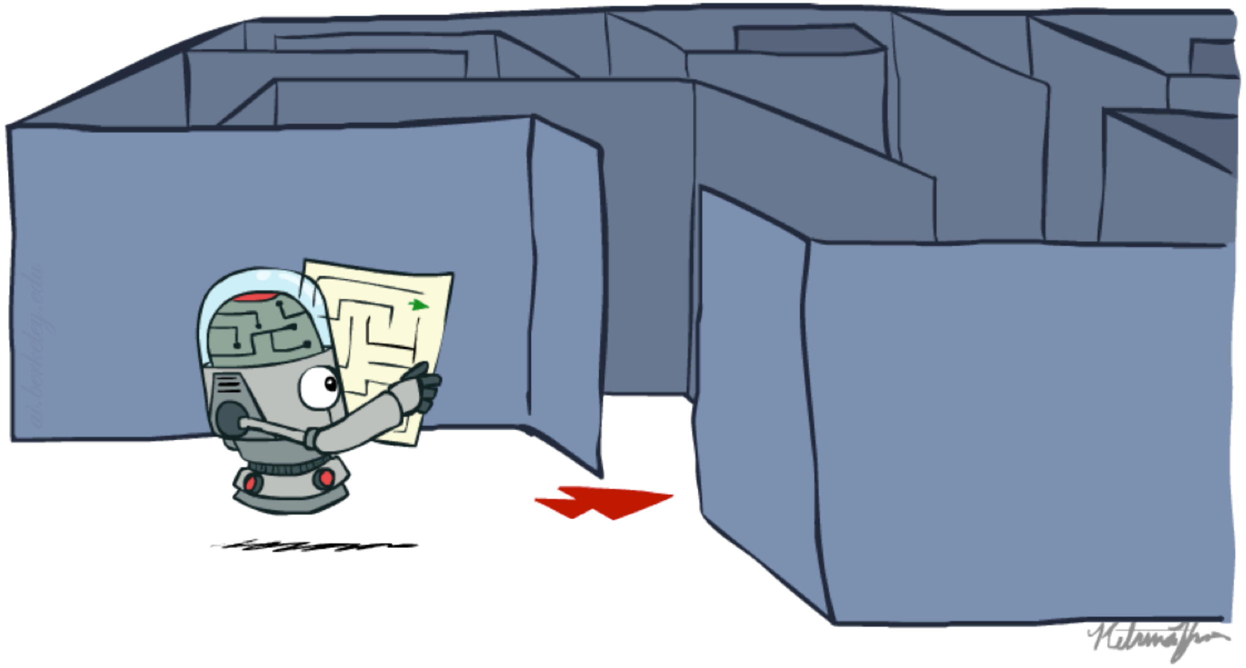
CS 5522: Artificial Intelligence II

Search



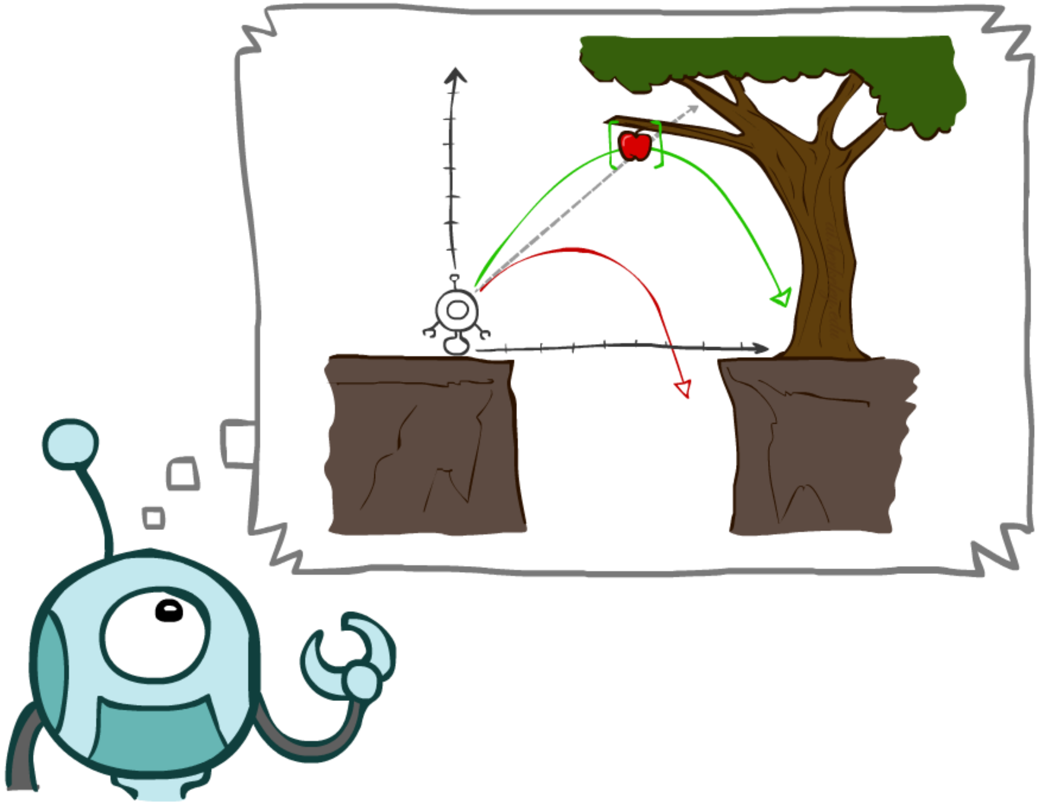
Instructor: Alan Ritter

Ohio State University

