CSE 473: Artificial Intelligence
Autumn 2011

Search

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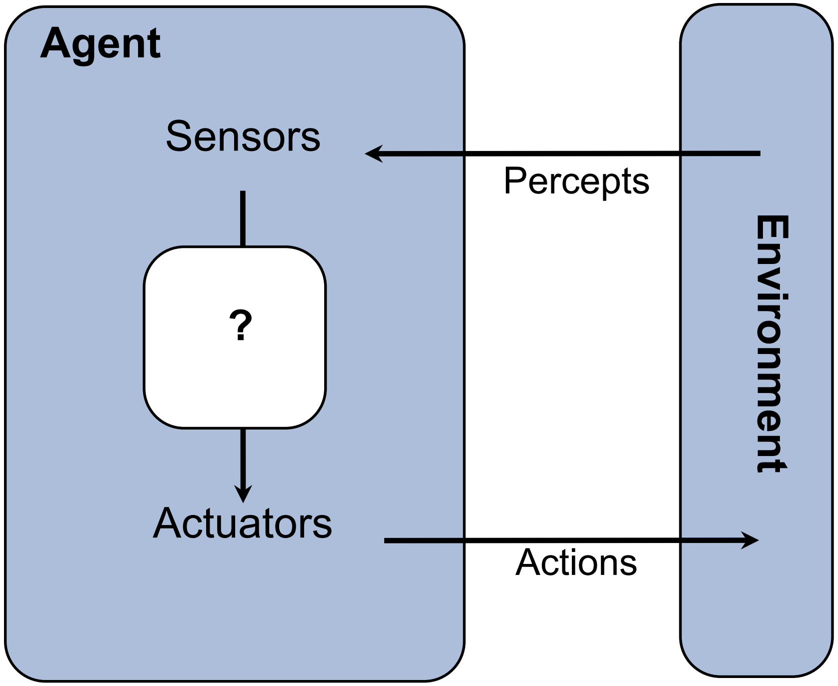
Slides from Dan Klein, Stuart Russell, Andrew Moore

Outline

- Agents that Plan Ahead
- Search Problems
- Uninformed Search Methods (part review for some)
    - Depth-First Search
    - Breadth-First Search
    - Uniform-Cost Search
- Heuristic Search Methods (new for all)
    - Best First / Greedy Search

Review: Rational Agents

- An **agent** is an entity that *perceives* and *acts*.
- A **rational agent** selects actions that maximize its **utility function**.
- Characteristics of the **percepts, environment,** and **action space** dictate techniques for selecting rational actions.

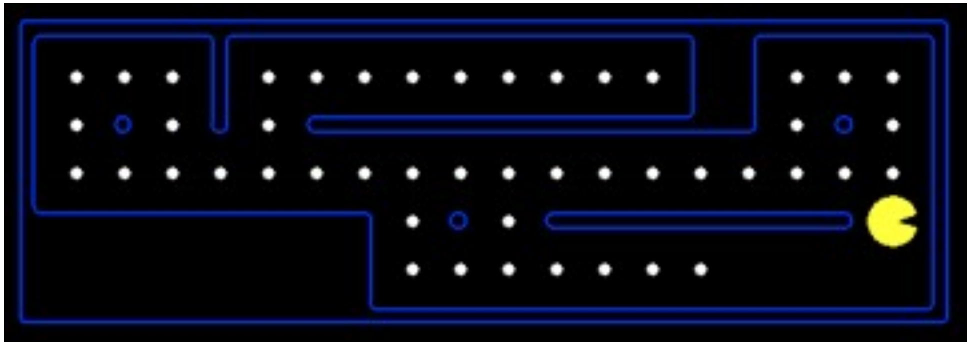


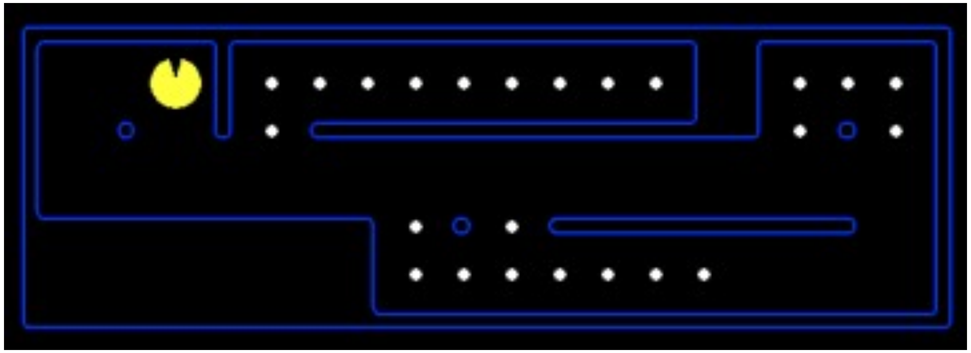
Search -- the environment is:

fully observable, single agent, deterministic, episodic, discrete

Reflex Agents

- Reflex agents:
    - Choose action based on current percept (and maybe memory)
    - Do not consider the future consequences of their actions
    - Act on how the world IS
- Can a reflex agent be rational?
- Can a non-rational agent achieve goals?

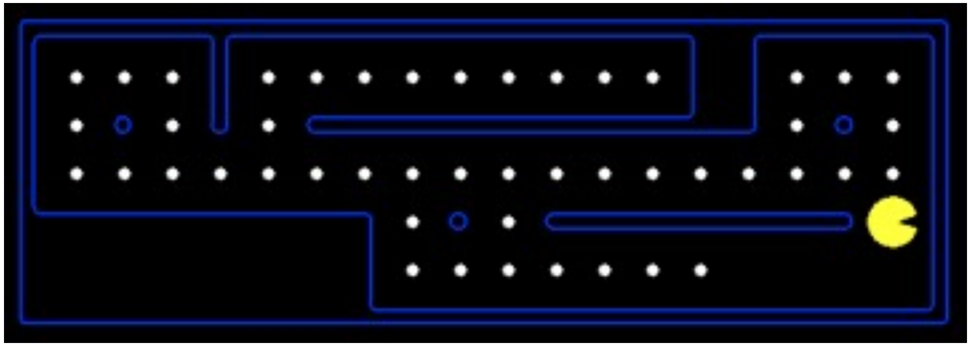


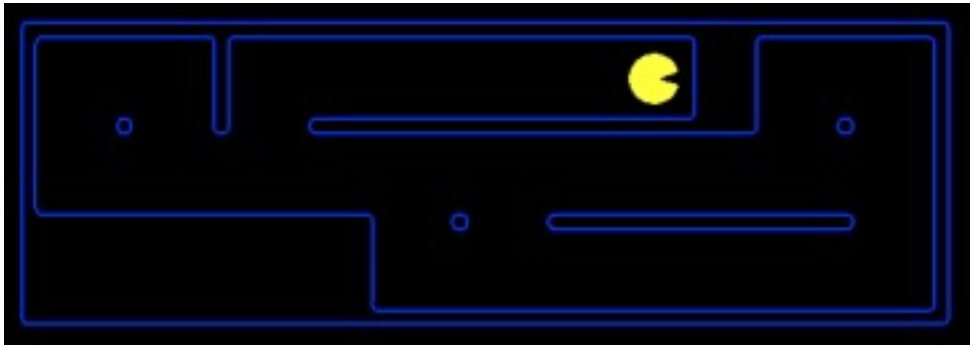


Famous Reflex Agents

Goal Based Agents

- Goal-based agents:
  - Plan ahead
  - Ask “what if”
  - Decisions based on (hypothesized) consequences of actions
  - Must have a model of how the world evolves in response to actions
  - Act on how the world WOULD BE

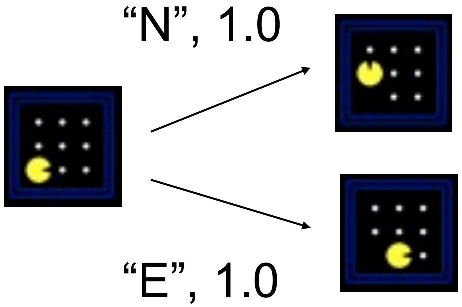




Search Problems

- A search problem consists of:
  - A state space

  - A successor function



  - A start state and a goal test

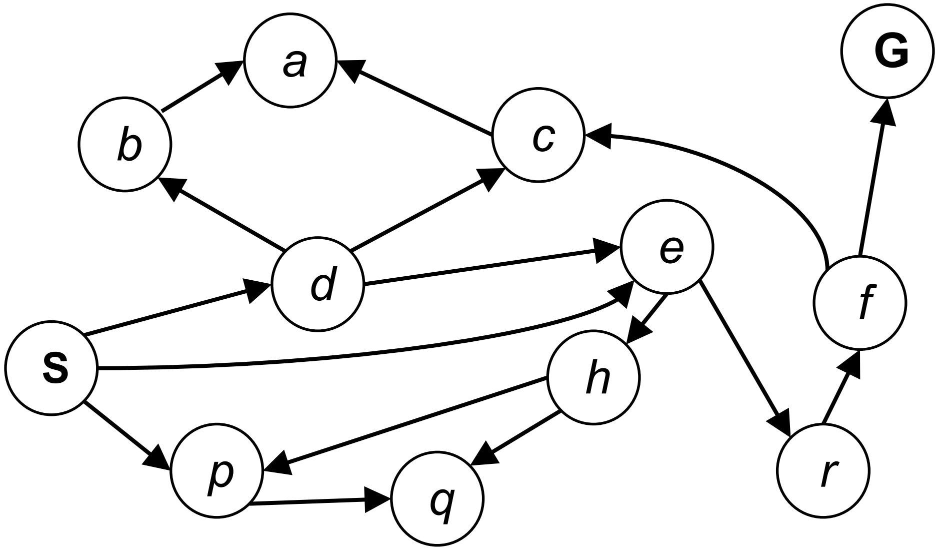
- A solution is a sequence of actions (a plan) which transforms the start state to a goal state

Example: Romania

- State space:
  - Cities
- Successor function:
  - Go to adj city with cost = dist
- Start state:
  - Arad
- Goal test:
  - Is state == Bucharest?
- Solution?

