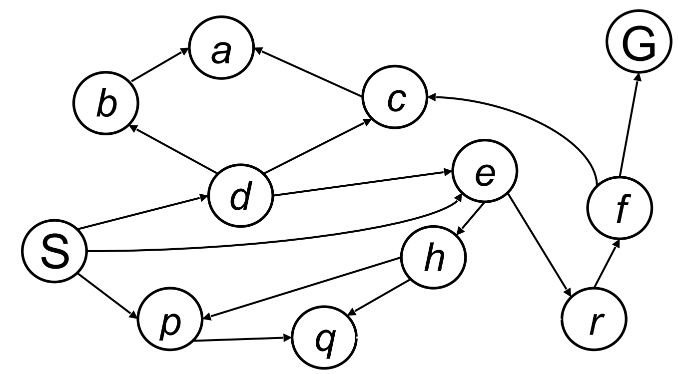
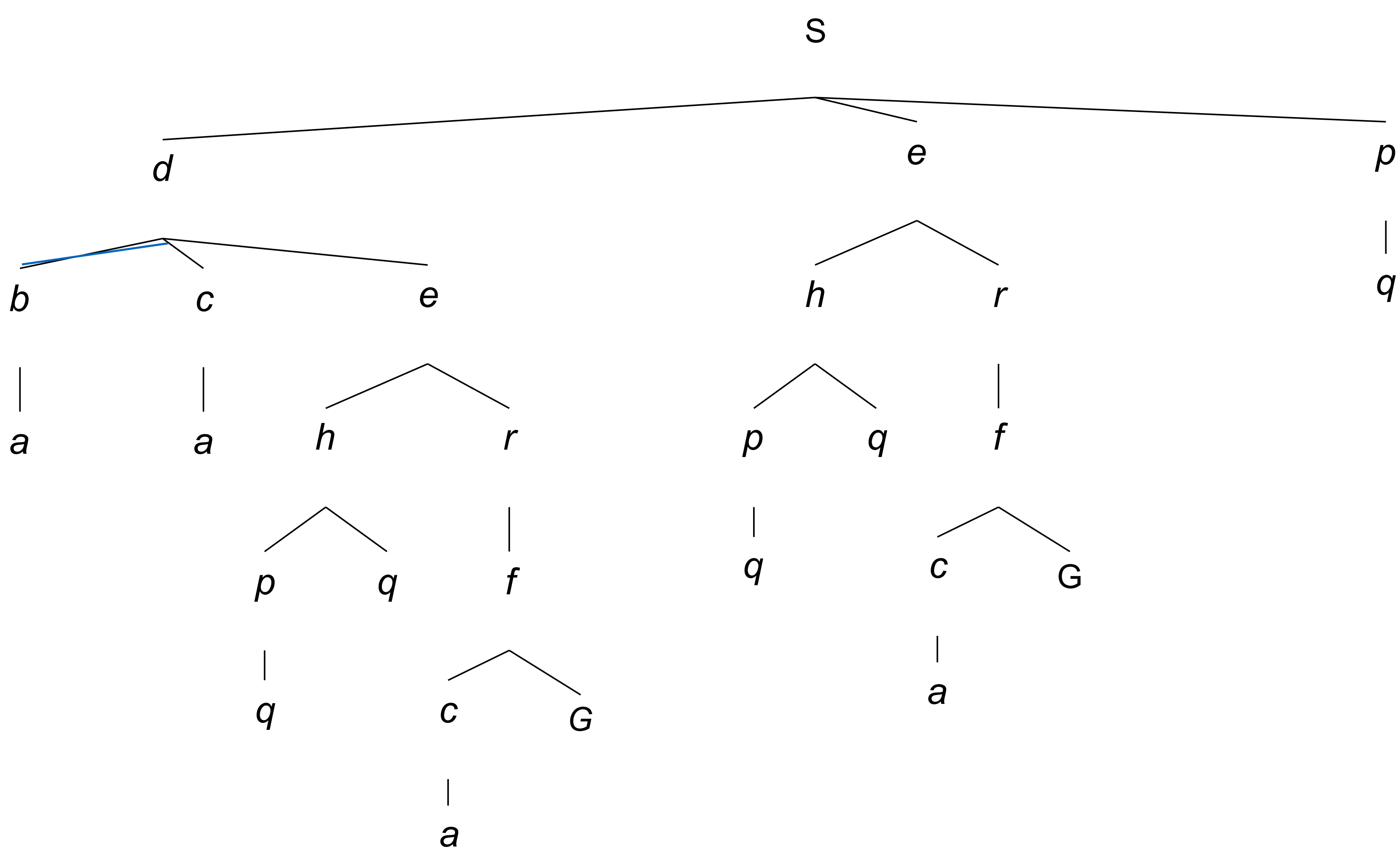
Search Strategies



