Uninformed Search

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CS 421: Introduction to Artificial Intelligence

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Many slides courtesy of
Dan Klein, Stuart Russell,
or Andrew Moore

Announcements

- Forgot to tell you login information for web page:
  - User name = “cs421” (but no quotes)
  - Password = “__________” (still no quotes)
  - (this will be used for posting solutions)

- Junkfood machines:
  - You may develop at home, but must *run* on Junkfood

- Homework 1 has been posted
- Project 1 will be posted soon

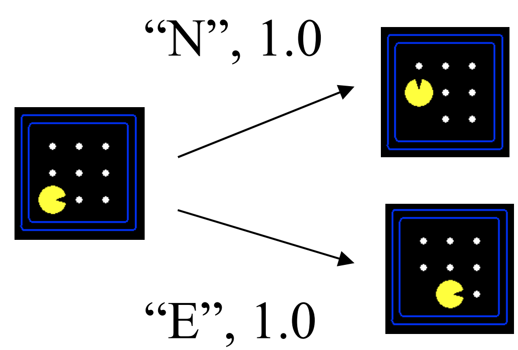
Today

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

Search Problems

- A search problem consists of:
  - A state space

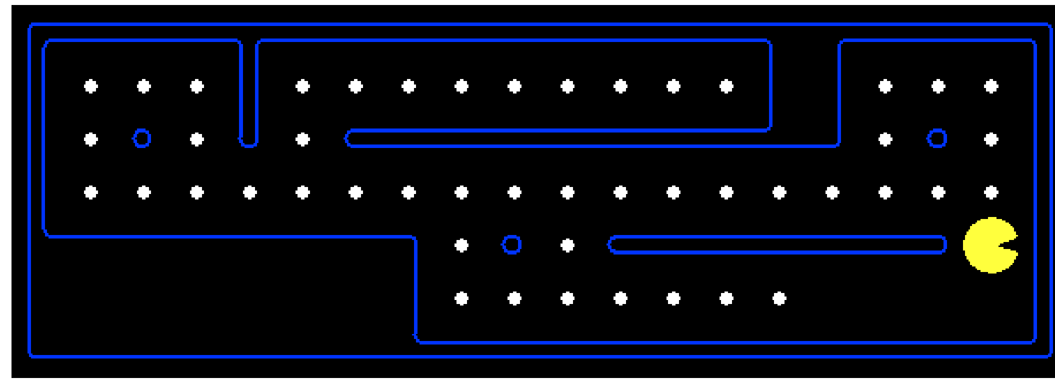
  - A successor function

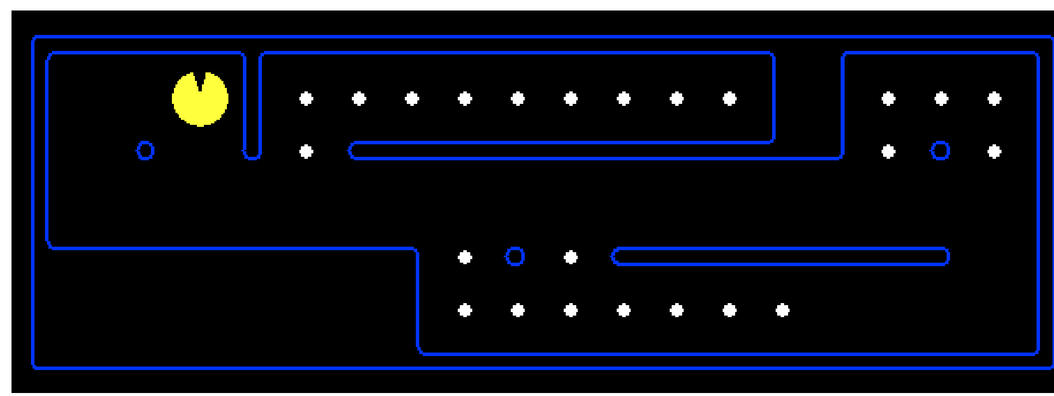


  - A start state and a goal test
- A solution is a sequence of actions (a plan) which transforms the start state to a goal state

Reflex Agents

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

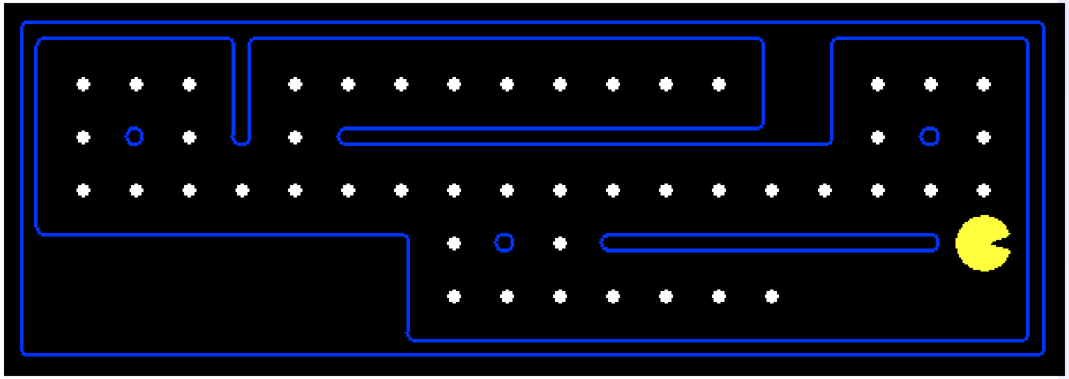


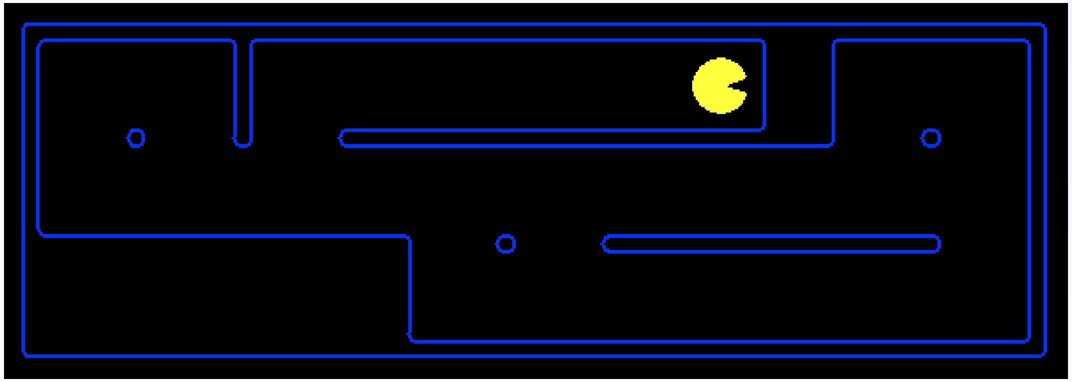


[demo: reflex]

Goal Based Agents

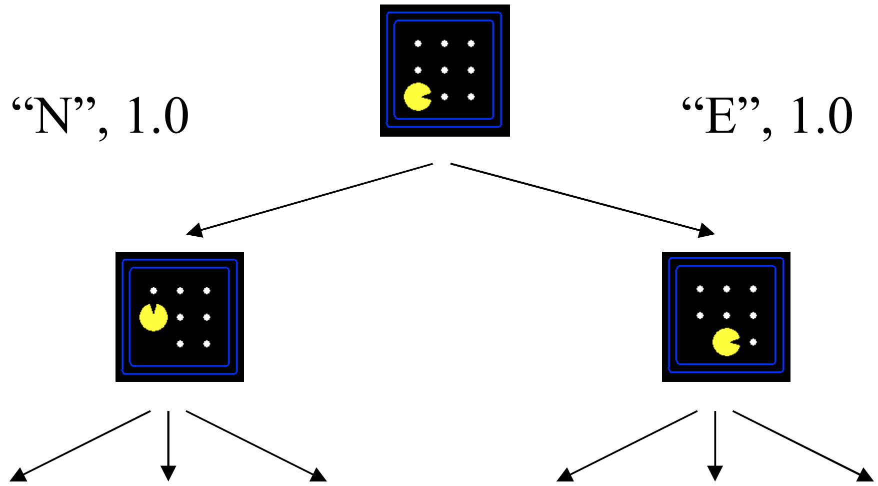
- Goal-based agents:
  - Plan ahead
  - Decisions based on (hypothesized) consequences of actions
  - Must have a model of how the world evolves in response to actions





[demo: plan fast / slow]

Search Trees



- A search tree:
  - This is a “what if” tree of plans and outcomes
  - Start state at the root node
  - Children correspond to successors
  - Nodes labeled with states, correspond to PLANS to those states
  - For most problems, can never build the whole tree
    - So, have to find ways to use only the important parts!