State Space Graphs

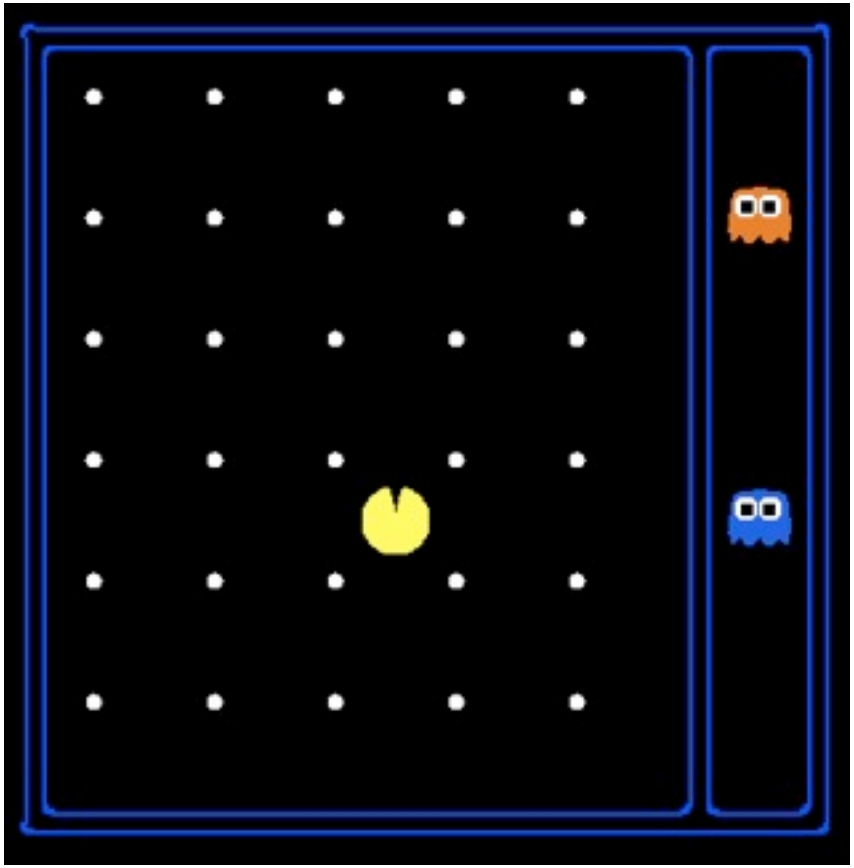
- State space graph:
  - Each node is a state
  - The successor function is represented by arcs
  - Edges may be labeled with costs
- We can rarely build this graph in memory (so we don't)



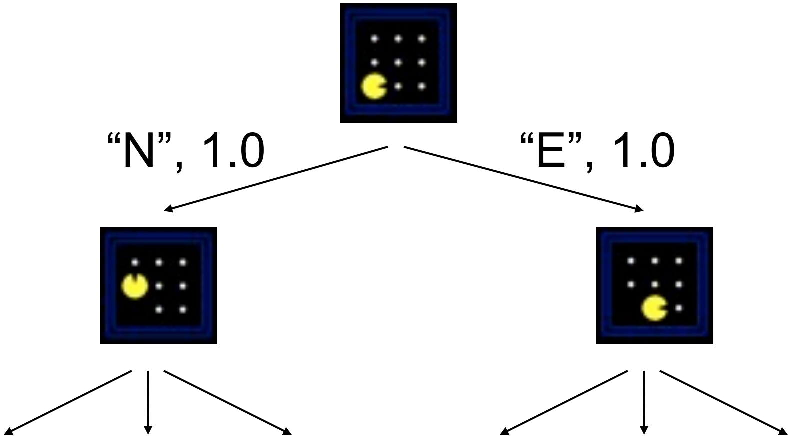
Ridiculously tiny search graph for a tiny search problem

State Space Sizes?

- Search Problem:
  Eat all of the food
- Pacman positions:
  10 x 12 = 120
- Pacman facing:
  up, down, left, right
- Food Count: 30
- Ghost positions: 12



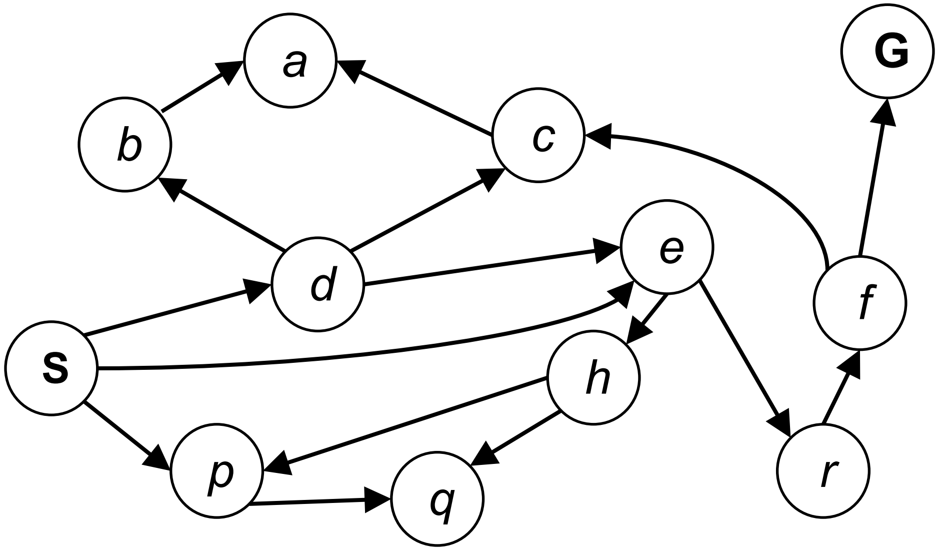
Search Trees



- A search tree:
  - Start state at the root node
  - Children correspond to successors
  - Nodes contain states, correspond to PLANS to those states
  - Edges are labeled with actions and costs
  - For most problems, we can never actually build the whole tree

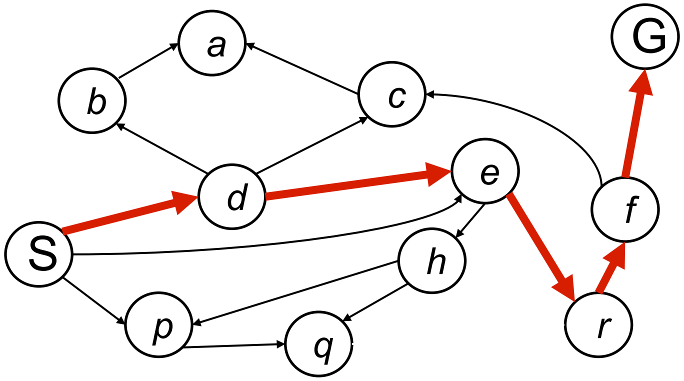
Example: Tree Search

State Graph:

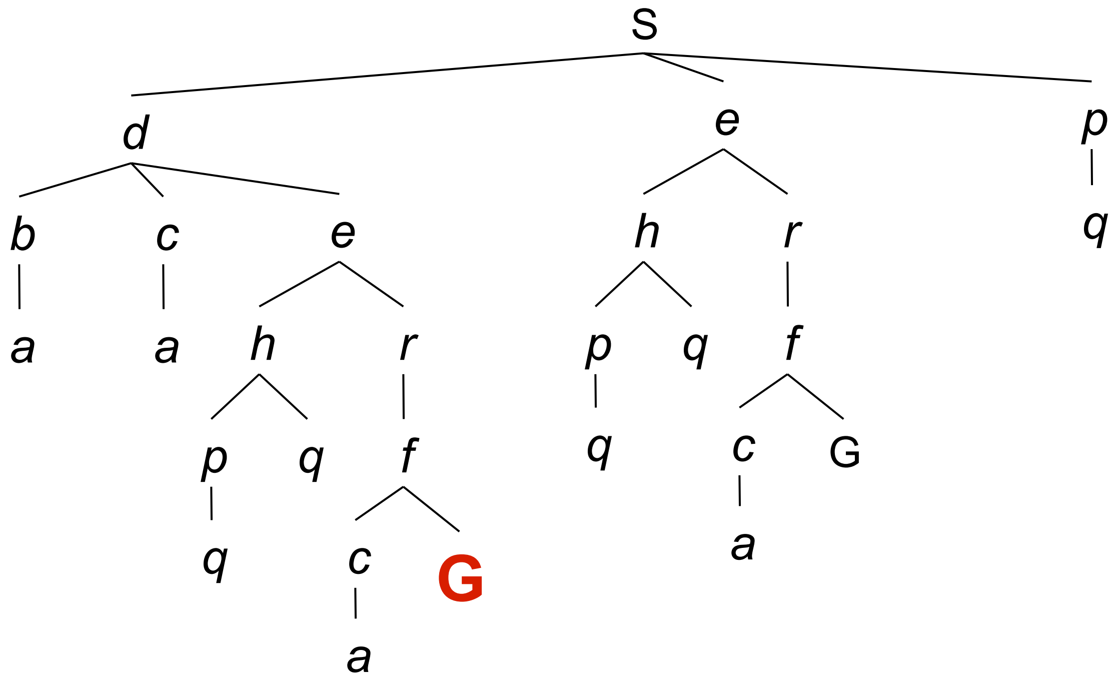


What is the search tree?