Depth-First Search

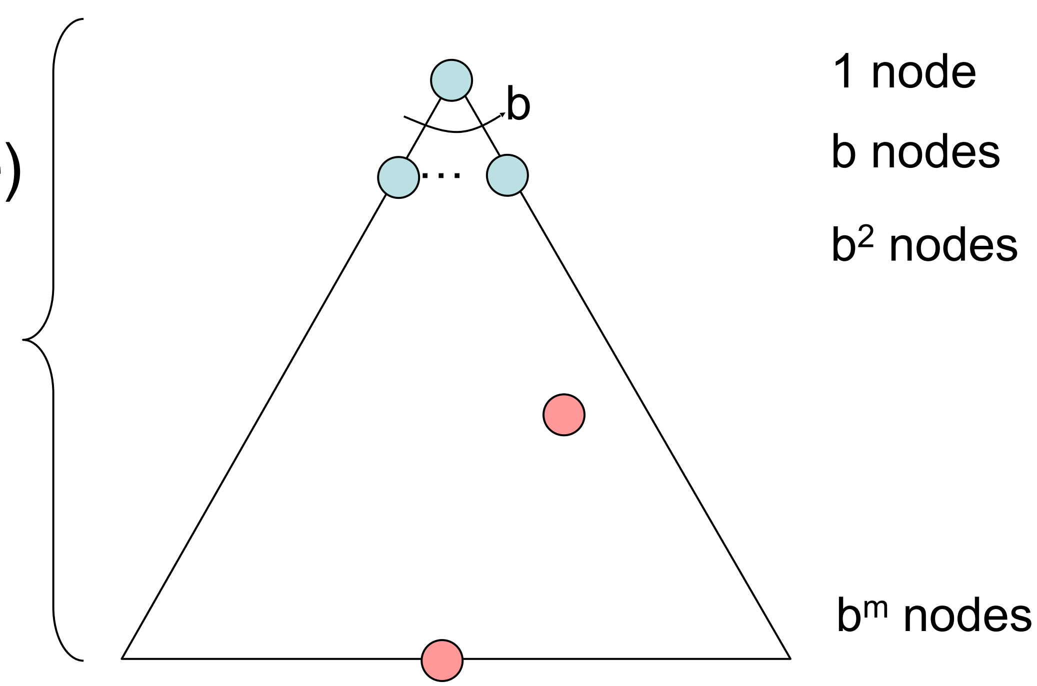
Strategy: Expand deepest node first
Implementation: LIFO stack





Key Properties

- **Completeness**: Is the alg. guaranteed to find a solution if the solution exists?
- **Optimality:** Does the alg. find the optimal solution?
- **Time complexity**
- **Space complexity** (size of the fringe)