State Space Graphs

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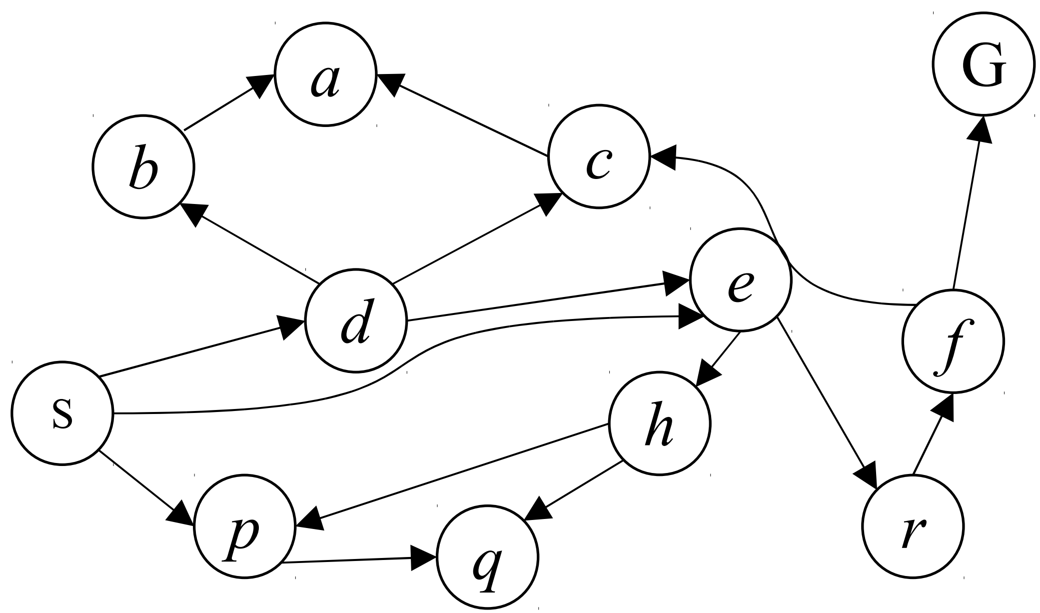
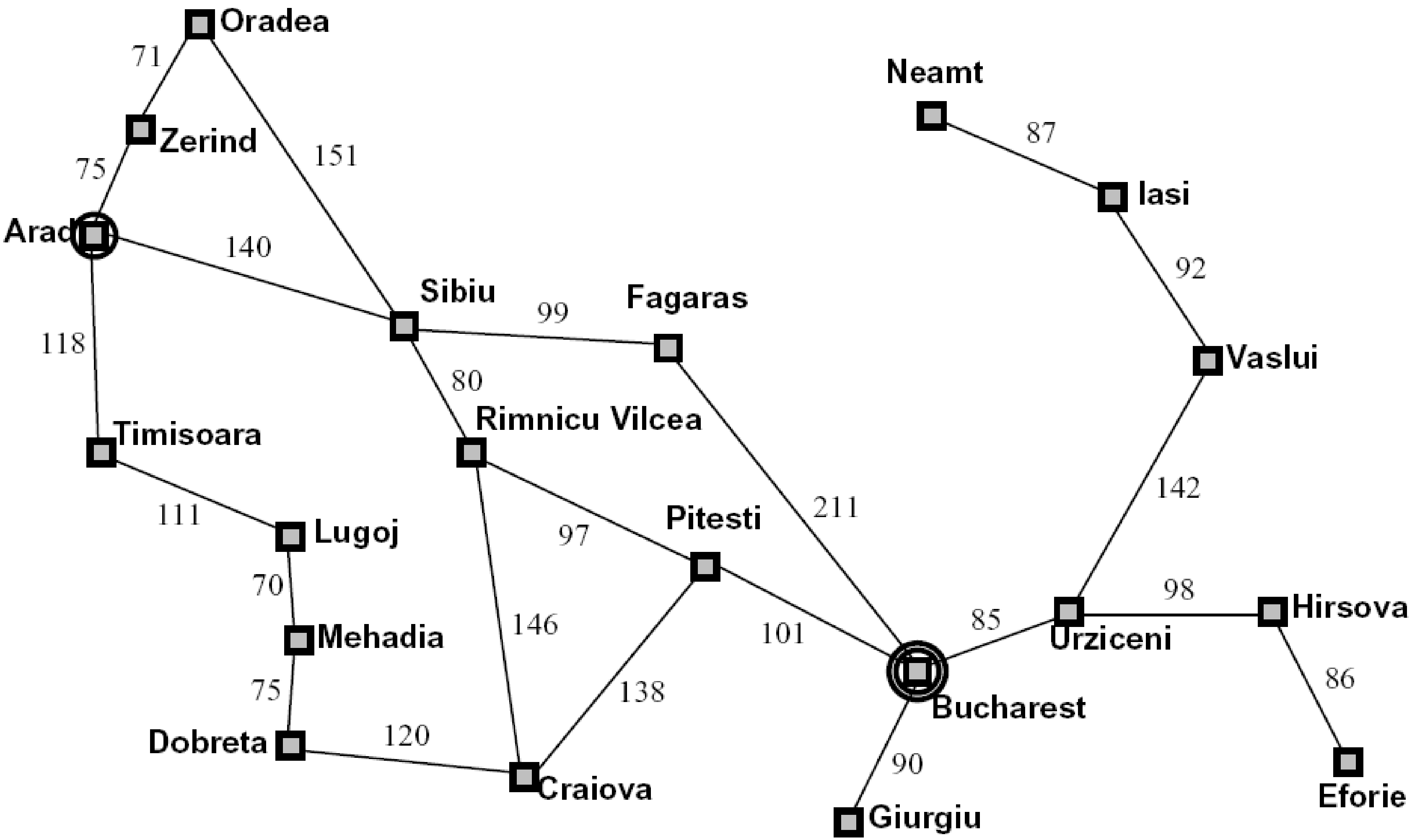
- There's some big graph in which
  - Each state is a node
  - Each successor is an outgoing arc
- Important: For most problems we could never actually build this graph
- How many states in Pacman?

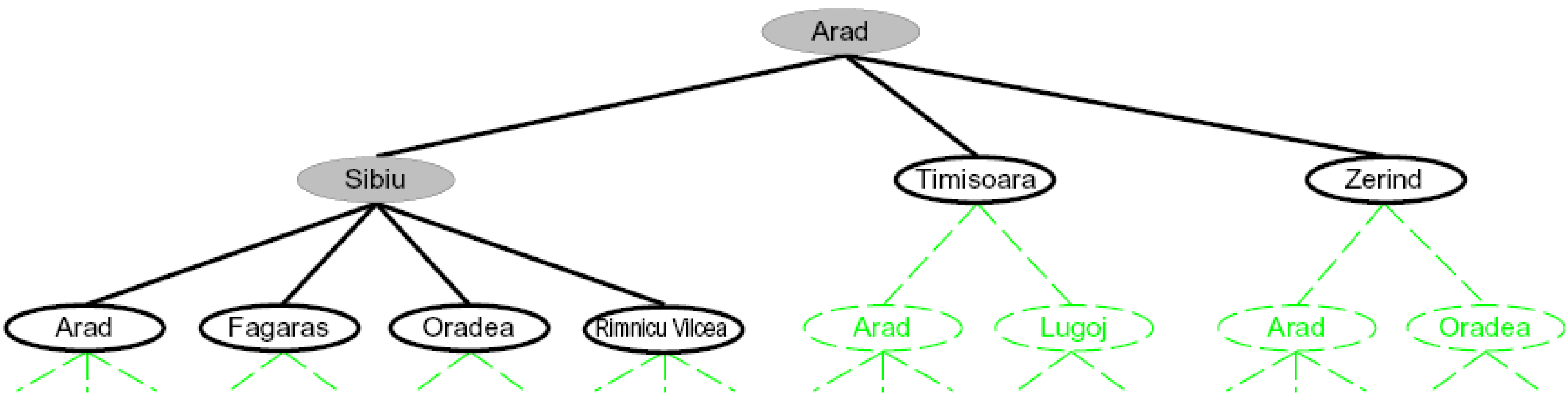


Laughably tiny search graph for a tiny search problem

Example: Romania



Another Search Tree

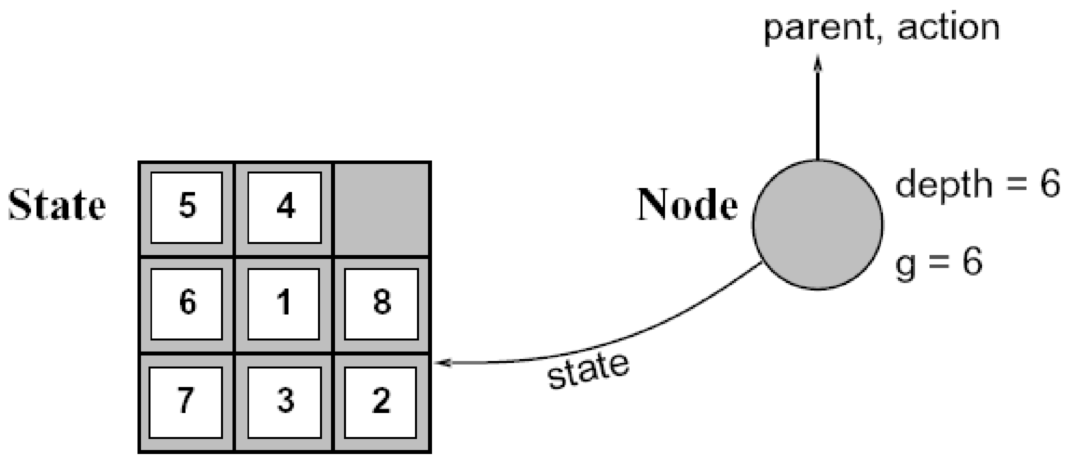


- Search:
  - Expand out possible plans
  - Maintain a fringe of unexpanded plans
  - Try to expand as few tree nodes as possible

States vs. Nodes

- Problem graphs have problem states
  - Represent an abstracted state of the world
  - Have successors, predecessors, can be goal / non-goal

- Search trees have search nodes
  - Represent a plan (path) which results in the node's state
  - Have 1 parent, a length and cost, point to a problem state
  - Expand uses successor function to create new tree nodes
  - The same problem state in multiple search tree nodes