State Graphs vs. Search Trees



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

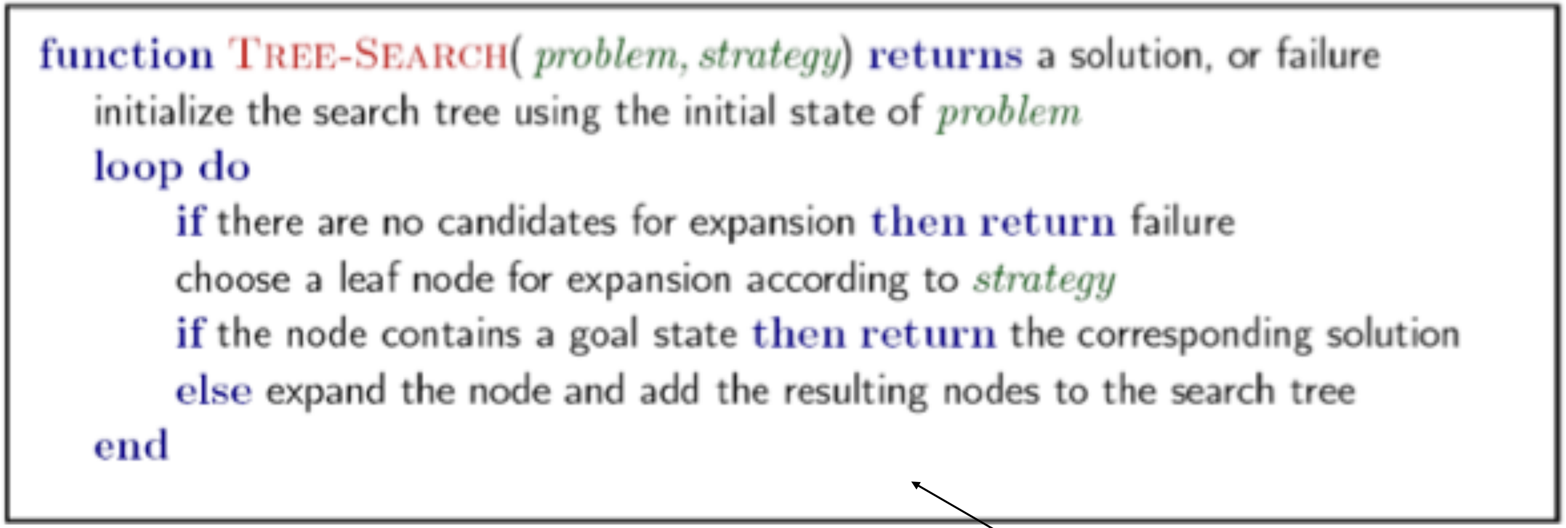


We construct both on demand – and we construct as little as possible.