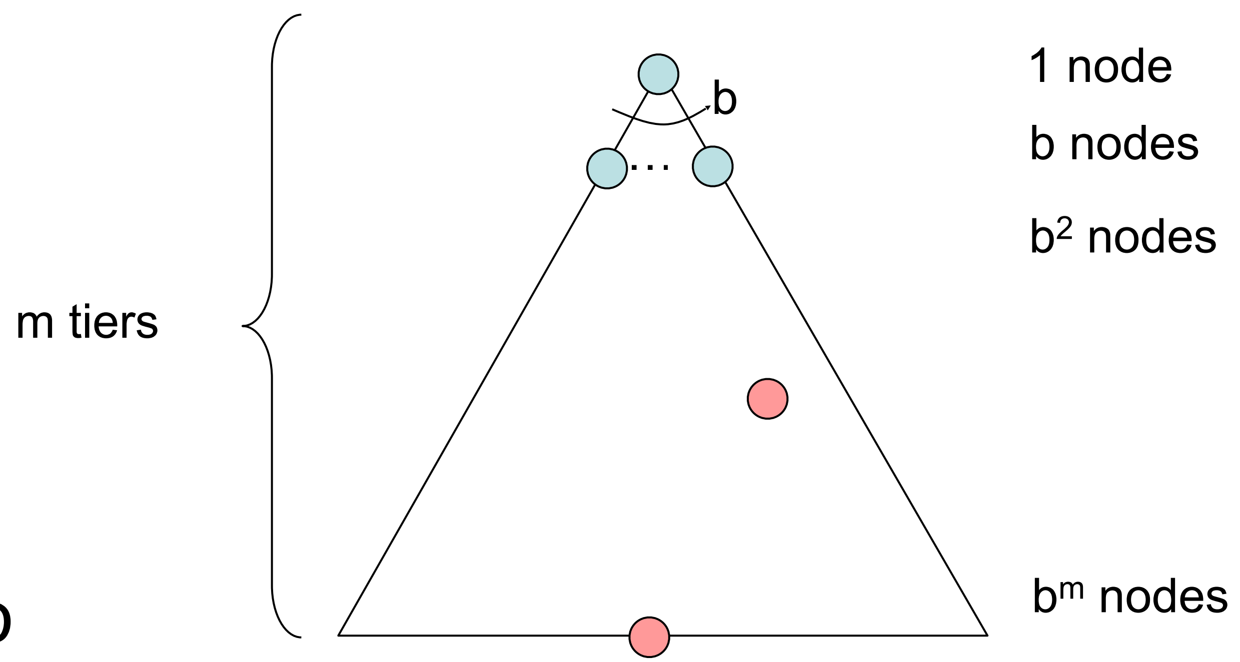


b: branching factor
m: maximum depth
d: depth of shallowest goal node

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

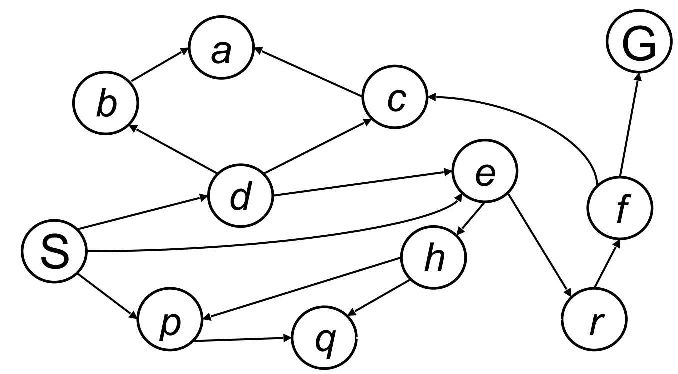
DFS Properties

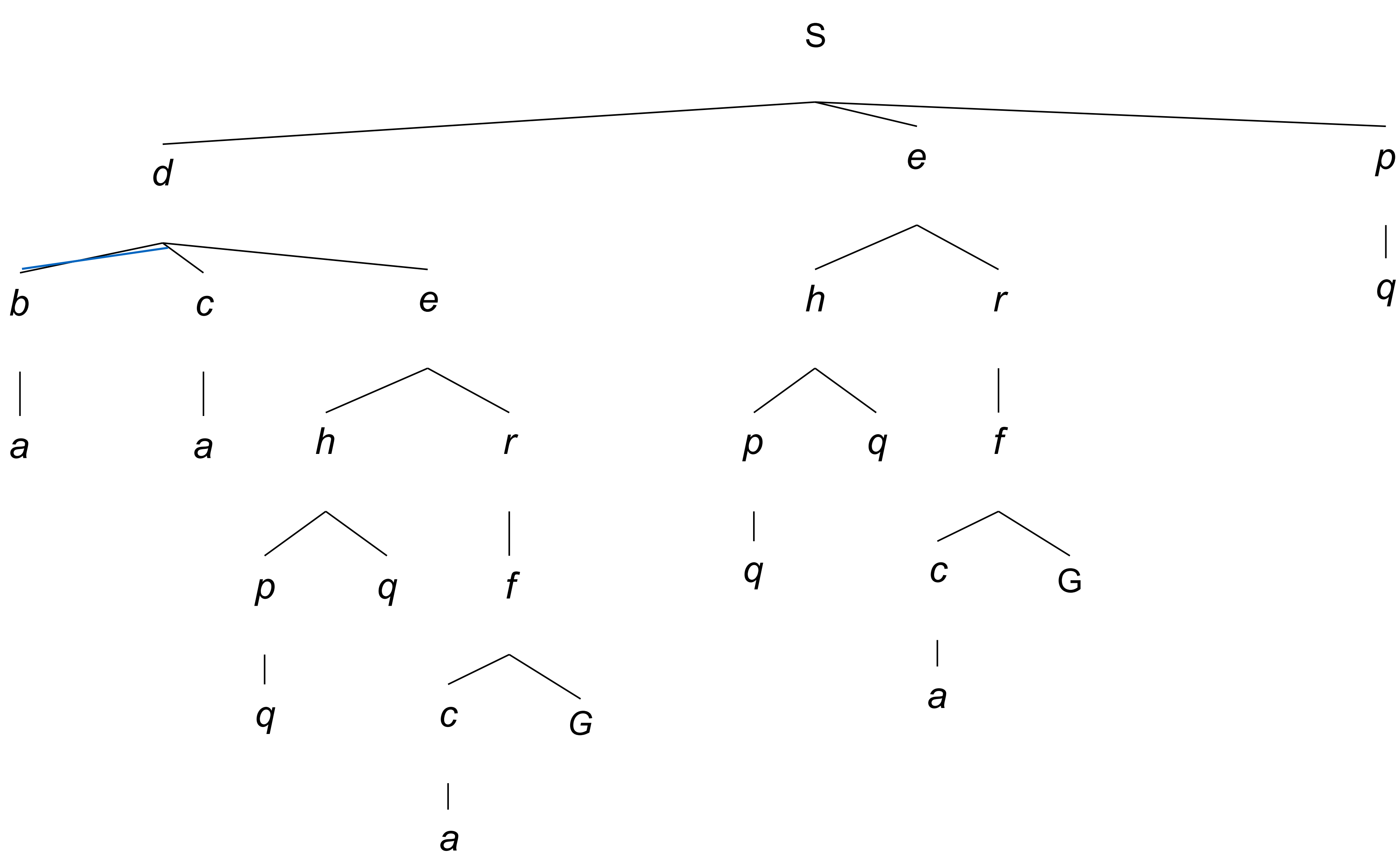
- **Complete?**
  - No! m could be infinite (why?)
- **Optimal?**
  - No! It finds “leftmost” solution first, regardless of cost or depth
- **Time complexity**
  - It could process the entire tree! Therefore $O(b^m)$
- **Space complexity**
  - Only has siblings on path to root! Therefore O(bm)!