General Tree Search

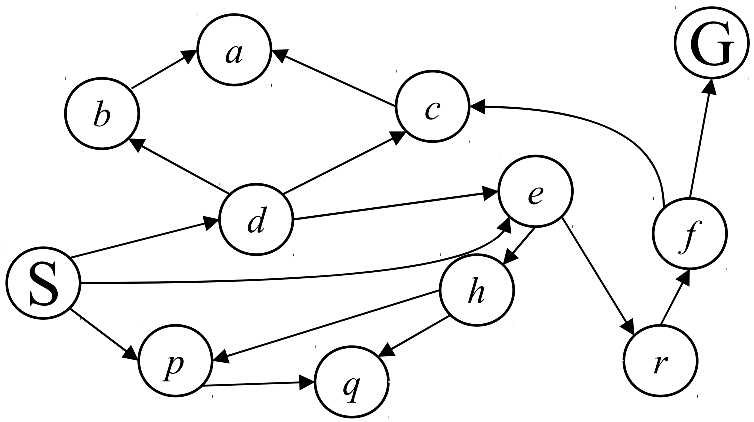
```
function TREE-SEARCH( problem, strategy) returns a solution, or failure
    initialize the search tree using the initial state of problem
    loop do
        if there are no candidates for expansion then return failure
        choose a leaf node for expansion according to strategy
        if the 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
  - Expansion
  - Exploration strategy

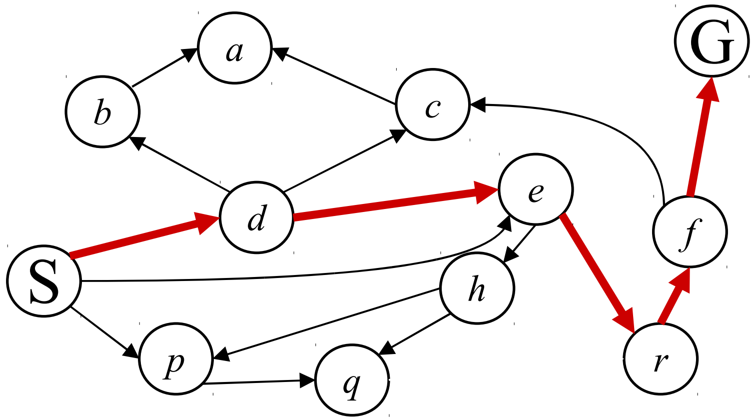
Detailed pseudocode is in the book!

- Main question: which fringe nodes to explore?

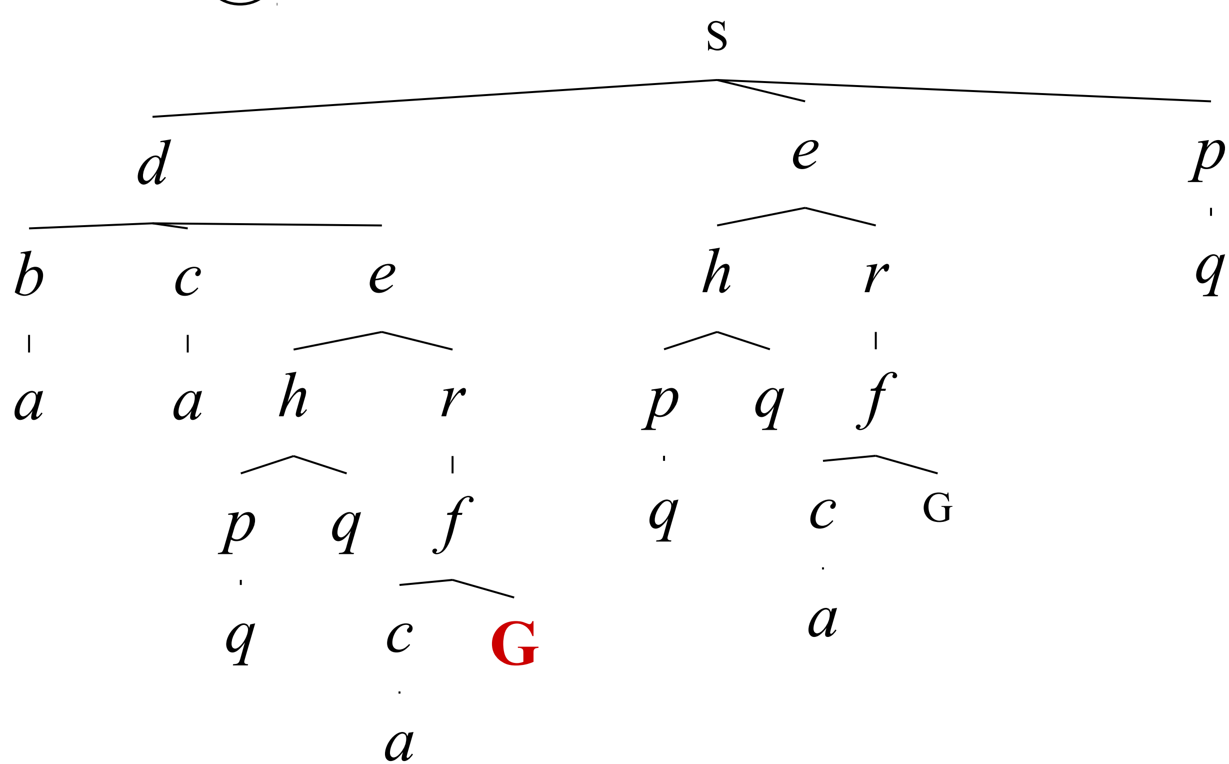
Example: Tree Search



State Graphs vs Search Trees



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

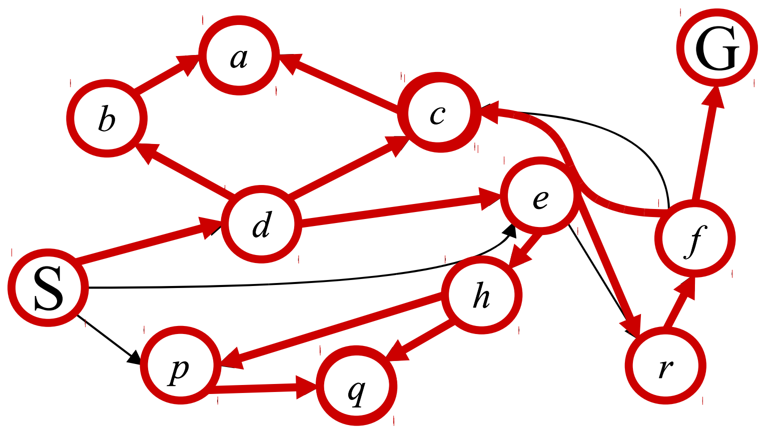


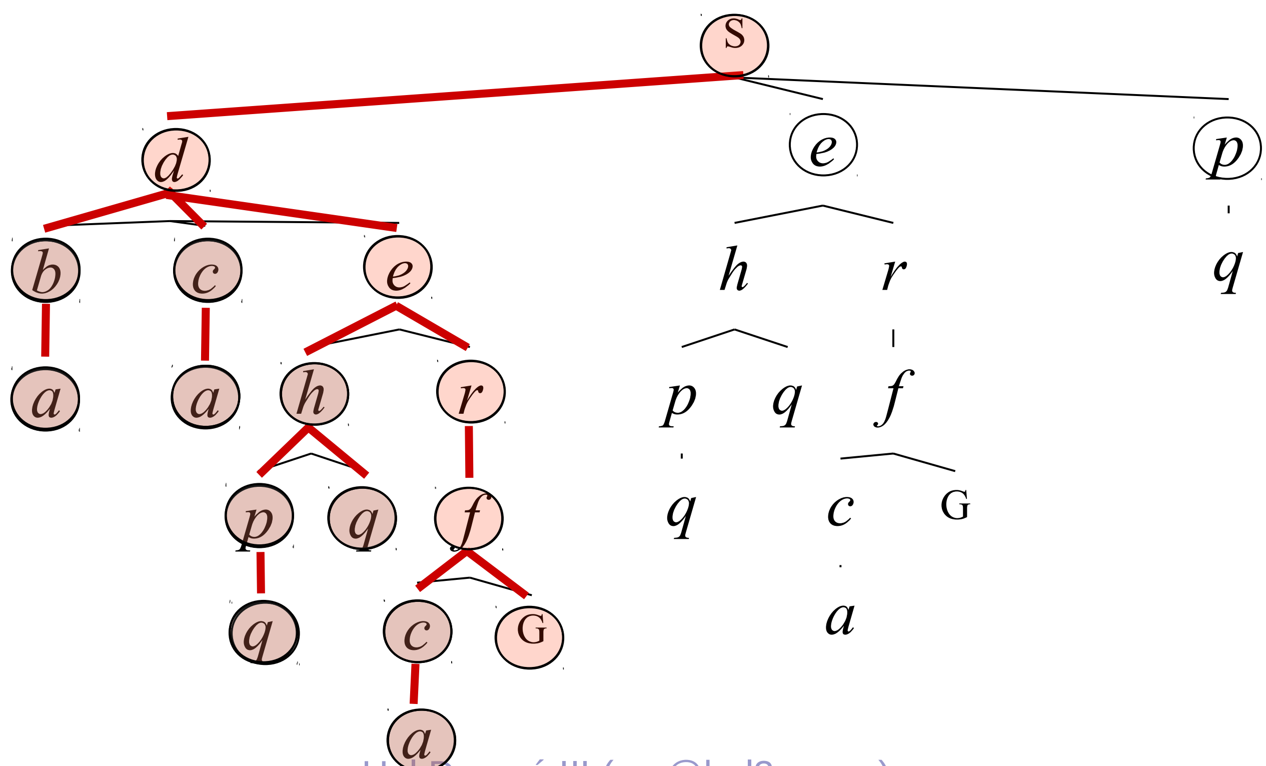
We almost always construct both on demand – and we construct as little as possible.

Review: Depth First Search

Strategy: expand deepest node first

Implementation: Fringe is a LIFO stack

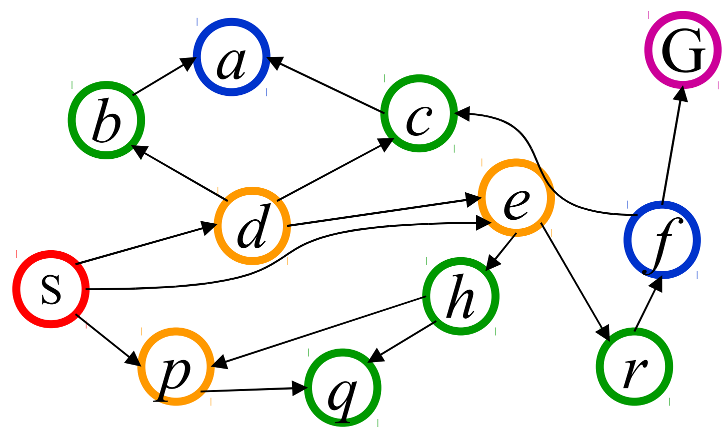