Building Search Trees

- Search:
    - Expand out possible plans
    - Maintain a fringe of unexpanded plans
    - 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
```

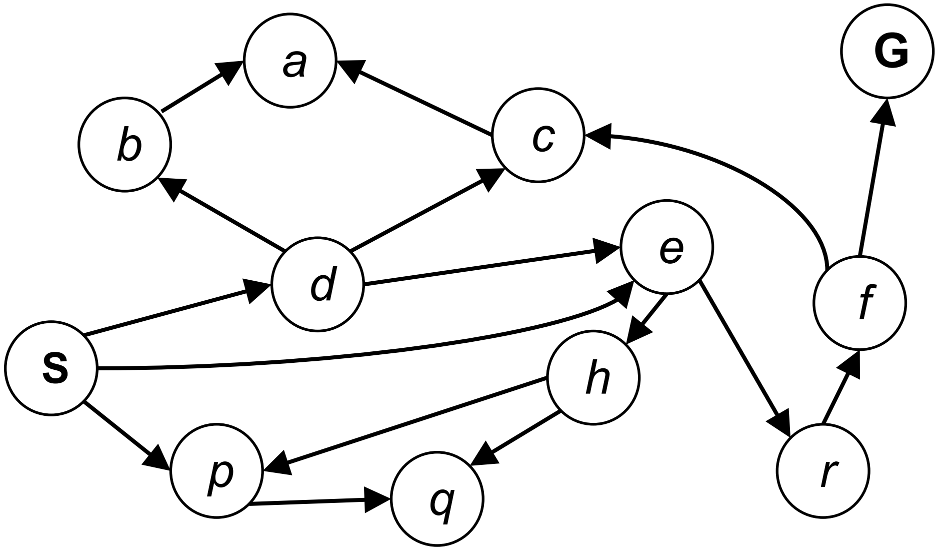
Detailed pseudocode is in the book!

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

Review: Depth First Search

Strategy: *expand deepest node first*

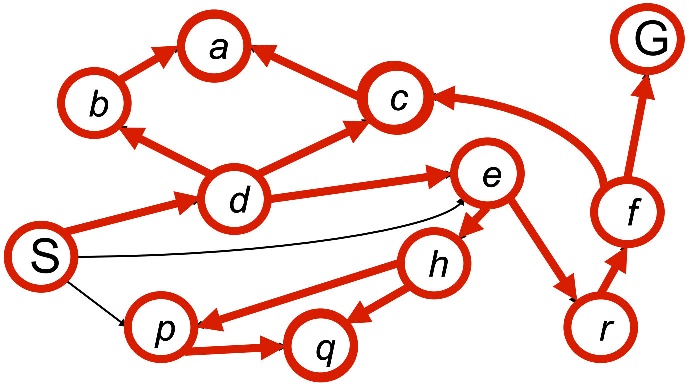
Implementation: *Fringe is a LIFO queue (a stack)*

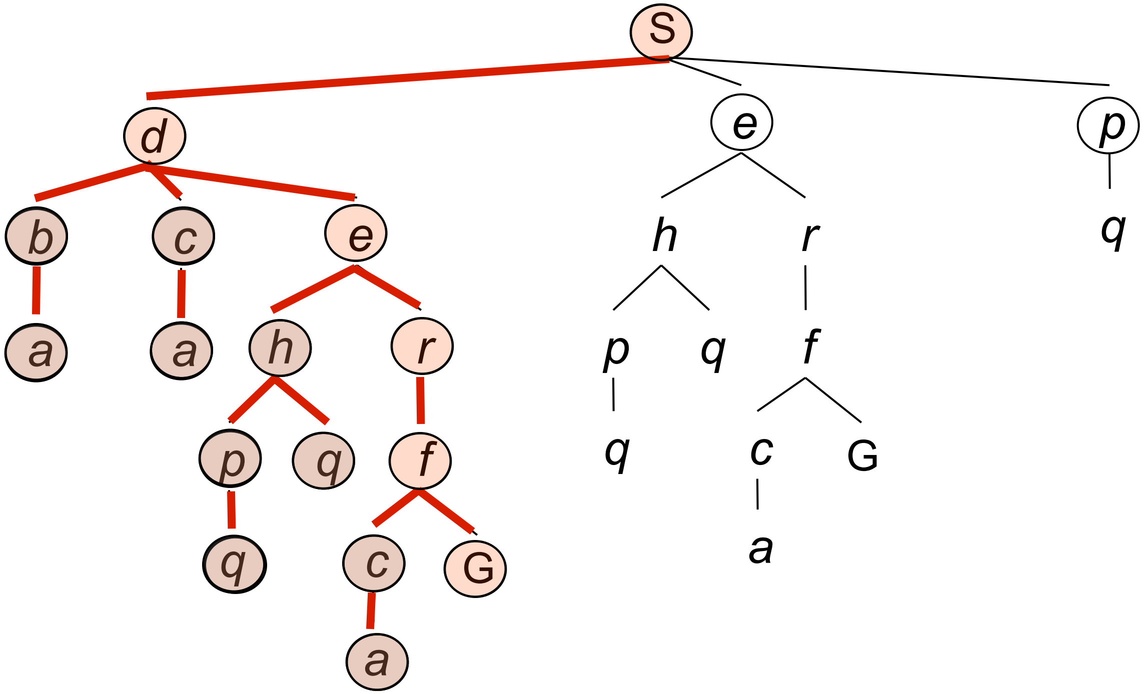


Review: Depth First Search

Expansion ordering:

(d,b,a,c,a,e,h,p,q,q,r,f,c,a,G)

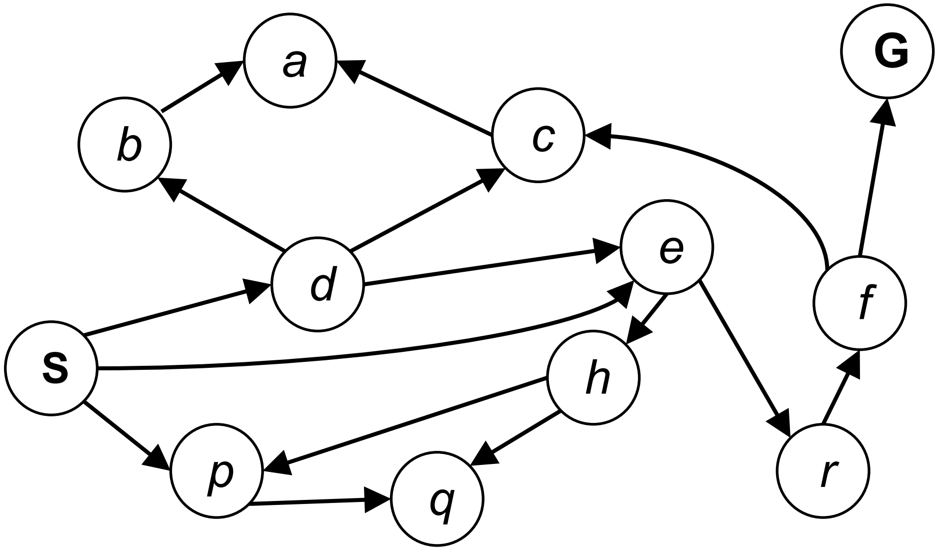




Review: Breadth First Search

***Strategy**: expand shallowest node first*

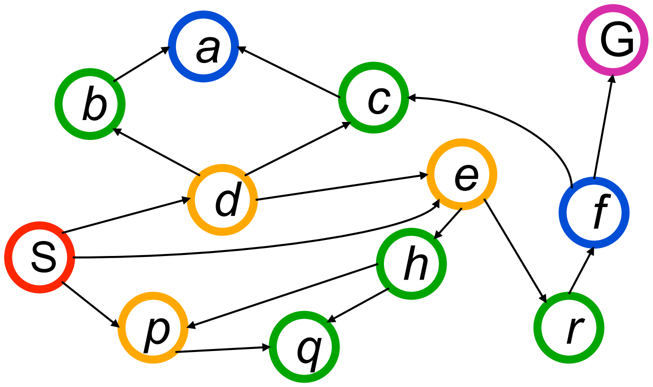
***Implementation**: Fringe is a FIFO queue*

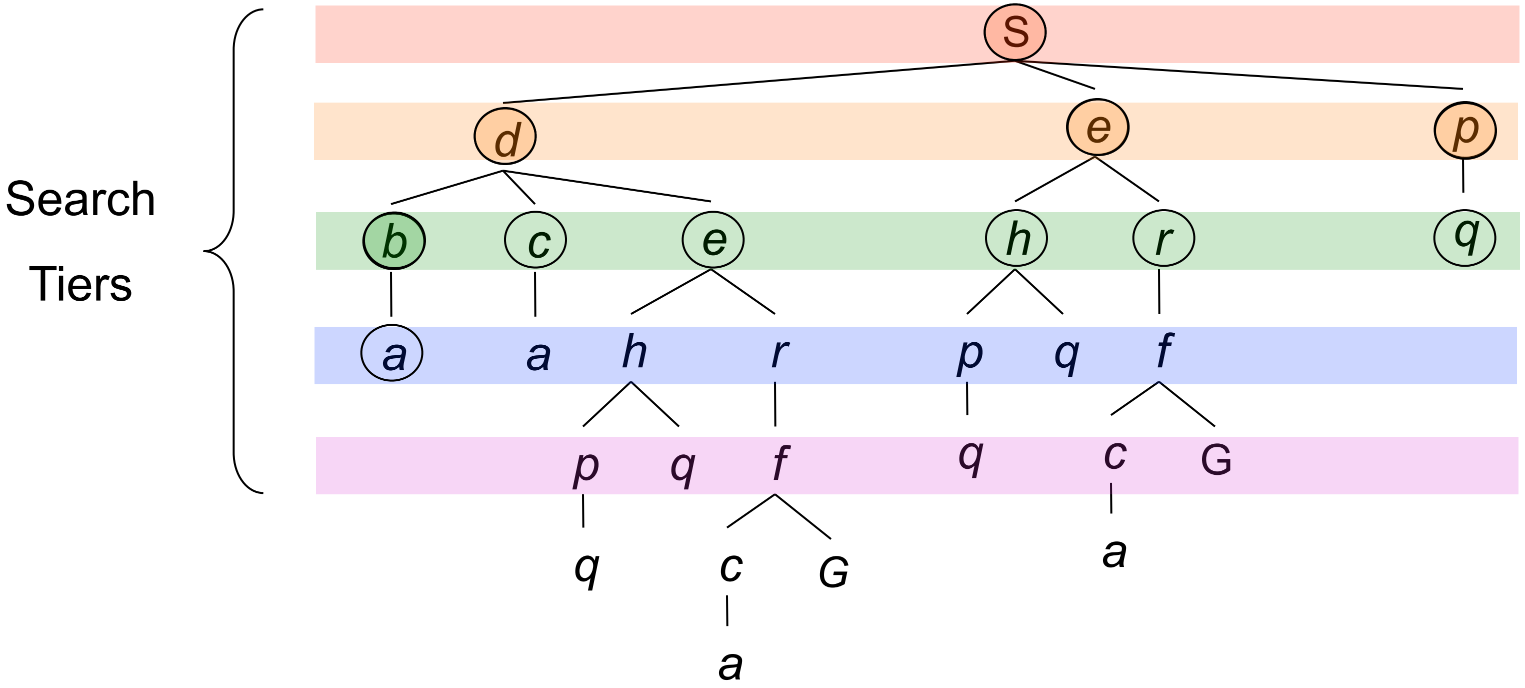


Review: Breadth First Search

Expansion order:

(S,d,e,p,b,c,e,h,r,q,a, a,h,r,p,q,f,p,q,f,q,c,G)





Search Algorithm Properties