Breadth-First Search

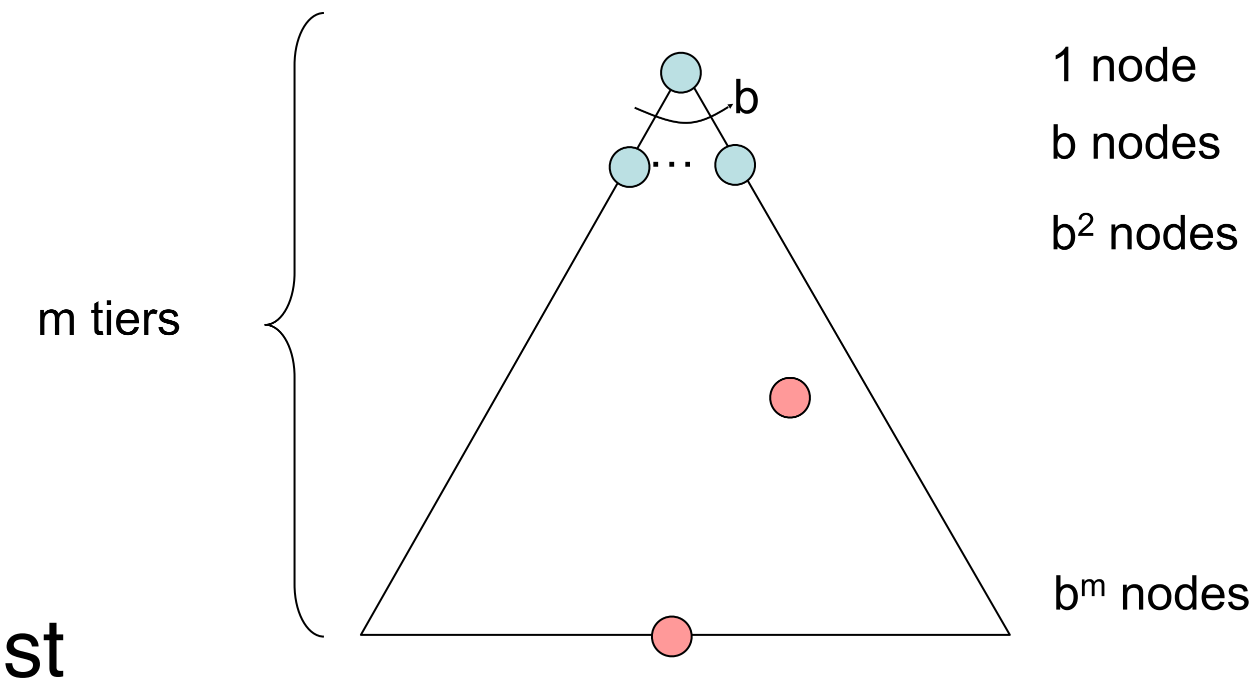
Strategy: Expand shallowest node first
Implementation: FIFO queue