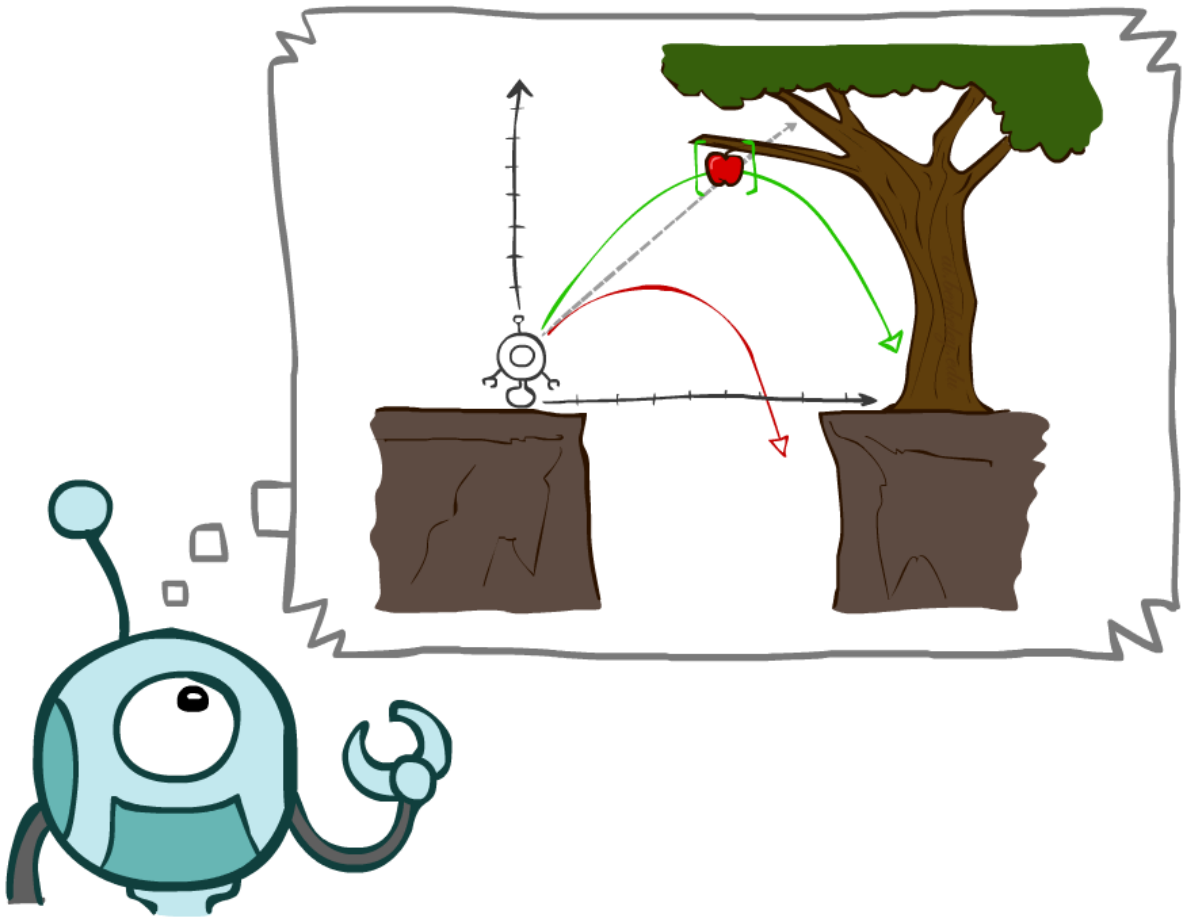
[These slides were adapted from CS188 Intro to AI at UC Berkeley. All materials available at http://ai.berkeley.edu.]