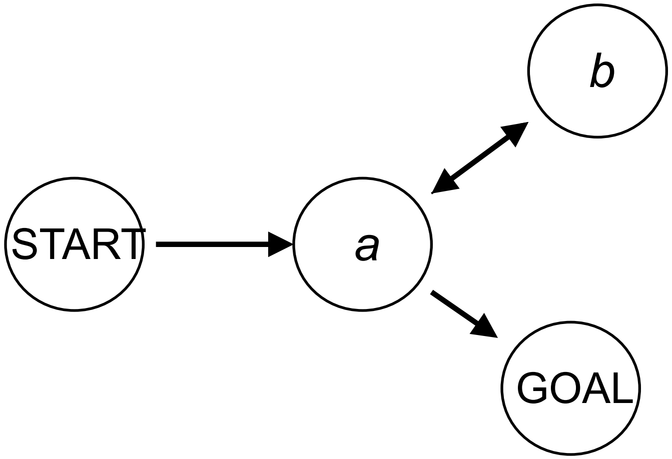
- Complete? Guaranteed to find a solution if one exists?
- Optimal? Guaranteed to find the least cost path?
- Time complexity?
- Space complexity?

Variables:

n	Number of states in the problem
b	The maximum branching factor B (the maximum number of successors for a state)
C^*	Cost of least cost solution
d	Depth of the shallowest solution
m	Max depth of the search tree

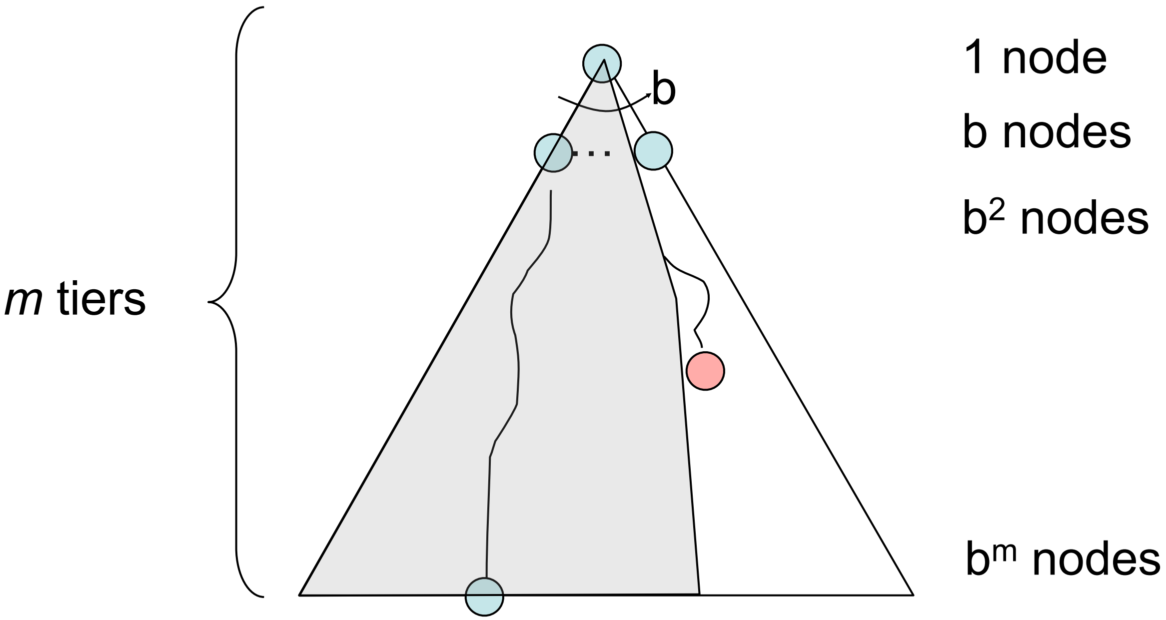
DFS

Algorithm		Complete	Optimal	Time	Space
DFS	Depth First Search	N	N	Infinite	Infinite



- Infinite paths make DFS incomplete…
- How can we fix this?

DFS

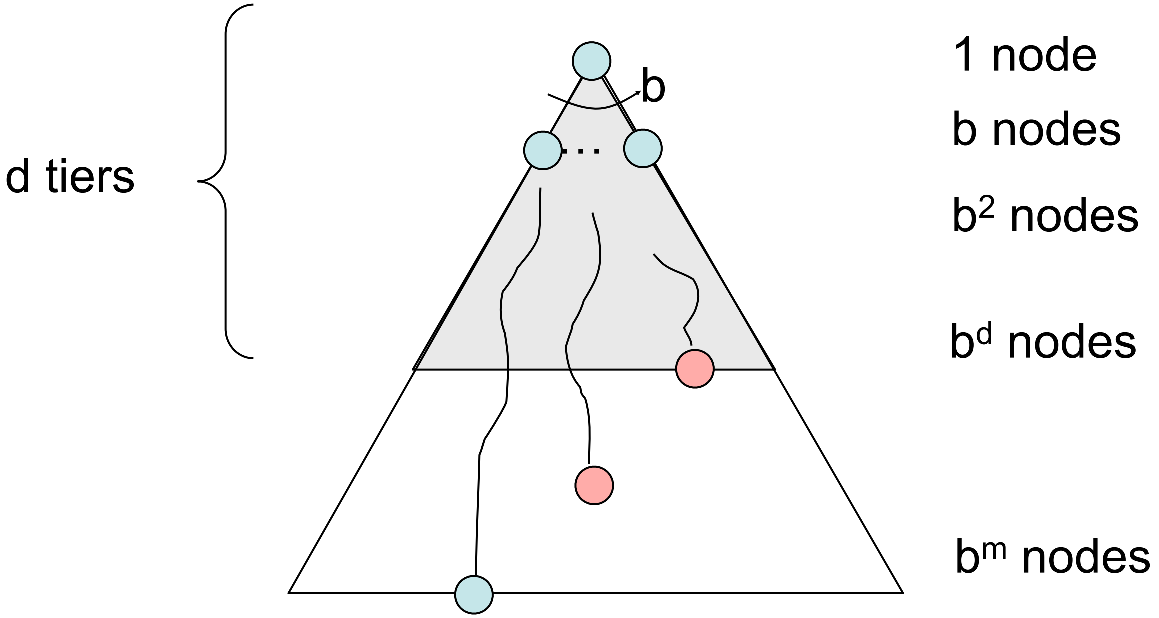


Algorithm		Complete	Optimal	Time	Space
DFS	w/ Path Checking	Y	N	$O(b^m)$	$O(bm)$

* Or graph search – next lecture.

BFS

Algorithm		Complete	Optimal	Time	Space
DFS	w/ Path Checking	Y	N	$O(b^m)$	$O(bm)$
BFS		Y	Y*	$O(b^d)$	$O(b^d)$



Comparisons

- When will BFS outperform DFS?

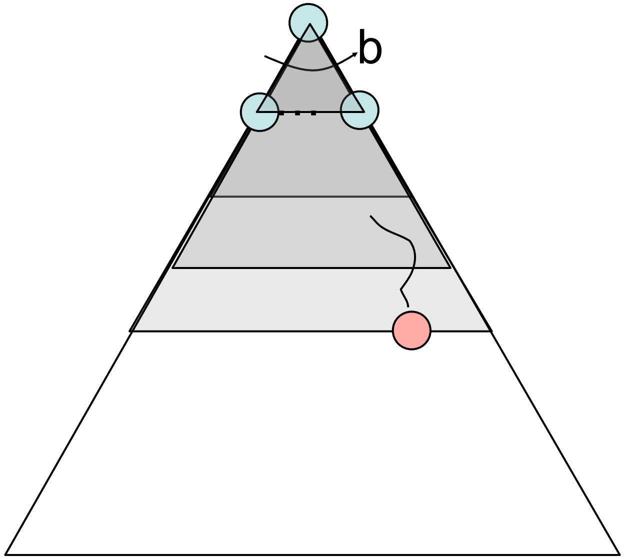