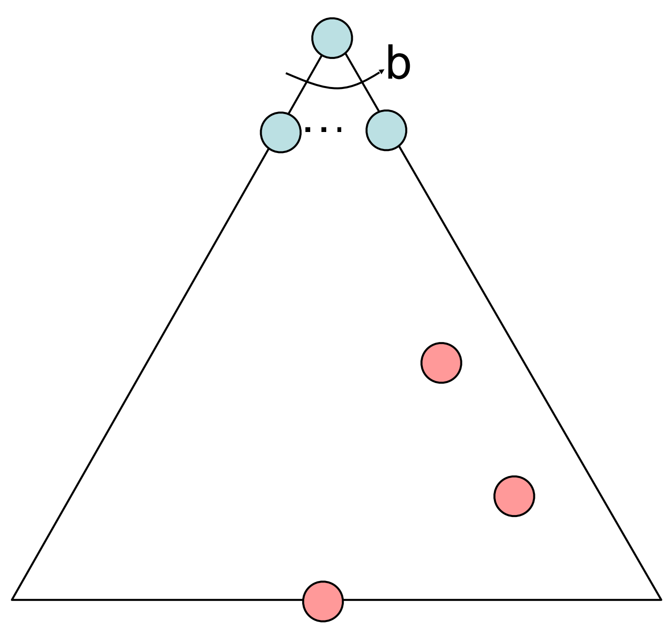


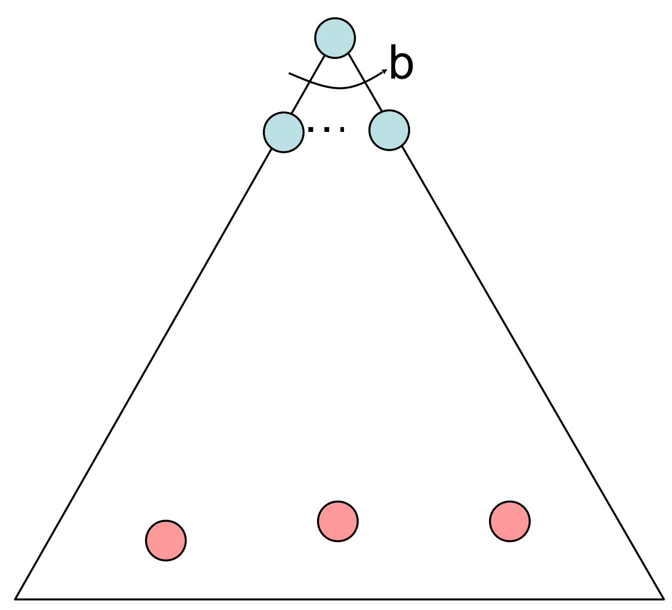
BFS Properties

- **Complete?**
  - Yes! d must be finite is a solution exists
- **Optimal?**
  - Maybe! If costs are all 1
- **Time complexity**
  - It could process the tree until it finds the shallowest goal! Therefore $O(b^d)$
- **Space complexity**
  - $O(b^d)$



Quiz: DFS vs BFS





Iterative Deepening Search

- Can we combine search methods to take advantage of DFS space complexity and BFS completeness/ shallow solution advantage?