Today

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

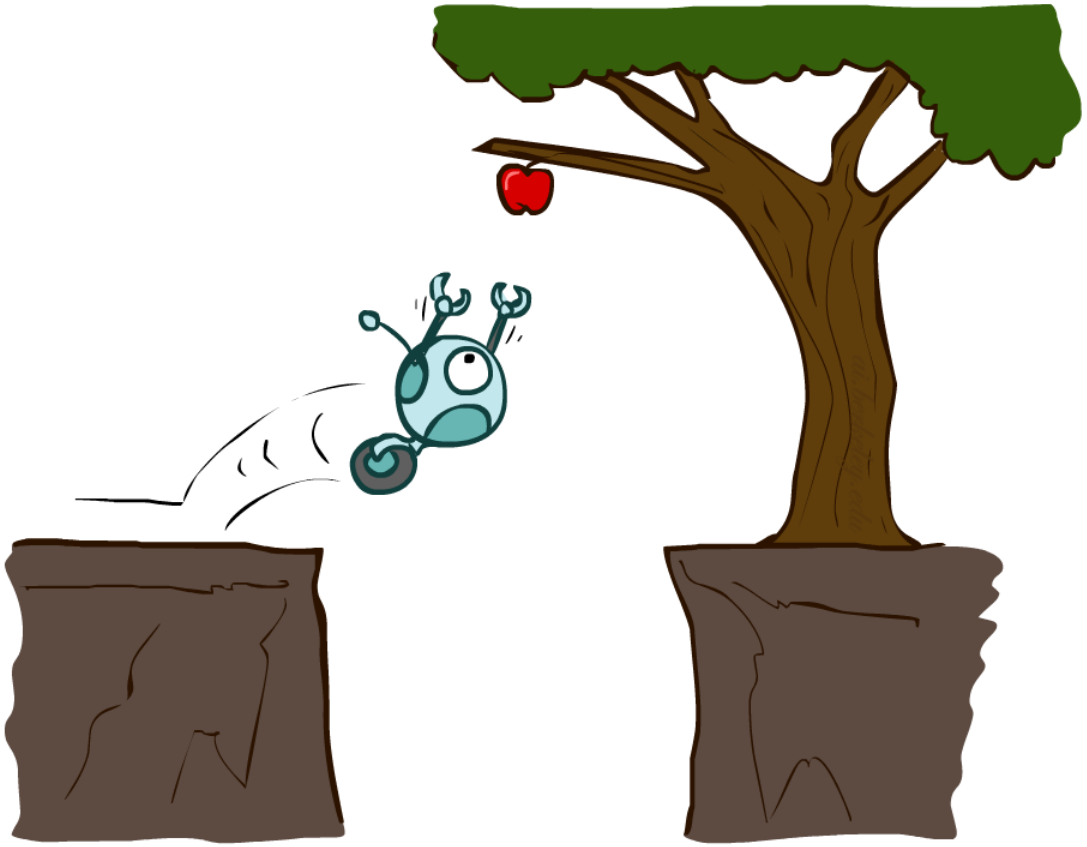


Agents that Plan