- When will DFS outperform BFS?

Iterative Deepening

Iterative deepening uses DFS as a subroutine:

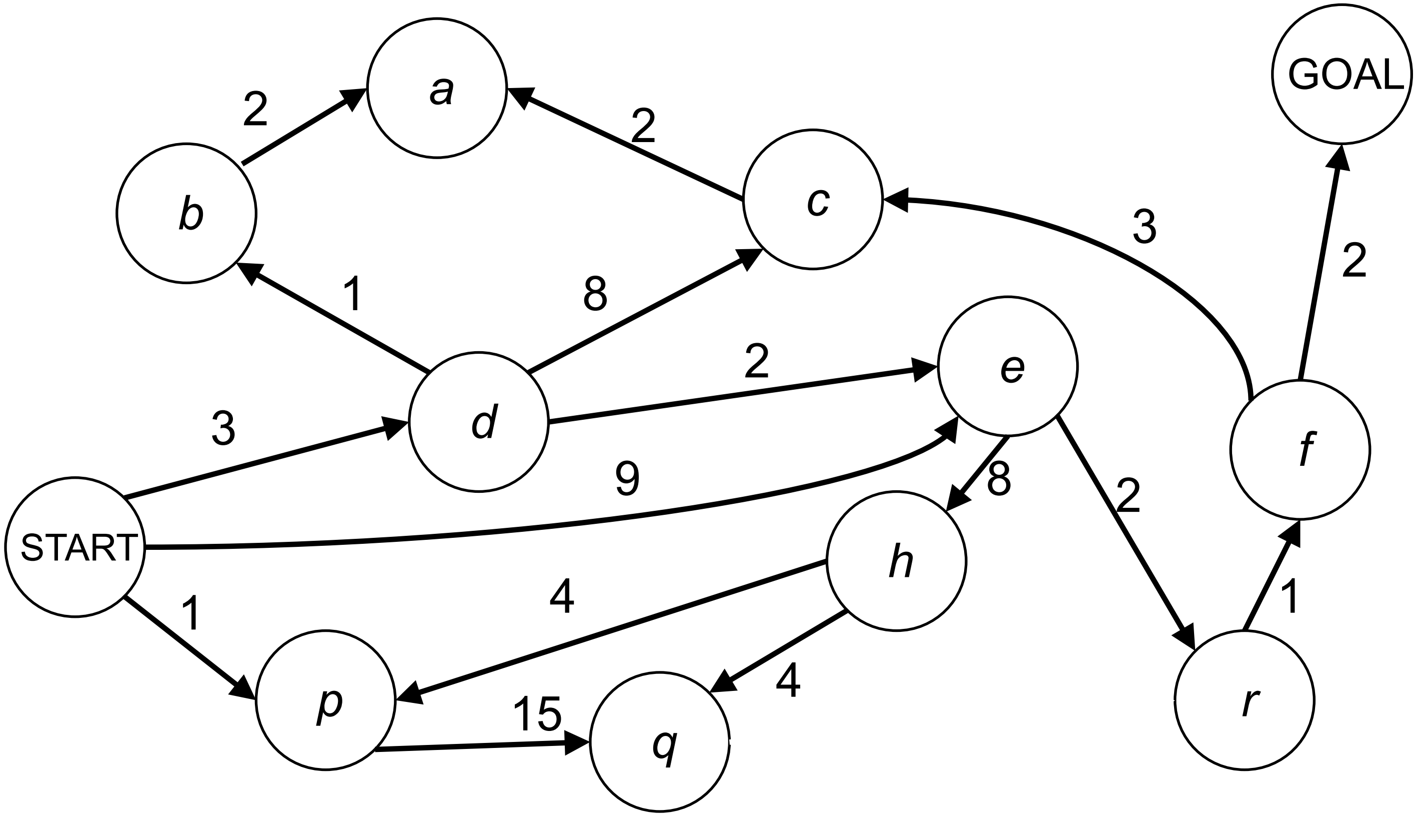
1. Do a DFS which only searches for paths of length 1 or less.
2. If “1” failed, do a DFS which only searches paths of length 2 or less.
3. If “2” failed, do a DFS which only searches paths of length 3 or less.

….and so on.



Algorithm		Complete	Optimal	Time	Space
DFS	w/ Path Checking	Y	N	$O(b^m)$	$O(bm)$
BFS		Y	Y*	$O(b^d)$	$O(b^d)$
ID		Y	Y*	$O(b^d)$	$O(bd)$

Costs on Actions

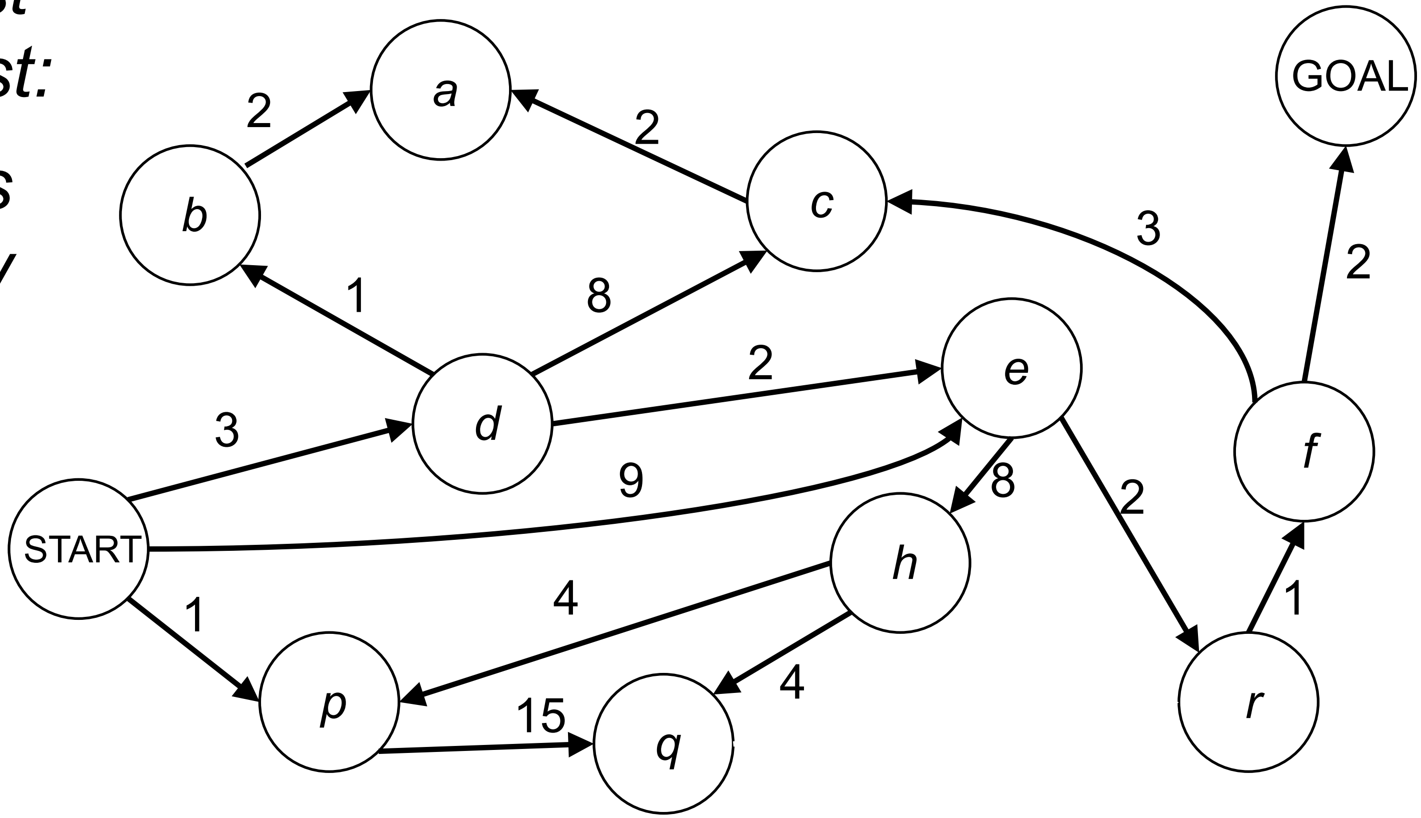


Notice that BFS finds the shortest path in terms of number of transitions. It does not find the least-cost path.

Uniform Cost Search

Expand cheapest node first:

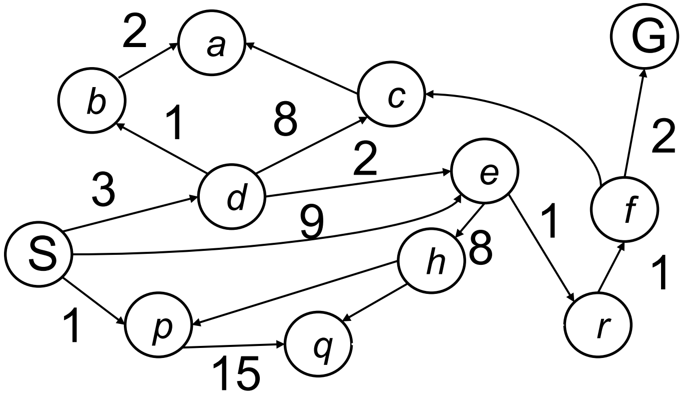
Fringe is a priority queue

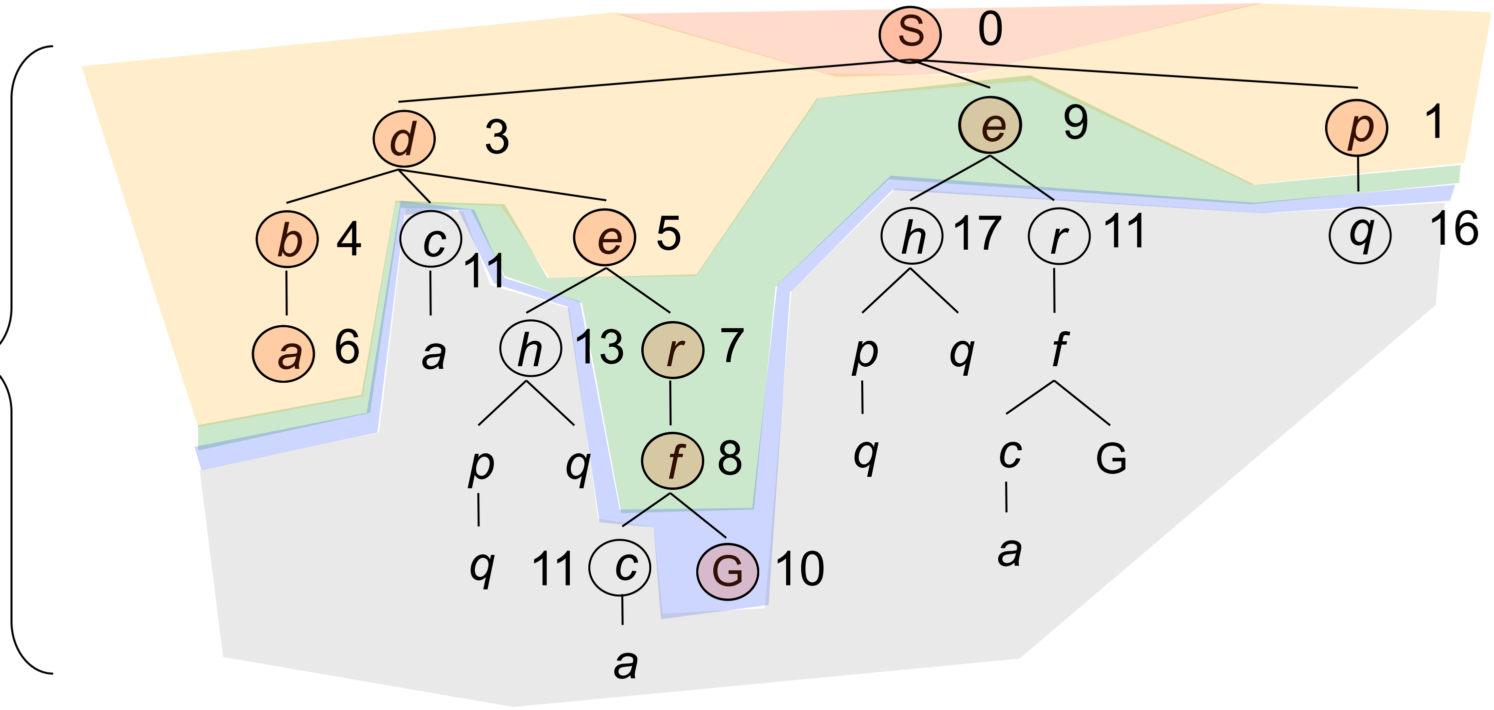


Uniform Cost Search

Expansion order:

(S,p,d,b,e,a,r,f,e,G)

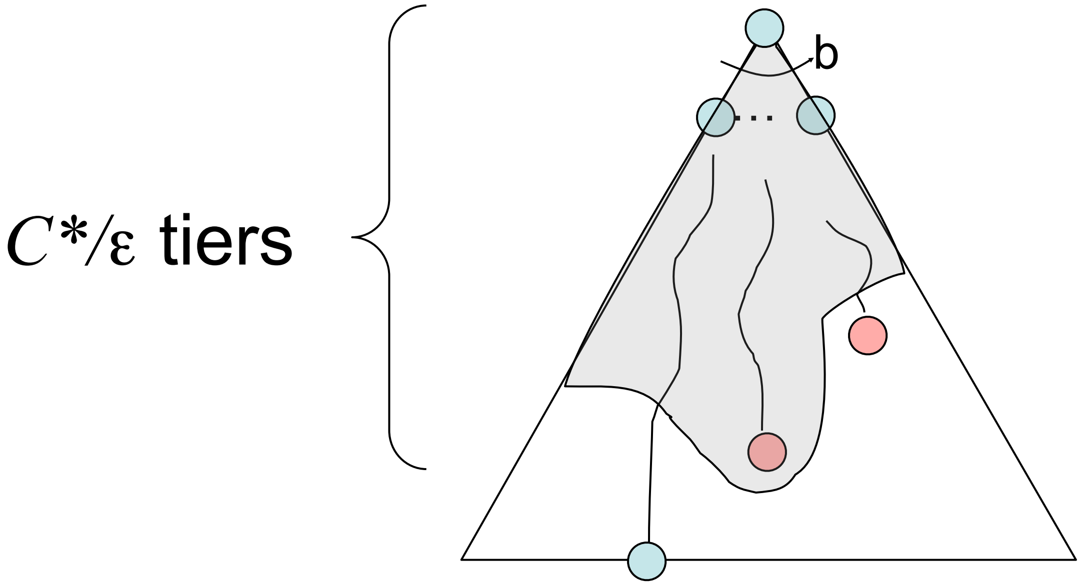




Cost contours

Uniform Cost Search