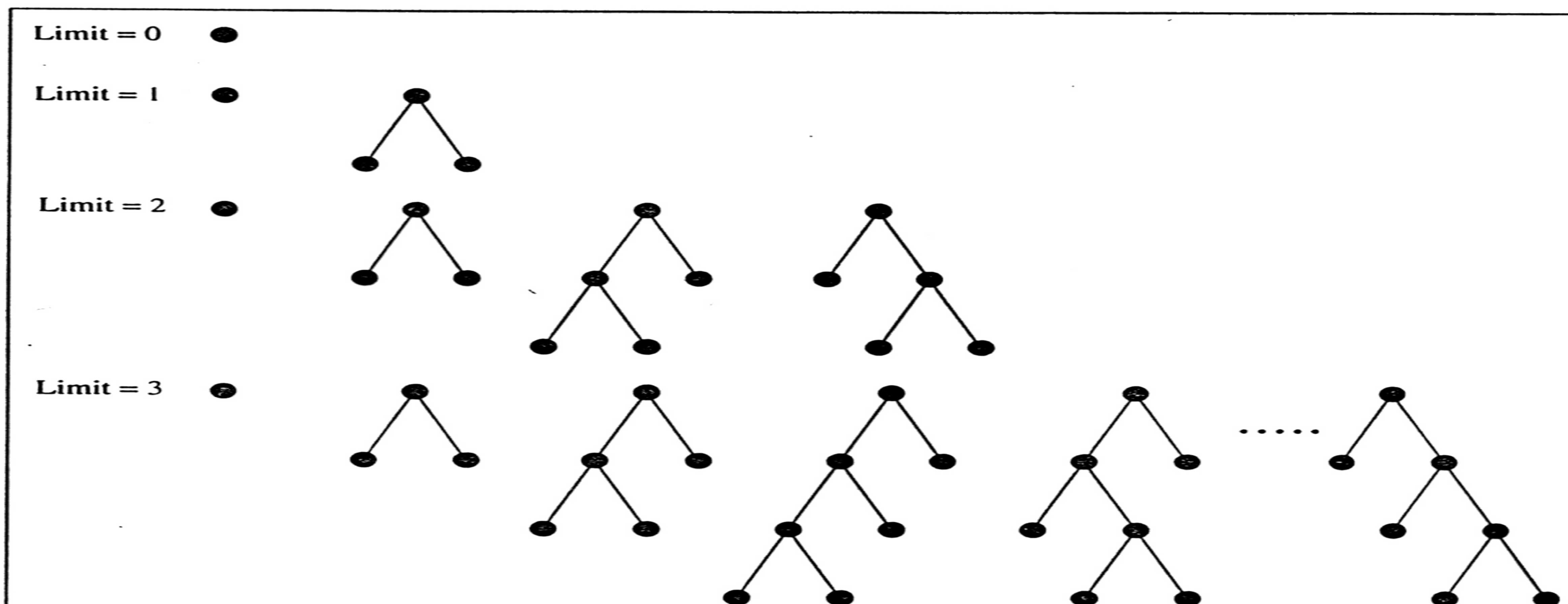
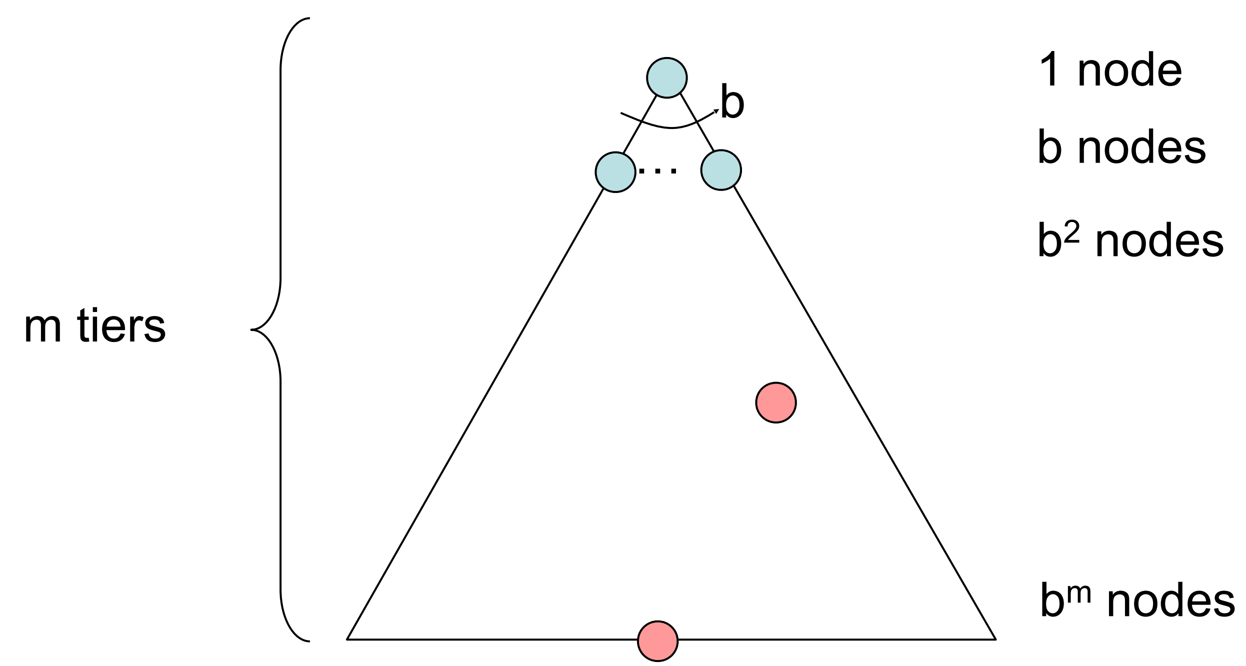


Figure 3.16 Four iterations of iterative deepening search on a binary tree.