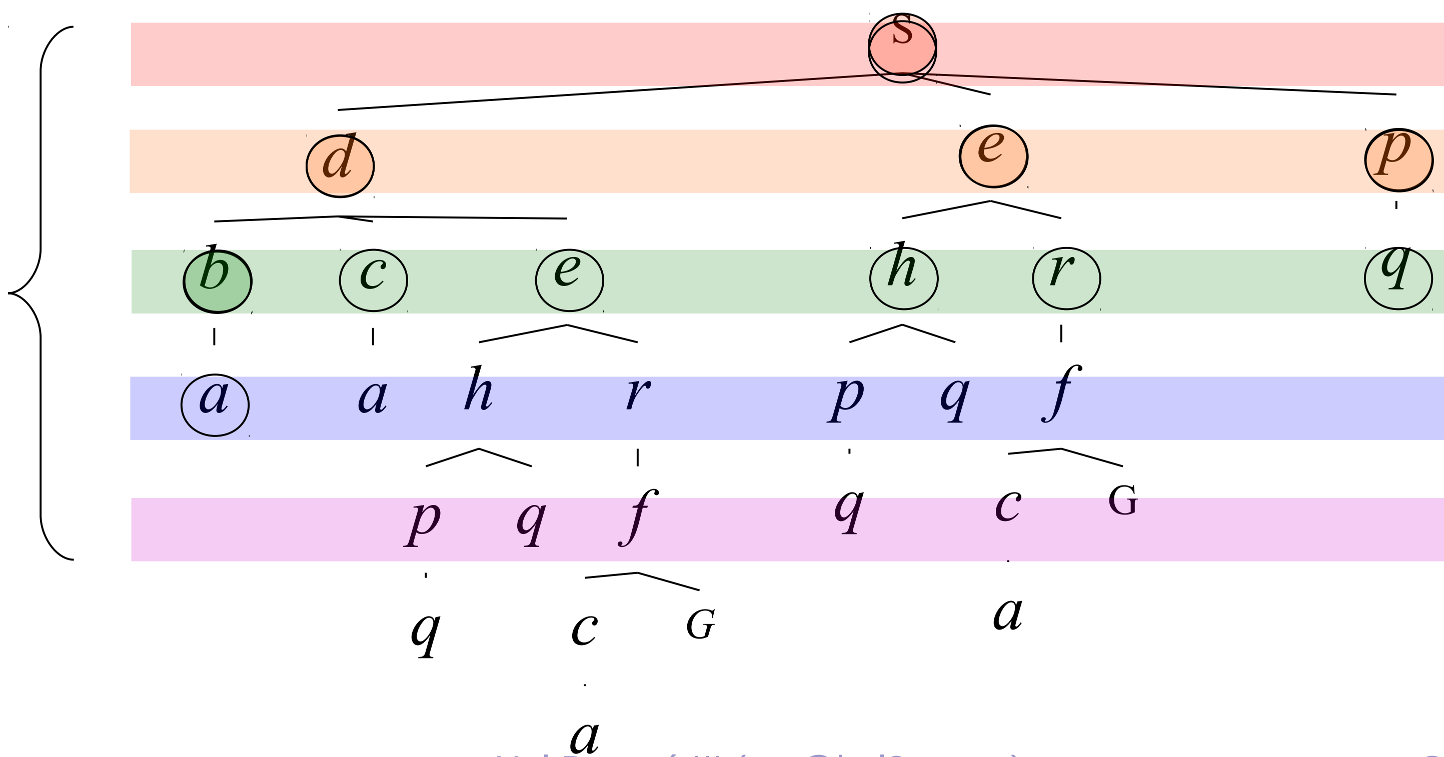
Review: Breadth First Search

Strategy: expand shallowest node first

Implementation: Fringe is a FIFO queue



Search Tiers



Search Algorithm Properties

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

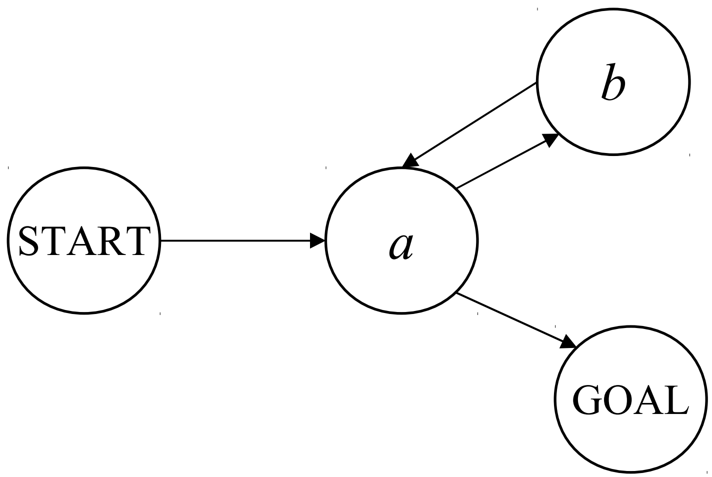
Variables:

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

DFS

n	# states
b	avg branch
C^*	least cost
s	shallow goal
m	max depth

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



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

DFS

n	# states
b	avg branch
*C**	least cost
s	shallow goal
m	max depth

- With cycle checking, DFS is complete.

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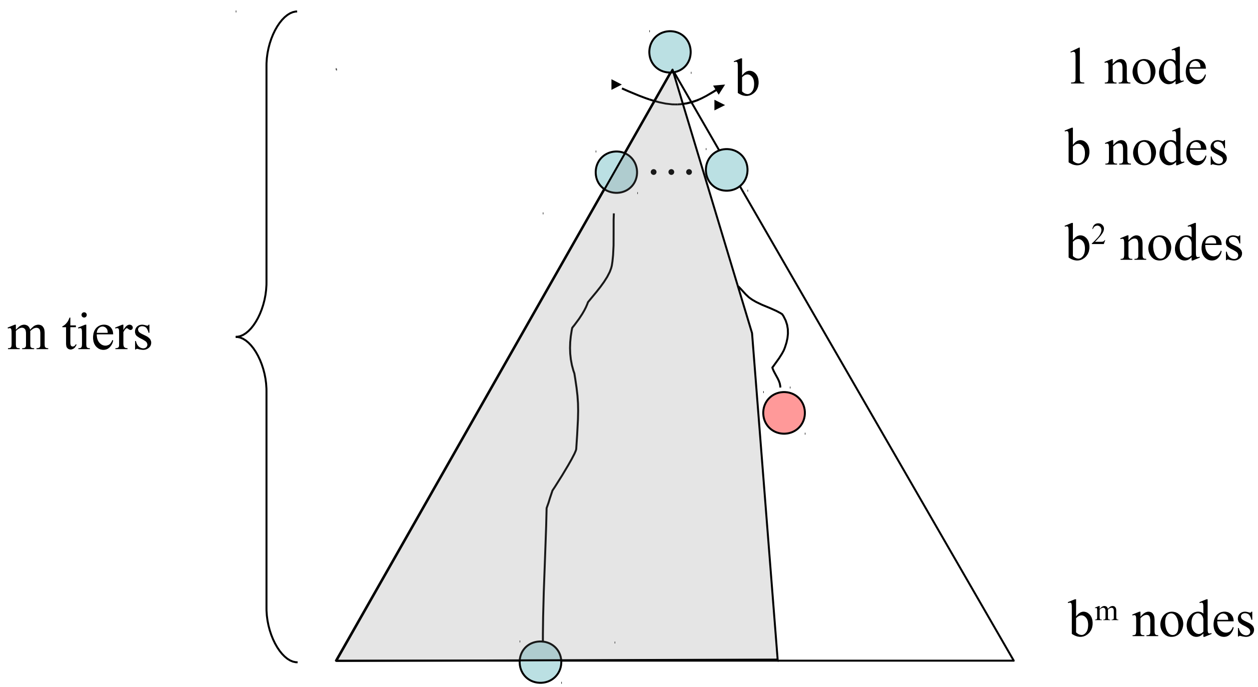
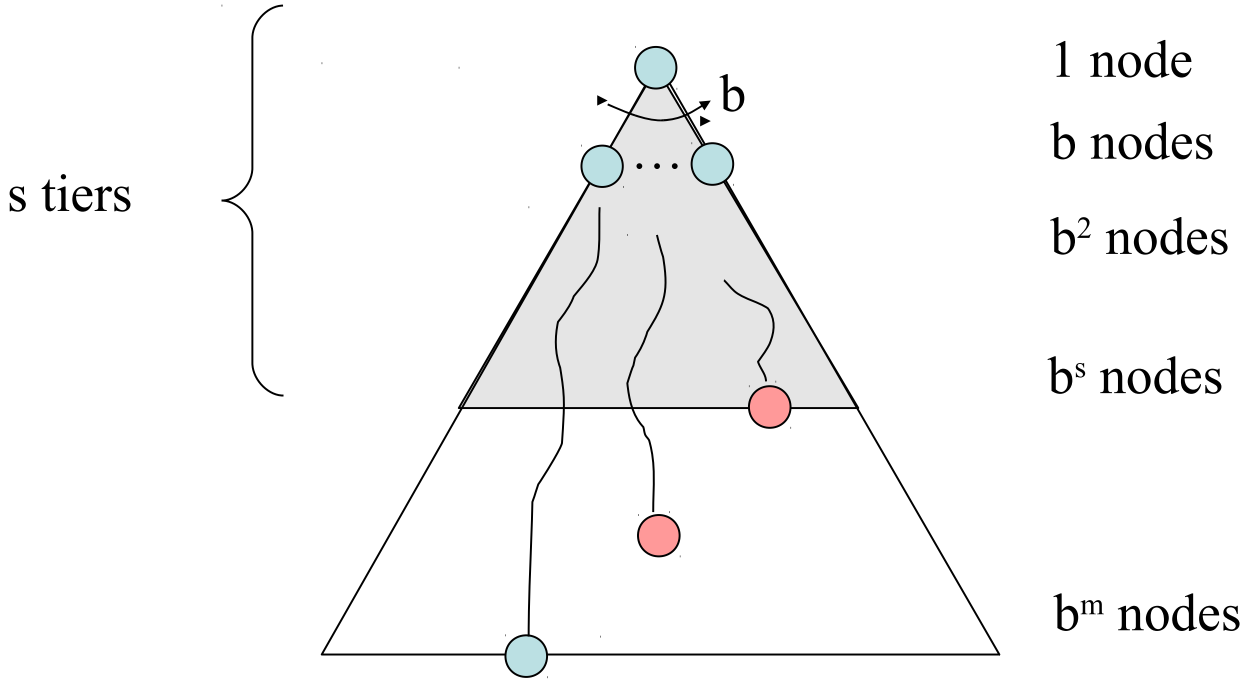


Algorithm		Complete	Optimal	Time	Space
DFS	w/ Path Checking	Y			

BFS

n	# states
b	avg branch
*C**	least cost
s	shallow goal
m	max depth



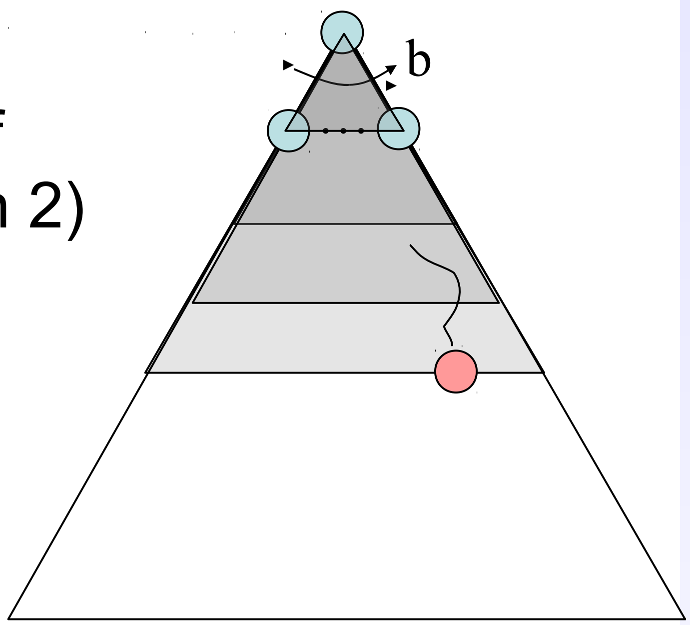
Iterative Deepening

n	# states