Algorithm		Complete	Optimal	Time	Space
DFS	w/ Path Checking	Y	N	$O(b^m)$	$O(bm)$
BFS		Y	Y*	$O(b^d)$	$O(b^d)$
UCS		Y*	Y	$O(b^{C^*/\varepsilon})$	$O(b^{C^*/\varepsilon})$

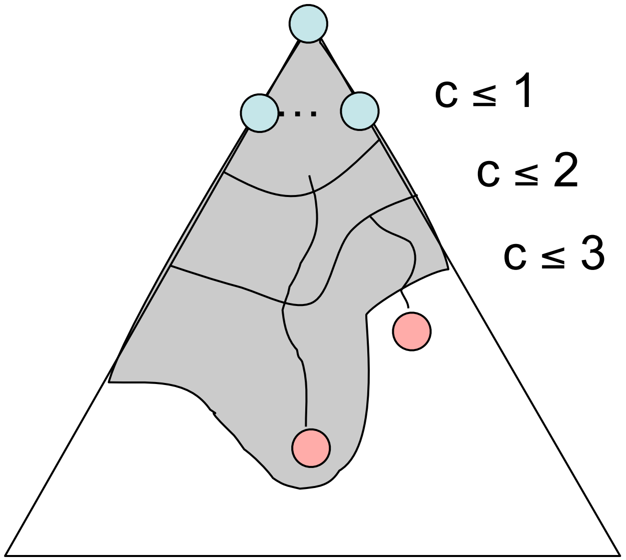


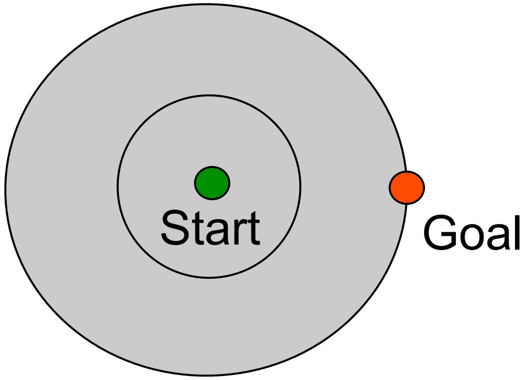
Uniform Cost Issues

- Remember: explores increasing cost contours

- The good: UCS is complete and optimal!

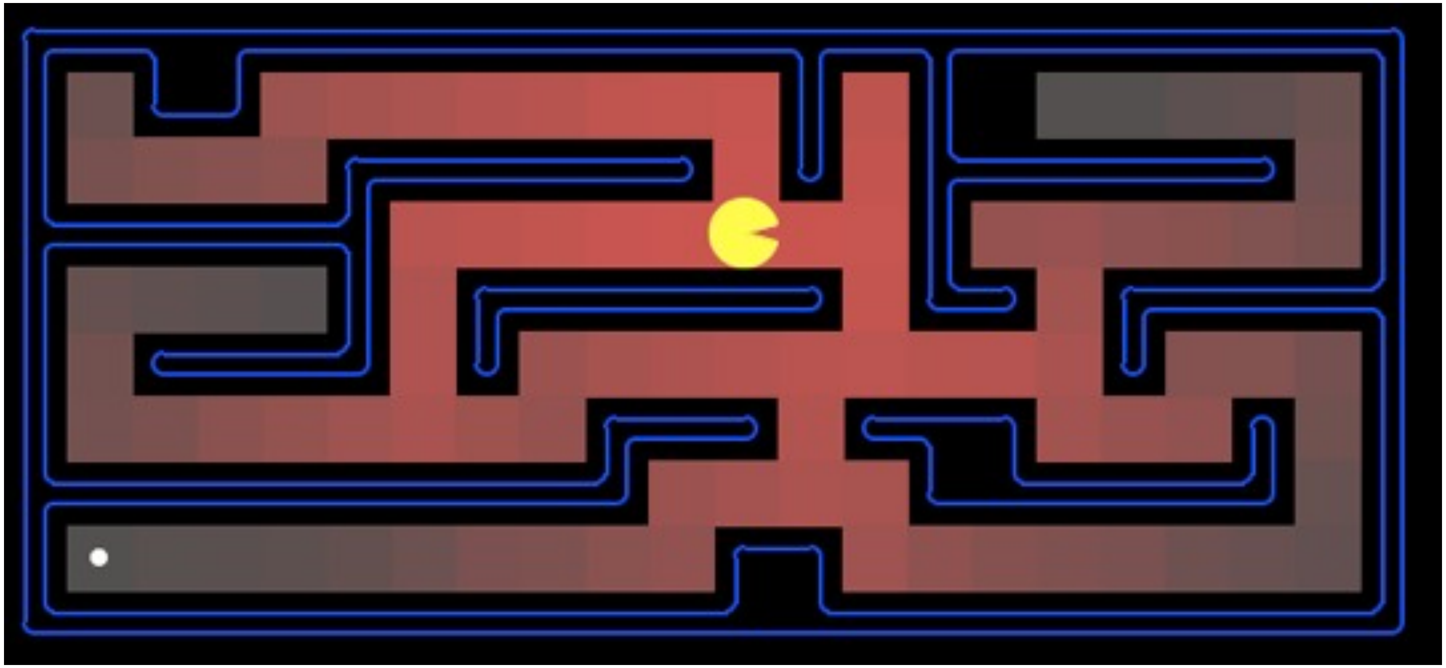
- The bad:
  - Explores options in every “direction”
  - No information about goal location





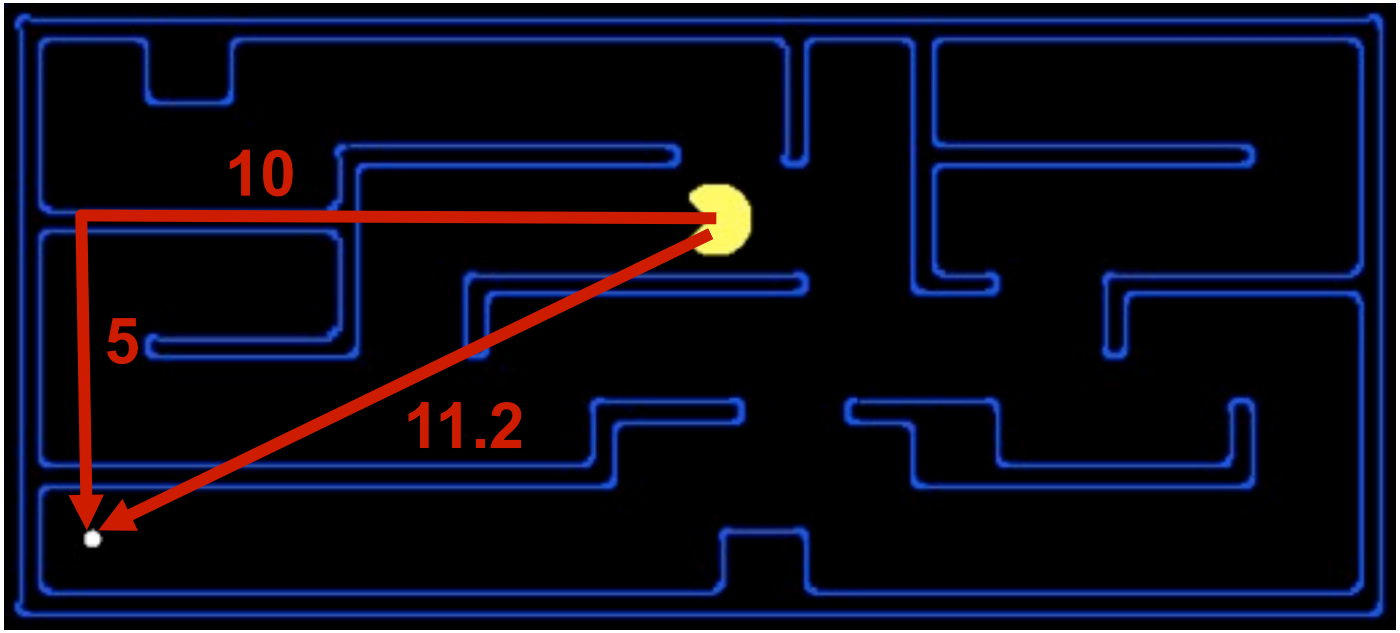
Uniform Cost: Pac-Man

- Cost of 1 for each action
- Explores all of the states, but one

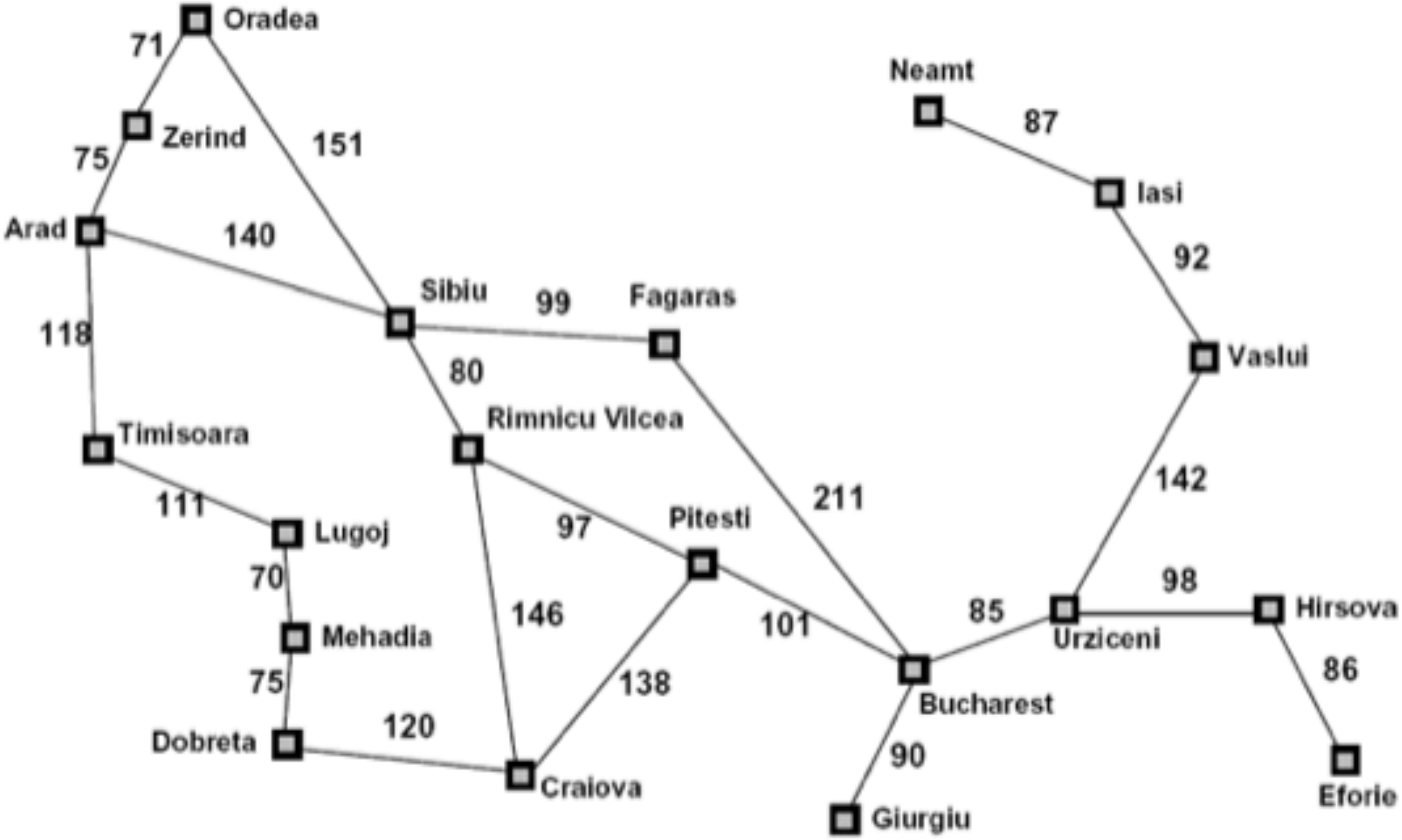


Search Heuristics

- Any *estimate* of how close a state is to a goal
- Designed for a particular search problem
- Examples: Manhattan distance, Euclidean distance



Heuristics

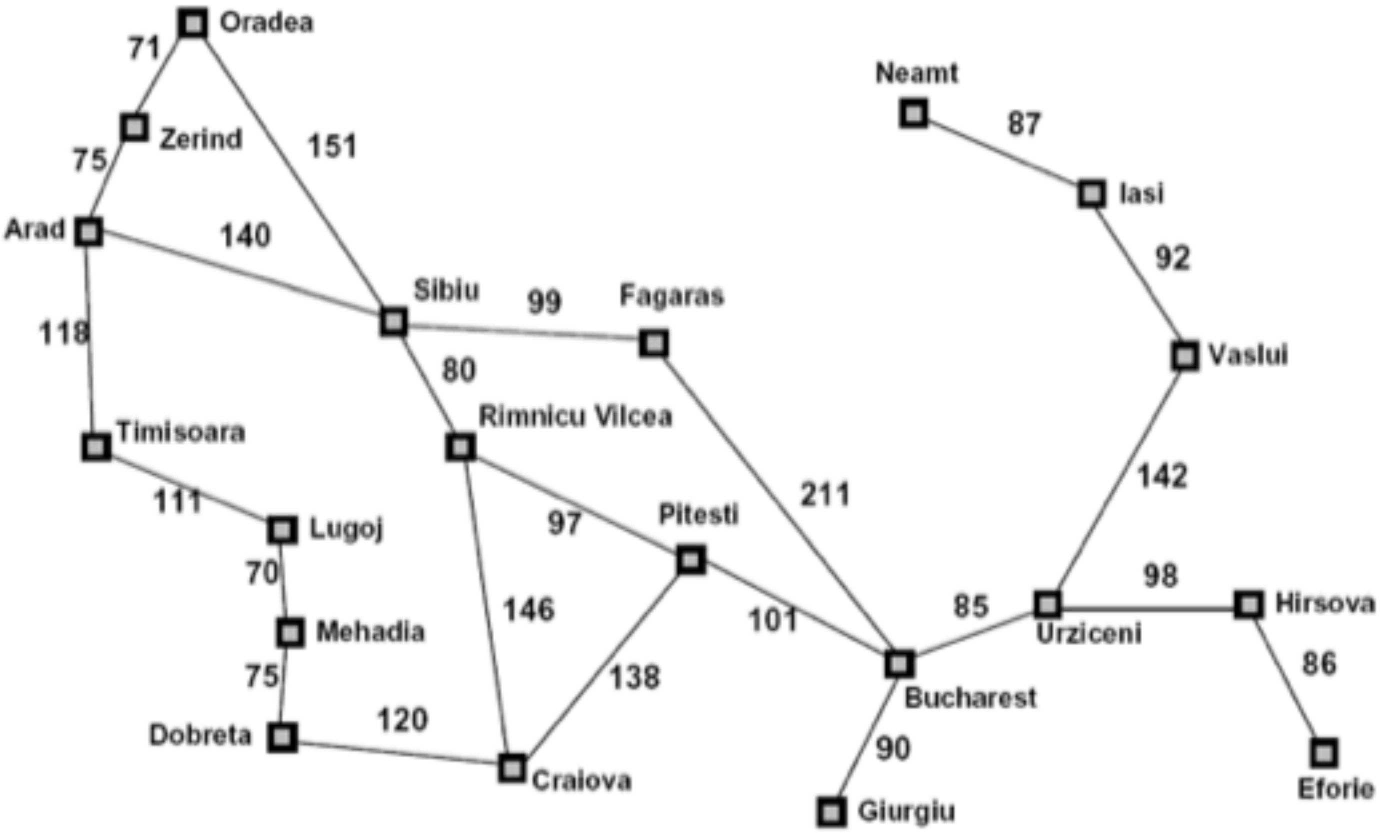


Straight−line distance to Bucharest

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