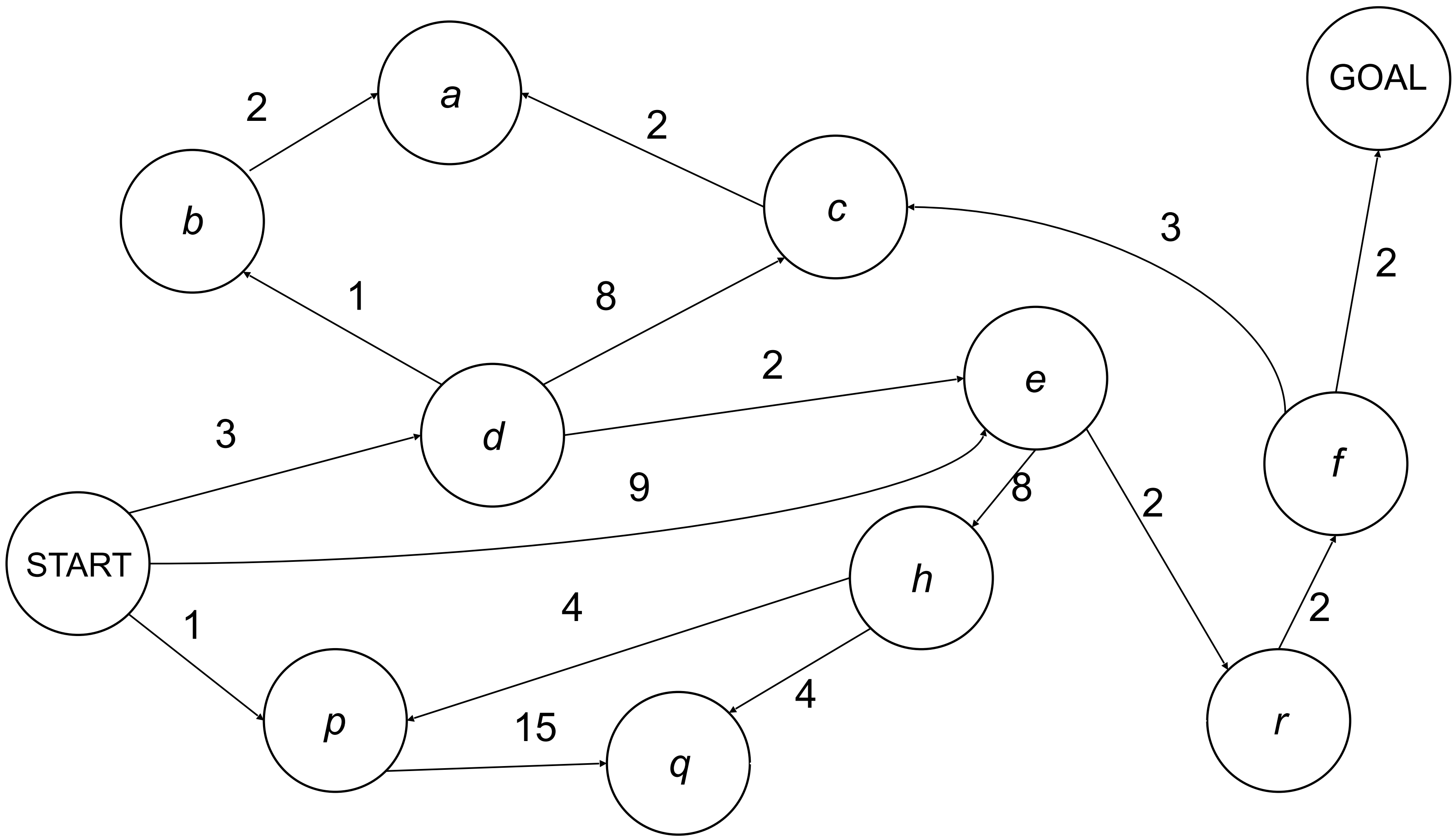
IDS Properties

- **Complete?**
  - Yes! d must be finite is a solution exists (like BFS)
- **Optimal?**
  - Maybe! If costs are all 1
- **Time complexity**
  - It could process the tree until it finds the shallowest goal! Therefore $O(b^d)$
- **Space complexity**
  - $O(bd)$