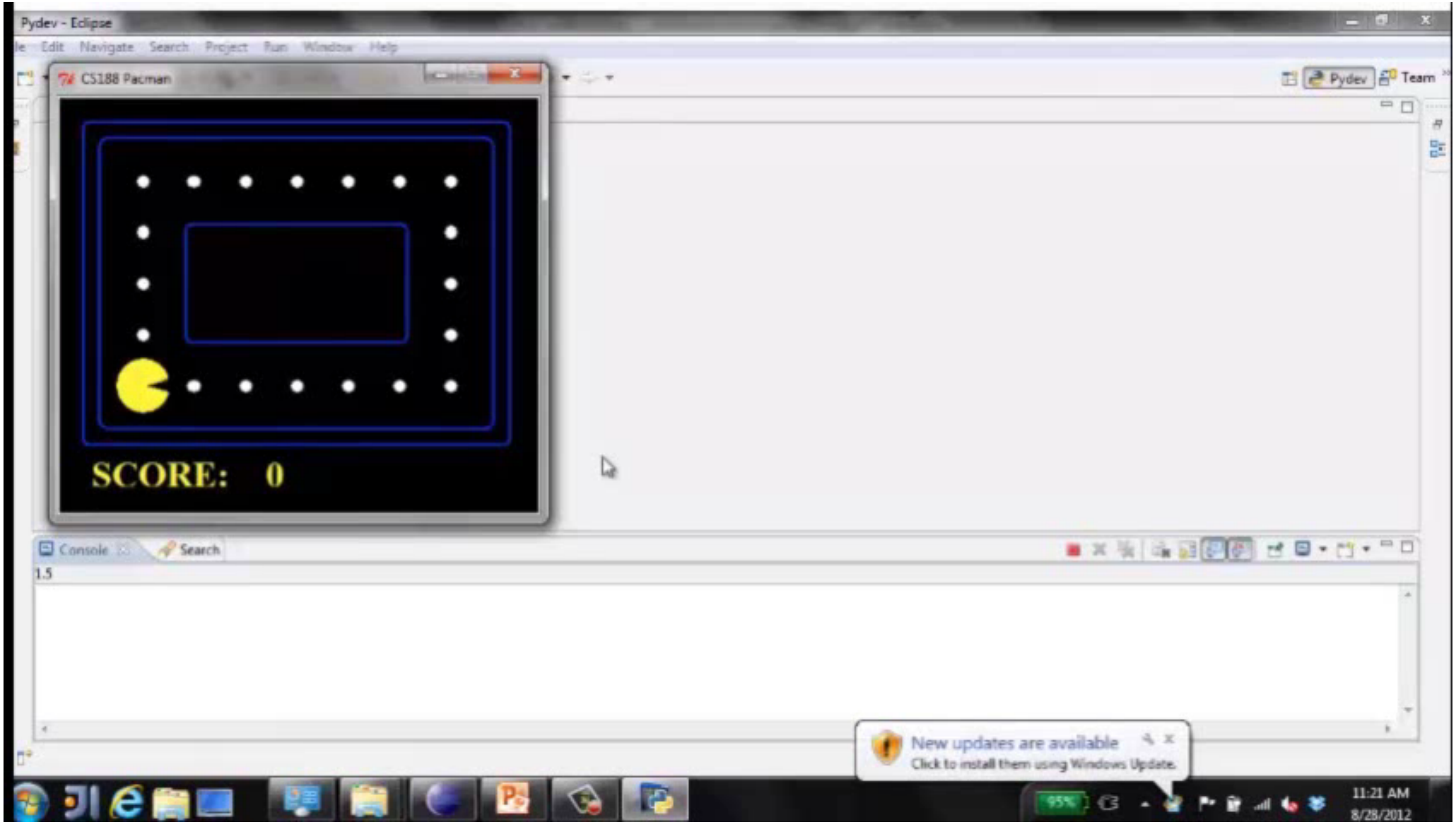
Reflex Agents

- 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?