b	avg branch
$C*$	least cost
s	shallow goal
m	max depth

Iterative deepening uses DFS as a subroutine:

1. Do a DFS which only searches for paths of length <=1 (DFS gives up on path of length 2)
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			
BFS		Y			
ID		Y			

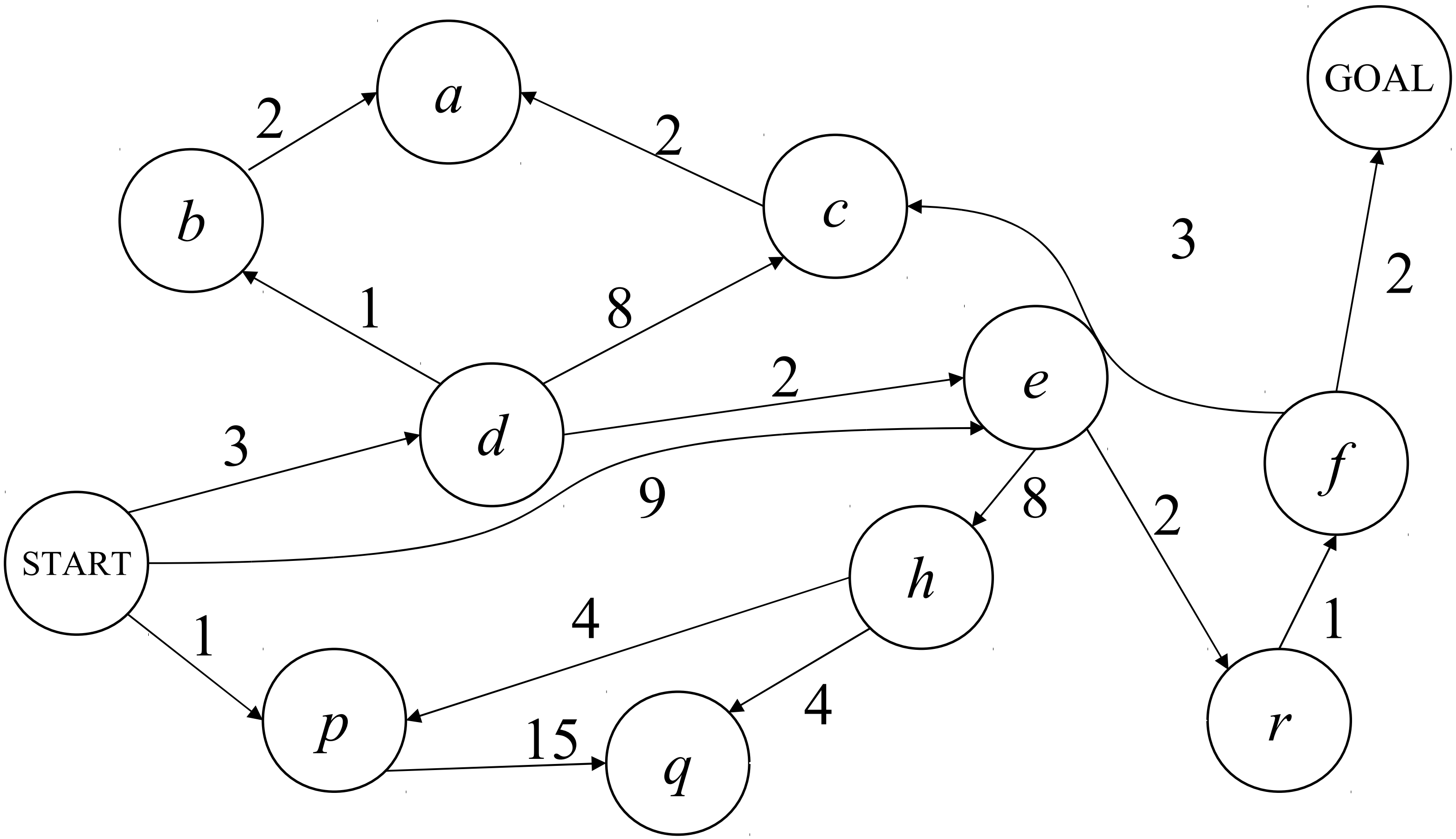
Comparisons

n	# states
b	avg branch
$C*$	least cost
s	shallow goal
m	max depth

- When will BFS outperform DFS?

- When will DFS outperform BFS?

Costs on Actions



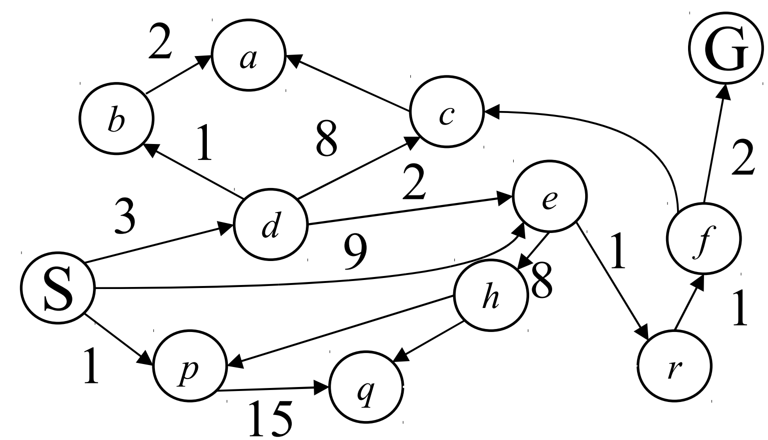
Notice that BFS finds the shortest path in terms of number of transitions. It does not find the least-cost path.

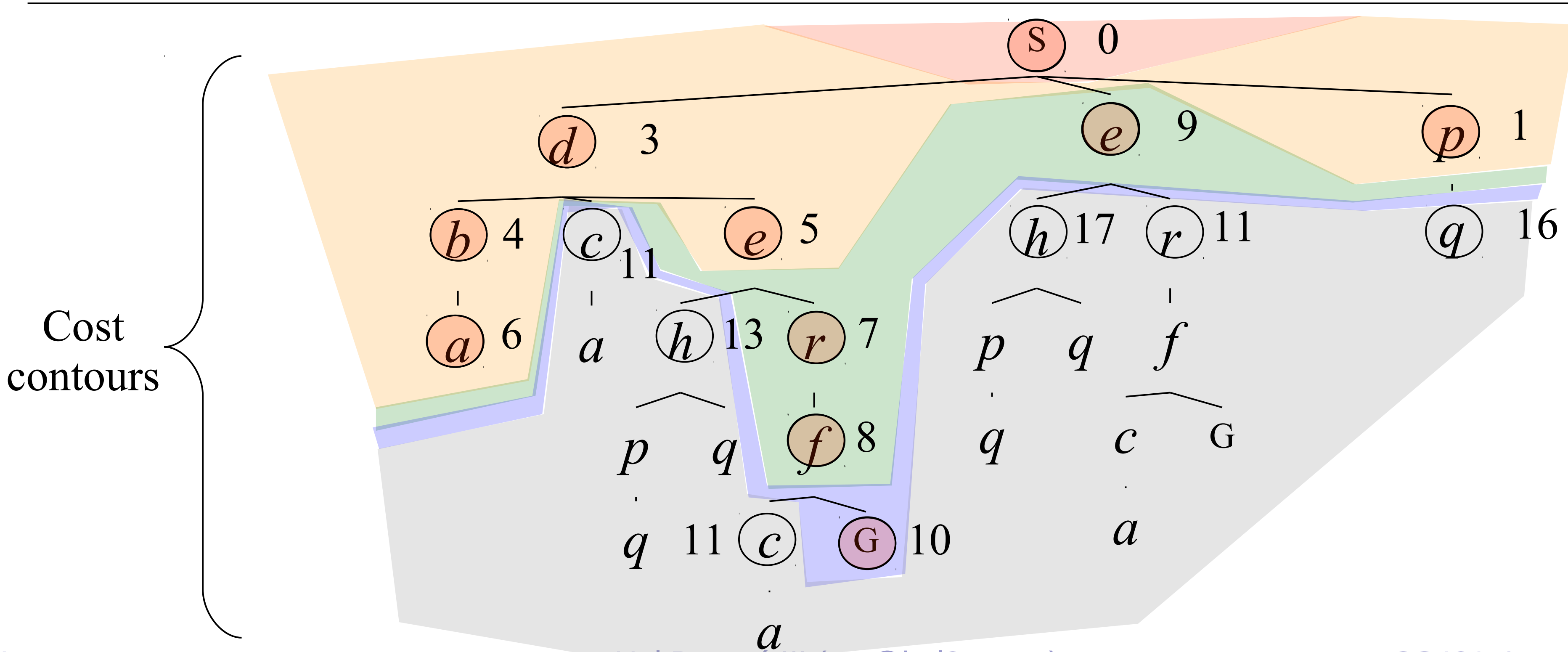
We will quickly cover an algorithm which does find the least-cost path.

Uniform Cost Search

Expand cheapest node first:

Fringe is a priority queue





Priority Queue Refresher

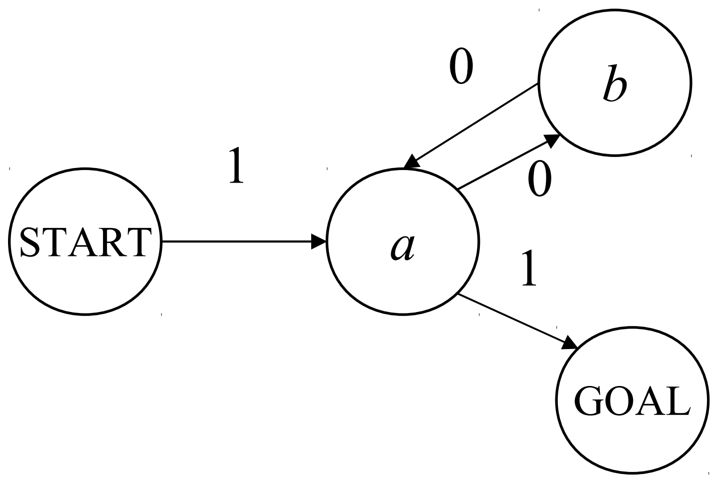
- A priority queue is a data structure in which you can insert and retrieve (key, value) pairs with the following operations:

pq.push(key, value)	inserts *(key, value)* into the queue.
pq.pop()	returns the key with the lowest value, and removes it from the queue.

- You can promote or demote keys by resetting their priorities
- Unlike a regular queue, insertions into a priority queue are not constant time, usually O(log *n*)
- We'll need priority queues for most cost-sensitive search methods.

Uniform Cost Search

- What will UCS do for this graph?

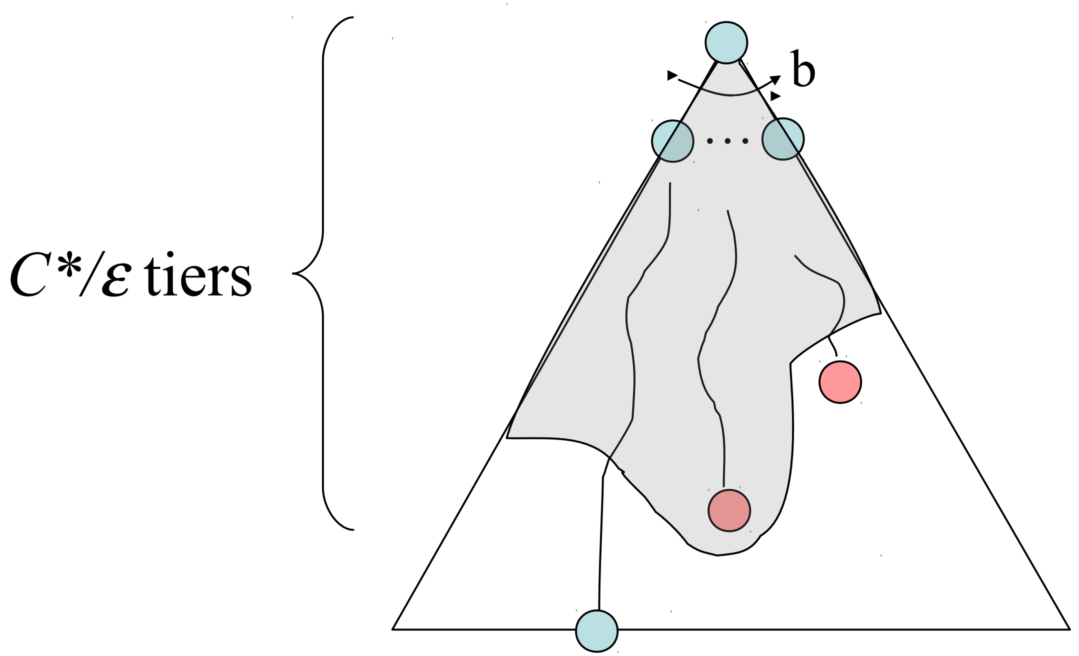


- What does this mean for completeness?

Uniform Cost Search

n	# states
b	avg branch
C^*	least cost
s	shallow goal
m	max depth

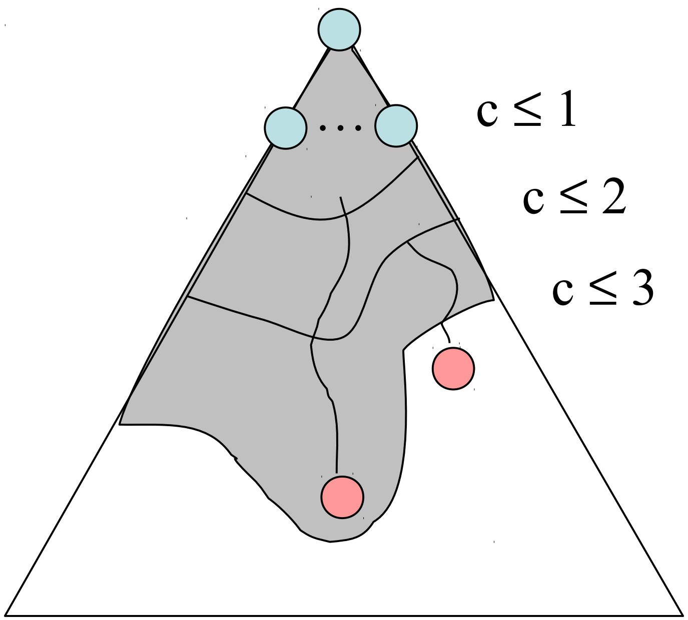
Algorithm		Complete	Optimal	Time	Space
DFS	w/ Path Checking				
BFS					
UCS		Y*	Y	$O(C^* \, b^{C^*/\varepsilon})$	$O(b^{C^*/\varepsilon})$

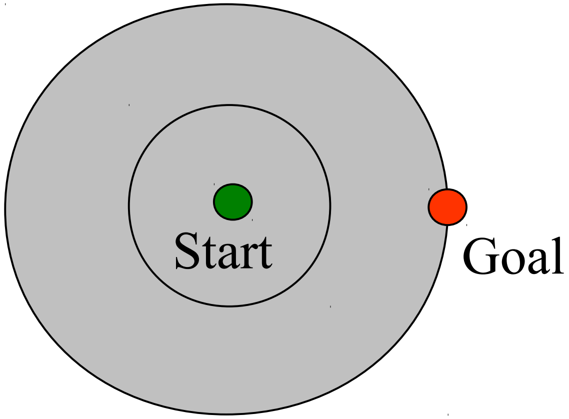


We'll talk more about uniform cost search's failure cases later…

Uniform Cost Problems

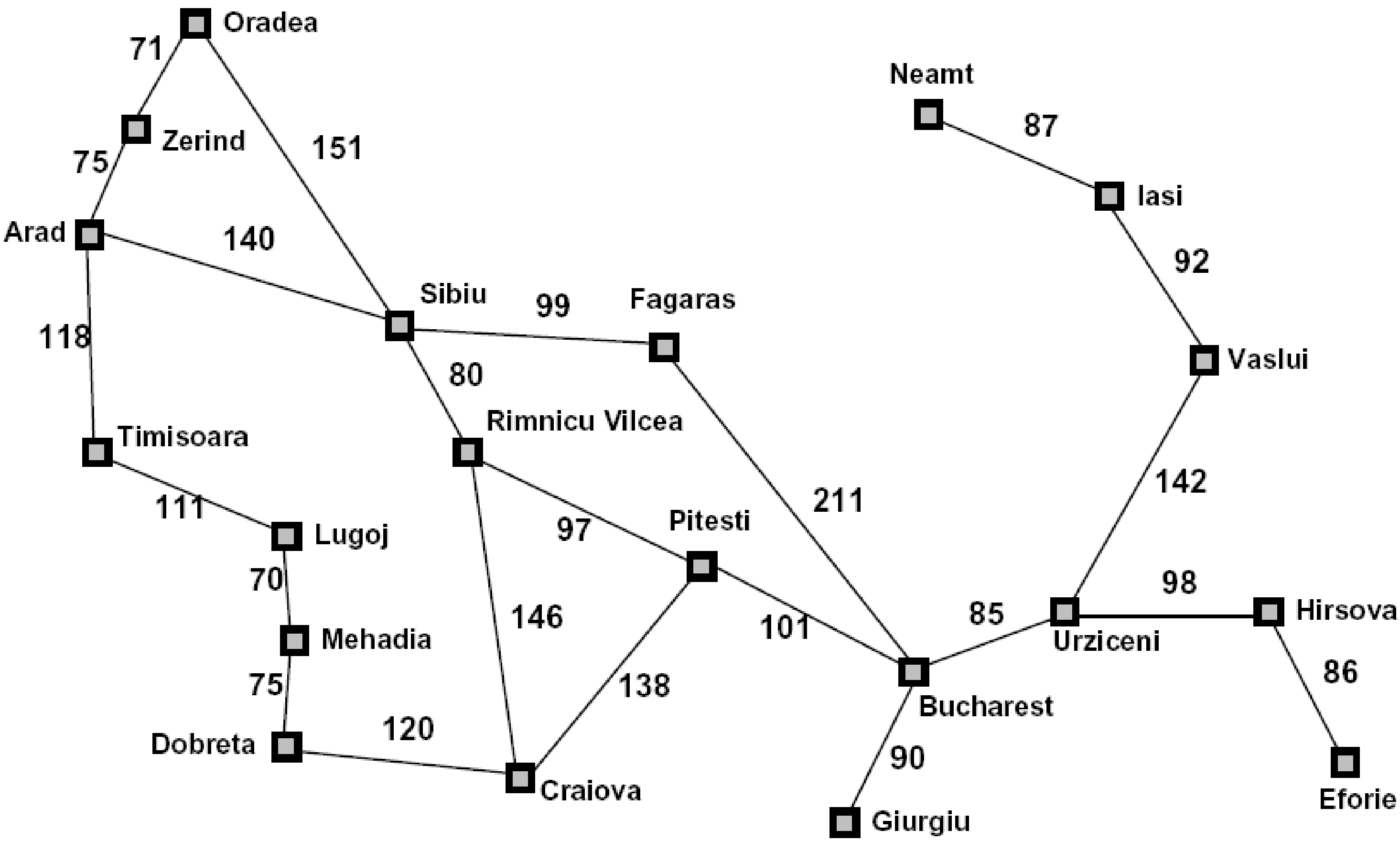
- Remember: explores increasing cost contours
- The good: UCS is complete and optimal!
- The bad:
  - Explores options in every "direction"
  - No information about goal location





[demo: ucs contours]

Heuristics

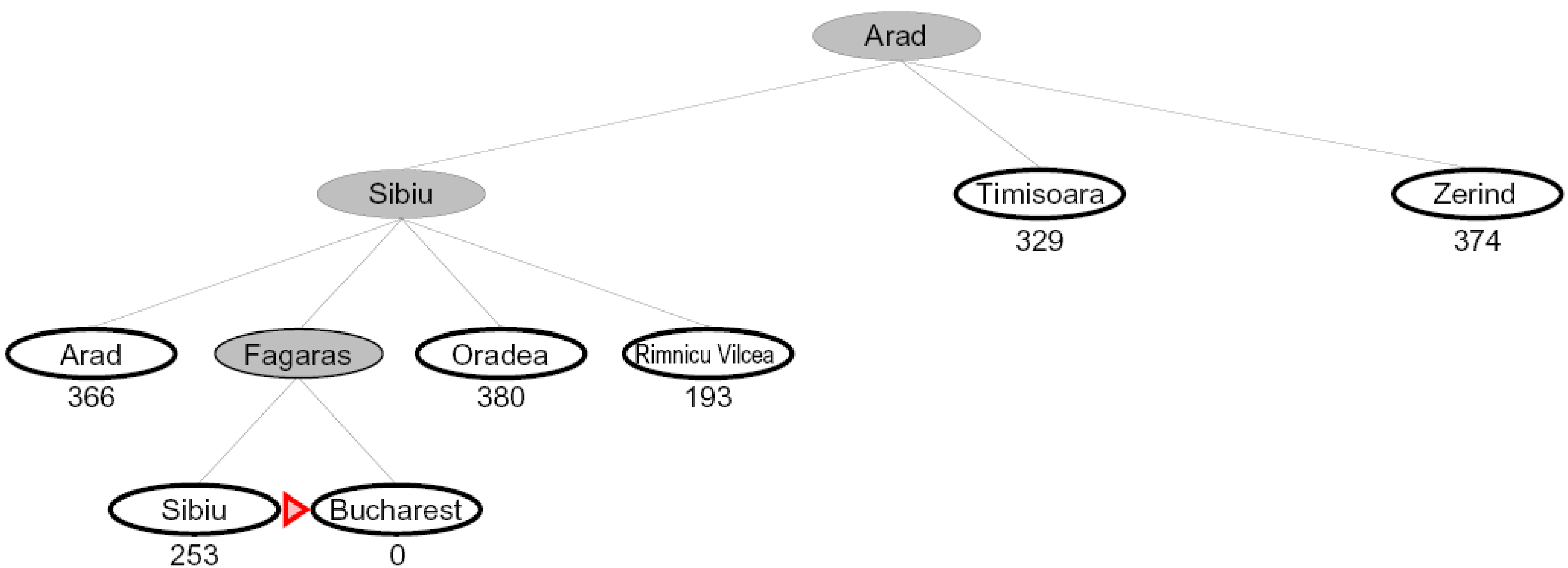


Straight−line distance to Bucharest

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

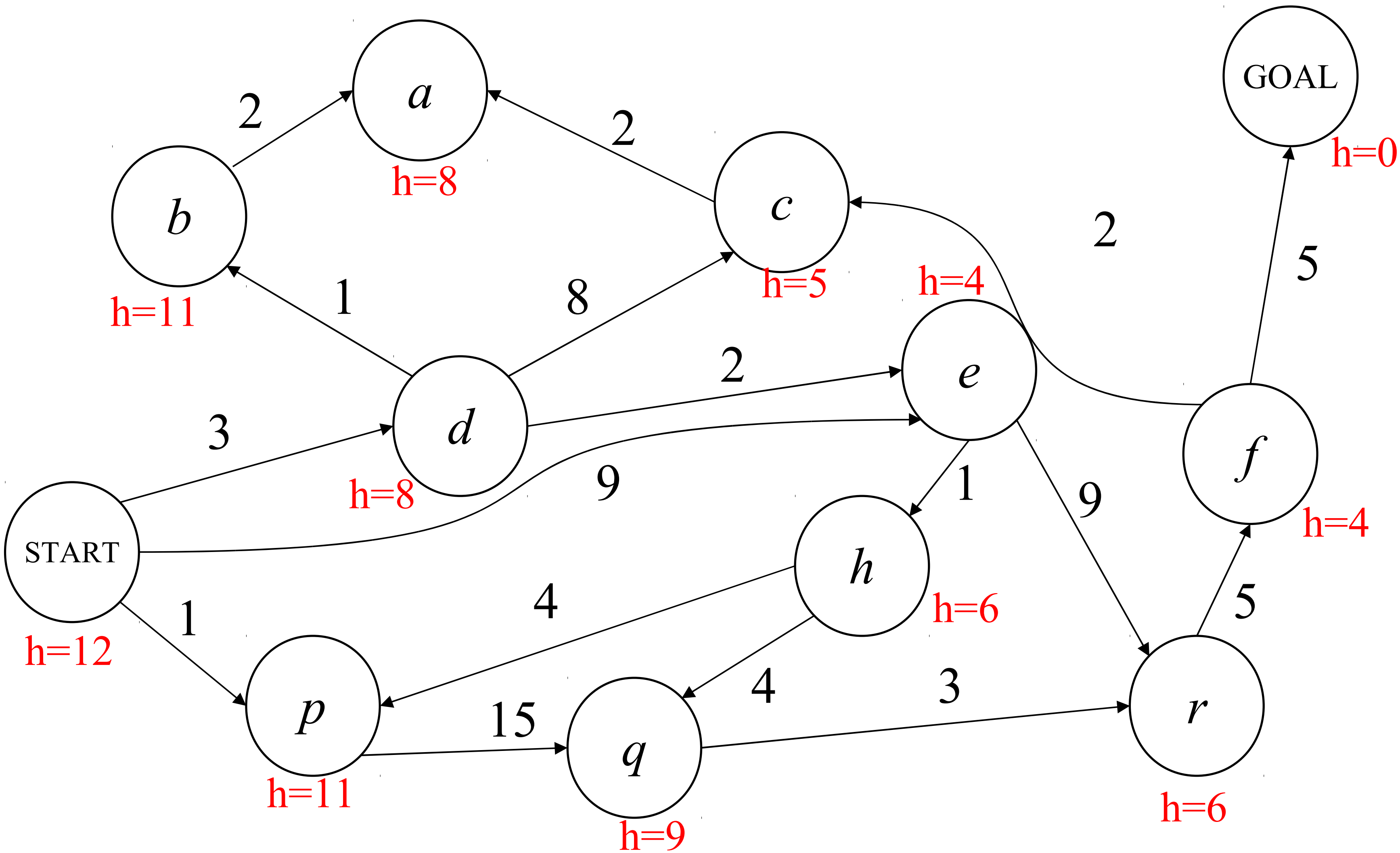
Best First / Greedy Search

- Expand the node that seems closest…



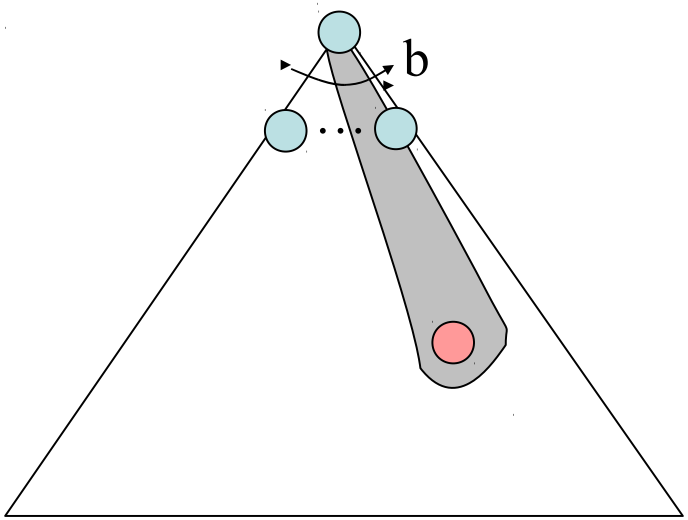
- What can go wrong?

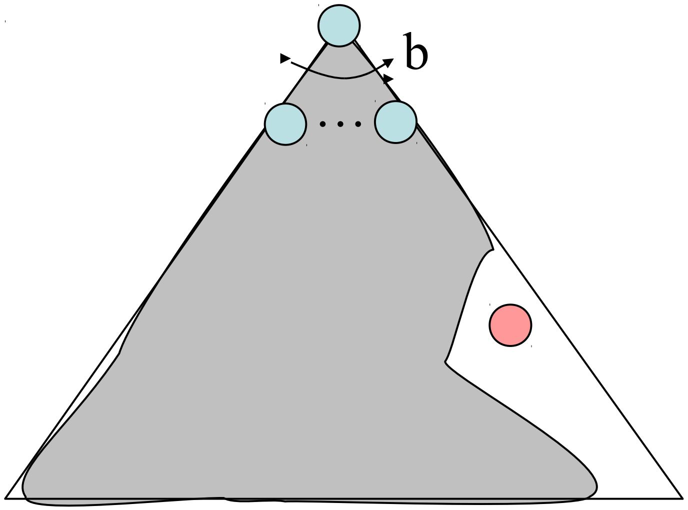
Best First / Greedy Search



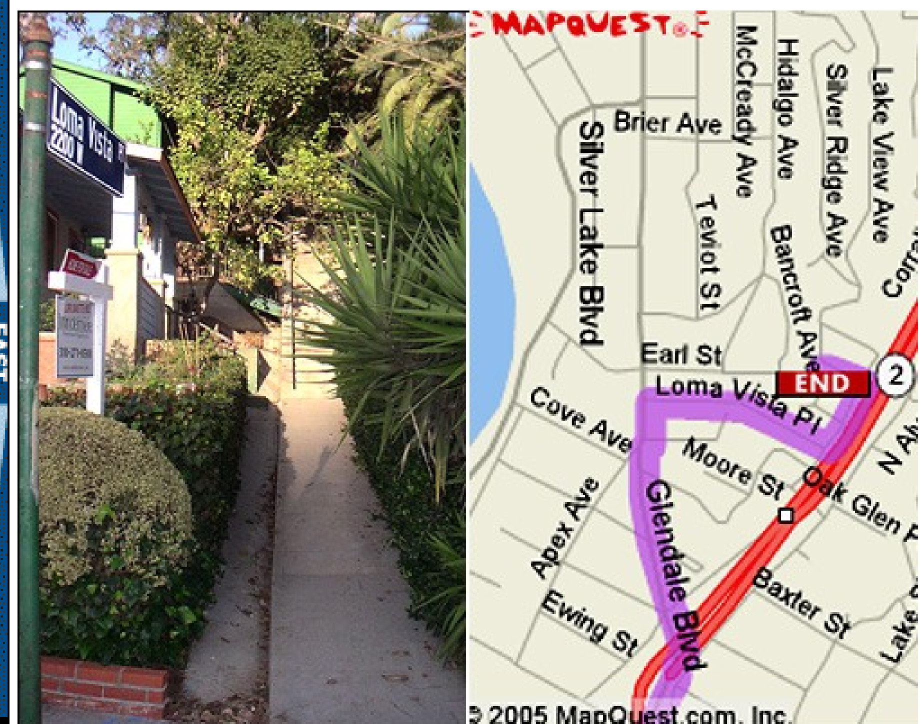
Best First / Greedy Search

- 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)



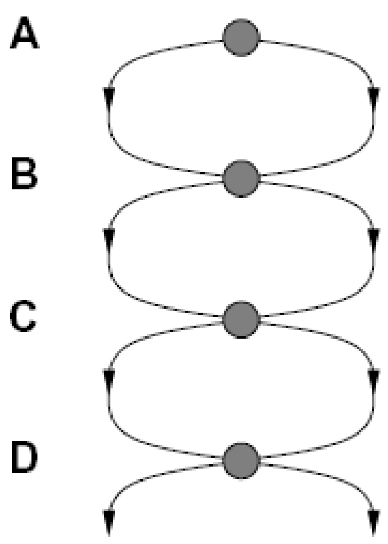


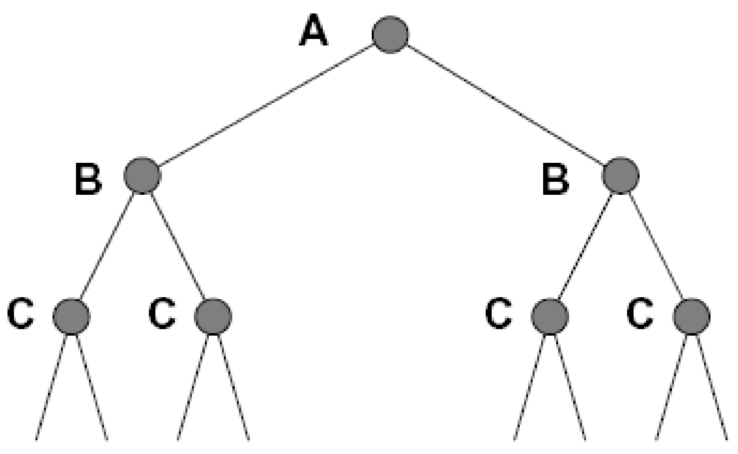
Search Gone Wrong?



Extra Work?

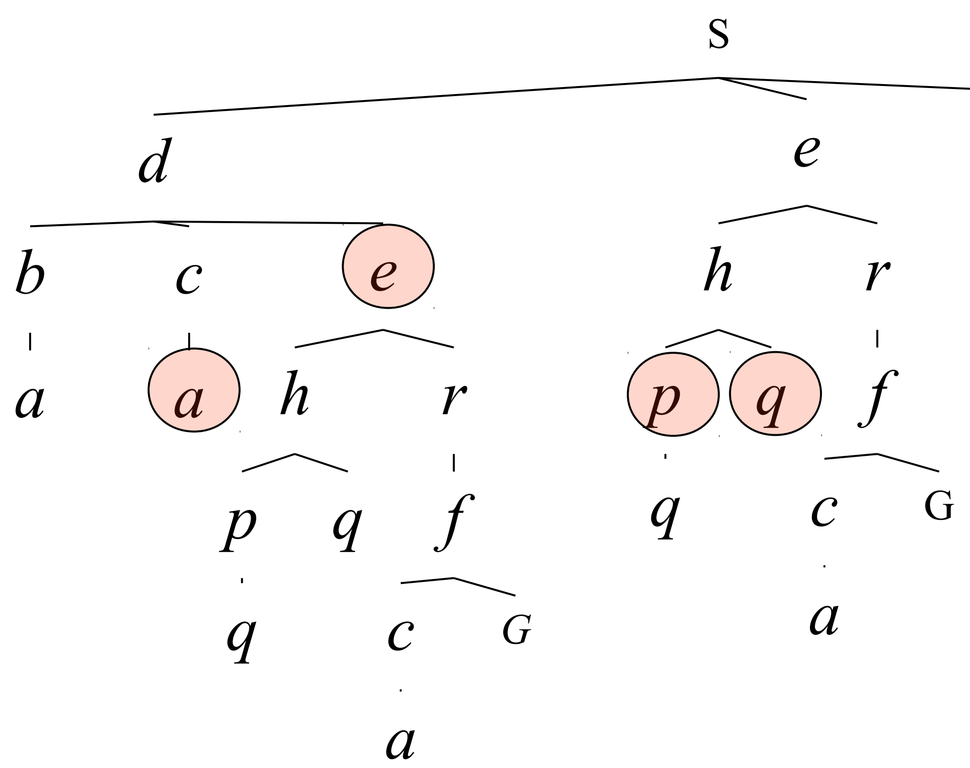
- Failure to detect repeated states can cause exponentially more work. Why?





Graph Search

- In BFS, for example, we shouldn't bother expanding the circled nodes (why?)



Graph Search

- Very simple fix: never expand a state type twice