Wasteful? Most nodes found in lowest level of search so not too bad

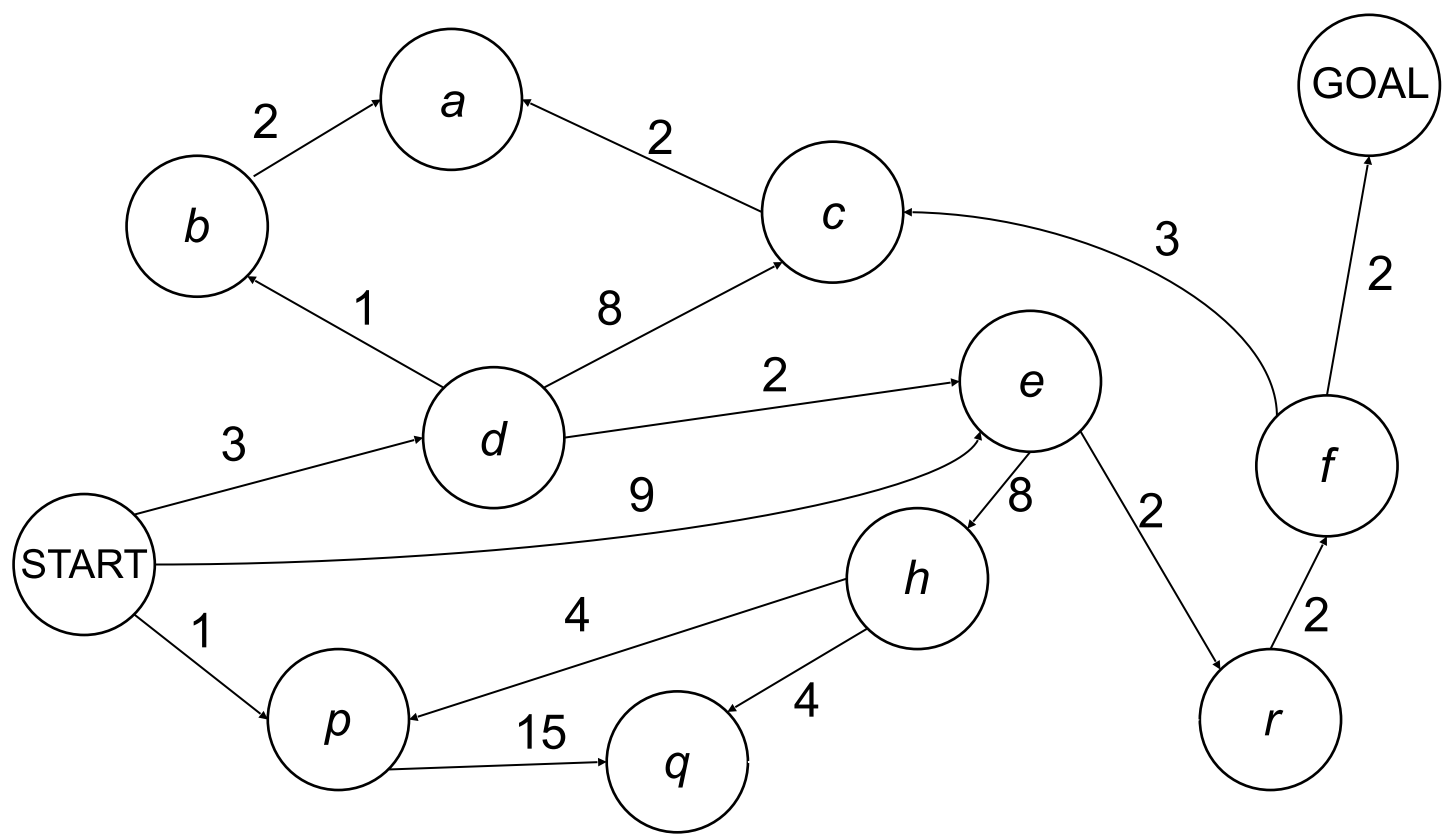
Cost-Sensitive Search



Recall that BFS was only optimal under some conditions (i.e. we only cared about number of actions taken). What can we do if actions have different costs?

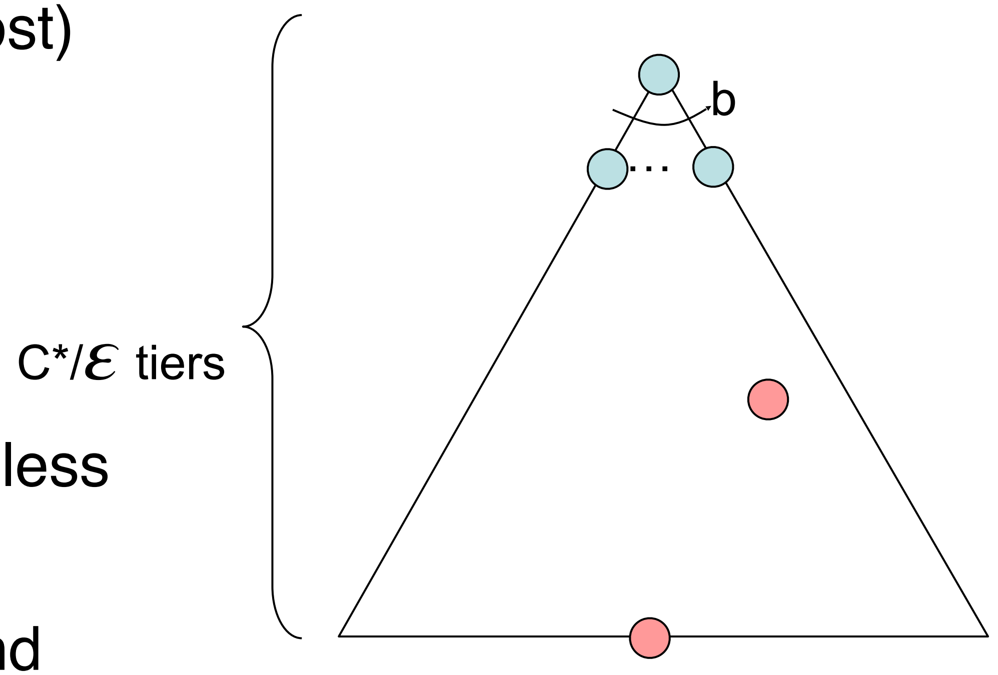
Uniform Cost Search

Strategy: Expand cheapest node first
Implementation: Priority queue



UCS Properties

- **Complete?**
  - Yes! (assuming min cost is positive and best solution has finite cost)
- **Optimal?**
  - Yes!
- **Time complexity**
  - Processes all nodes with cost less than cheapest solution
  - If cheapest solution cost C* and edges cost at least ε then "depth" is approximately C^*/ε. Thus time $O(b^{C^*/\varepsilon})$
- **Space complexity**
  - $O(b^{C^*/\varepsilon})$



Summary

- These algorithms are basically the same except for the order in which they expand nodes
    - Basically all priority queues with different ways to determining priorities

- How successful the search is depends heavily on your model!

Questions?

- Next class: Informed search