[Demo: reflex optimal (L2D1)]
[Demo: reflex optimal (L2D2)]

Video of Demo Reflex Optimal



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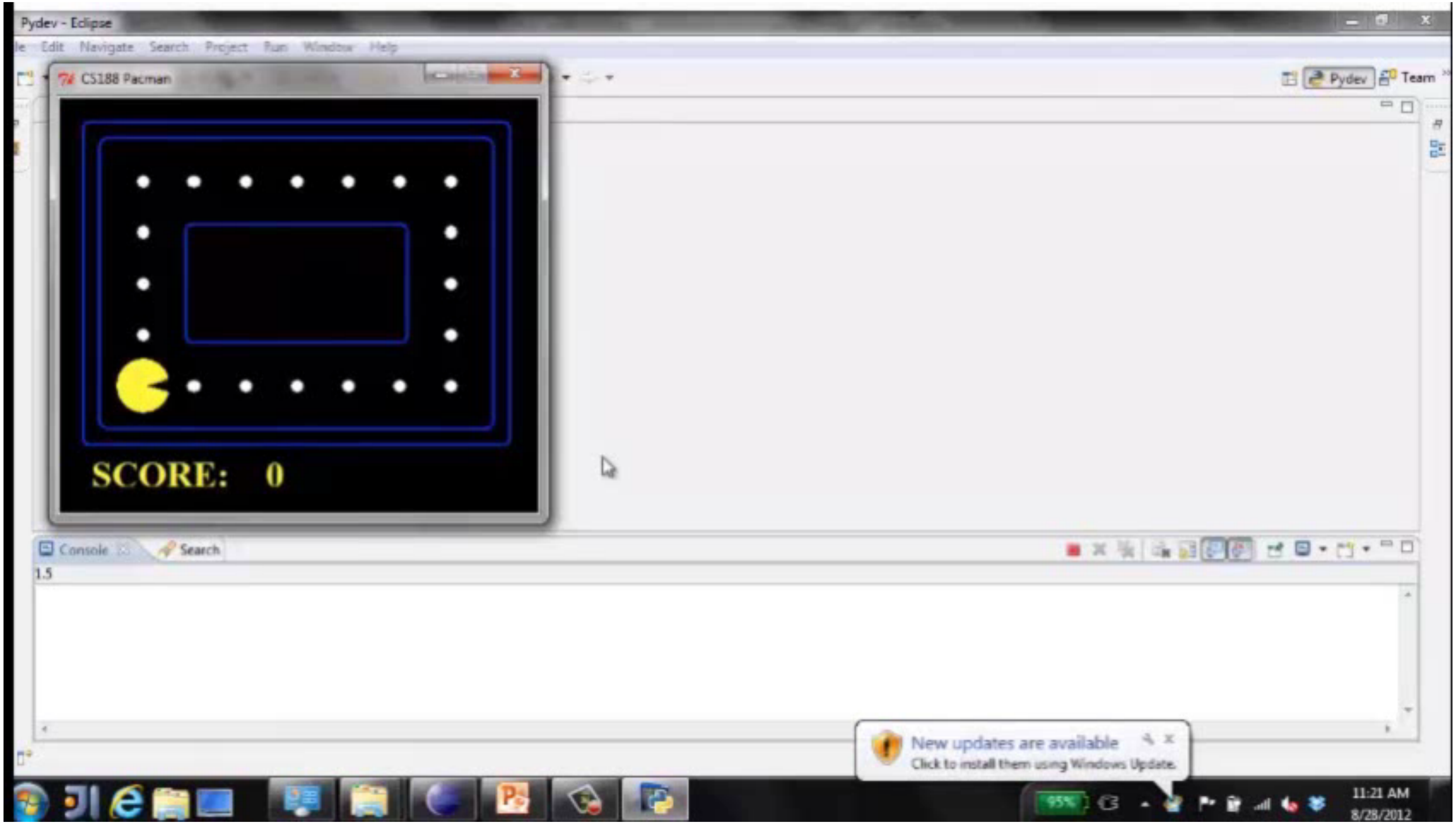