```
function GRAPH-SEARCH( problem, fringe) returns a solution, or failure

    closed ← an empty set
    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
        if STATE[node] is not in closed then
            add STATE[node] to closed
            fringe ← INSERTALL(EXPAND(node, problem), fringe)
    end
```

- Can this wreck completeness? Why or why not?
- How about optimality? Why or why not?

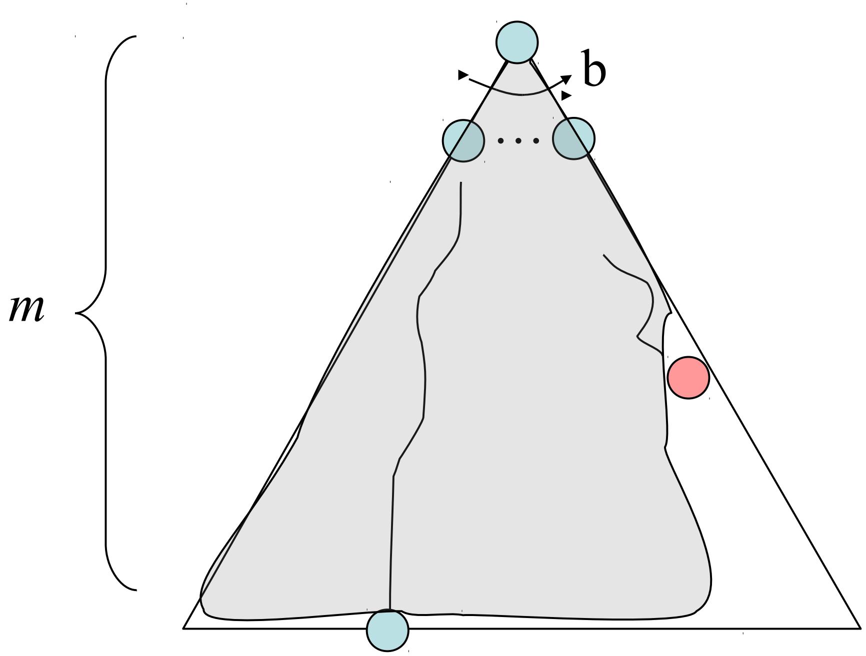
Some Hints

- Graph search is almost always better than tree search (when not?)
- Fringes are sometimes called “closed lists” – but don’t implement them with lists (use sets)!
- Nodes are conceptually paths, but better to represent with a state, cost, and reference to parent node

Best First Greedy Search

n	# states
b	avg branch
C^*	least cost
s	shallow goal
m	max depth

Algorithm	Complete	Optimal	Time	Space
Greedy Best-First Search	Y*	N	$O(b^m)$	$O(b^m)$



- What do we need to do to make it complete?
- Can we make it optimal? Next class!