Best First / Greedy Search

Expand closest node first: Fringe is a priority queue



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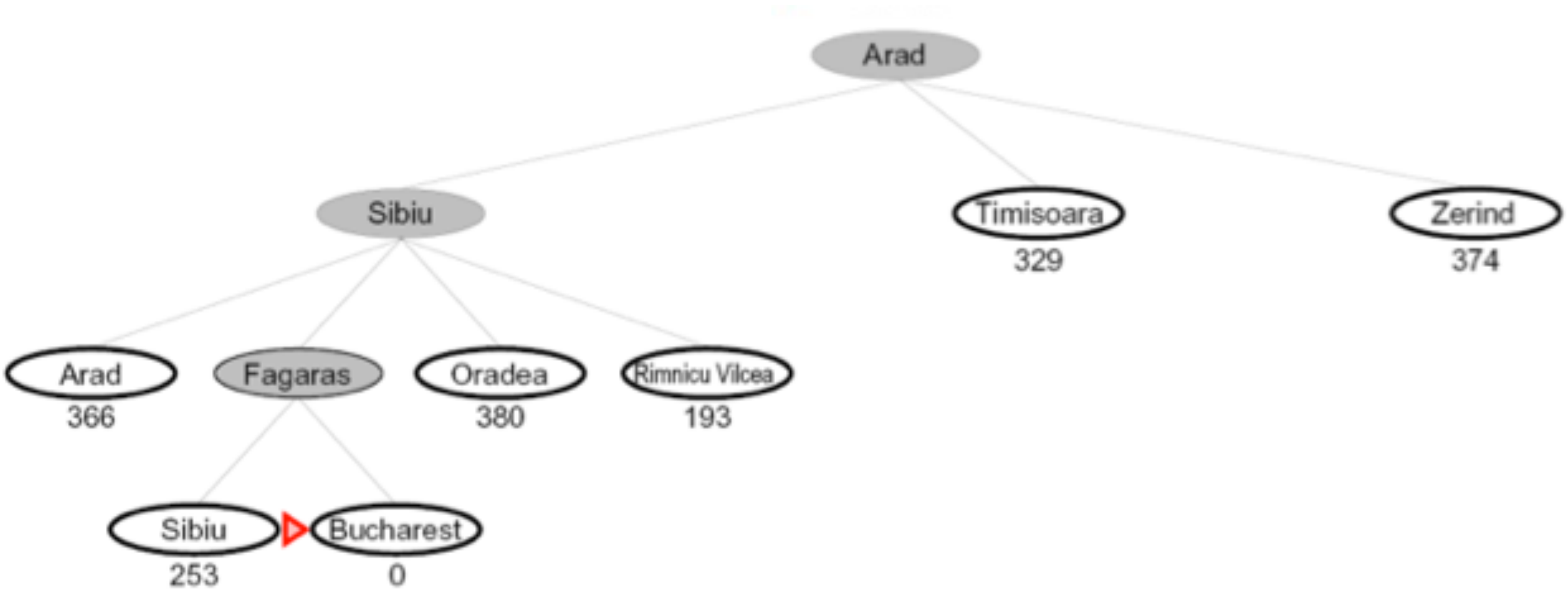
Best First / Greedy Search

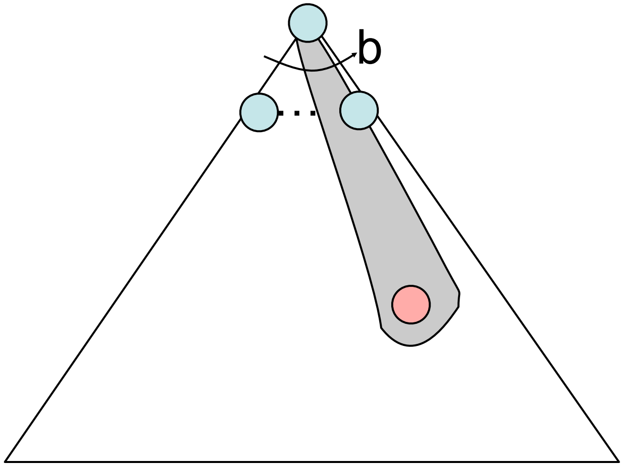
- Expand the node that seems closest…

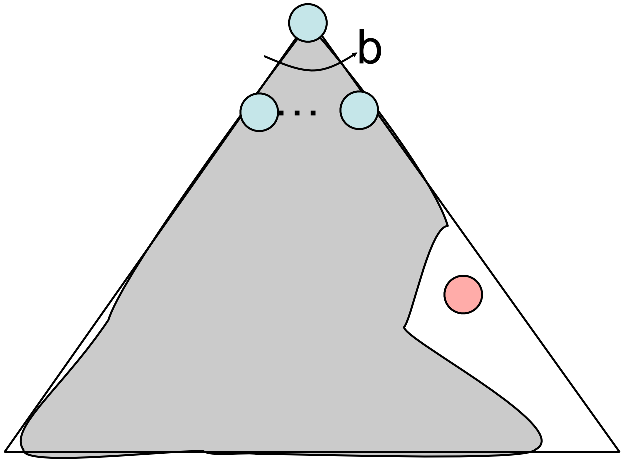


- What can go wrong?

Best First / Greedy Search

- A common case:
  - Best-first takes you straight to the (wrong) goal
- Worst-case: like a badly-guided DFS in the worst case
  - Can explore everything
  - Can get stuck in loops if no cycle checking
- Like DFS in completeness (finite states w/ cycle checking)





To Do:

- Look at the course website:
  - http://www.cs.washington.edu/cse473/11au/
- Do the readings
- Get started on PS1, when it is posted

Search Gone Wrong?

Start: Haugesund, Rogaland, Norway
End: Trondheim, Sør-Trøndelag, Norway
Total Distance: 2713.2 Kilometers
Estimated Total Time: 47 hours, 31 minutes