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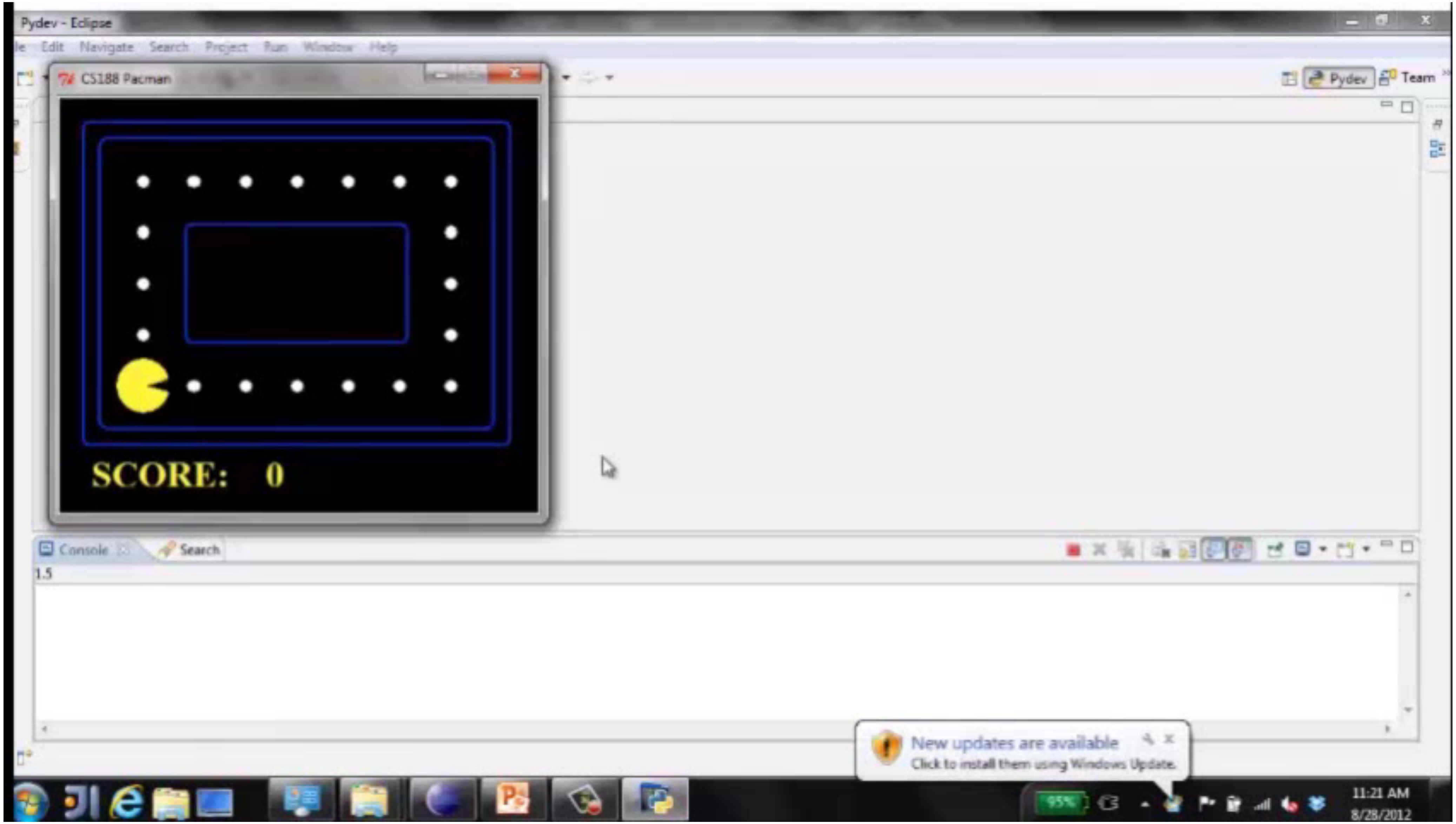

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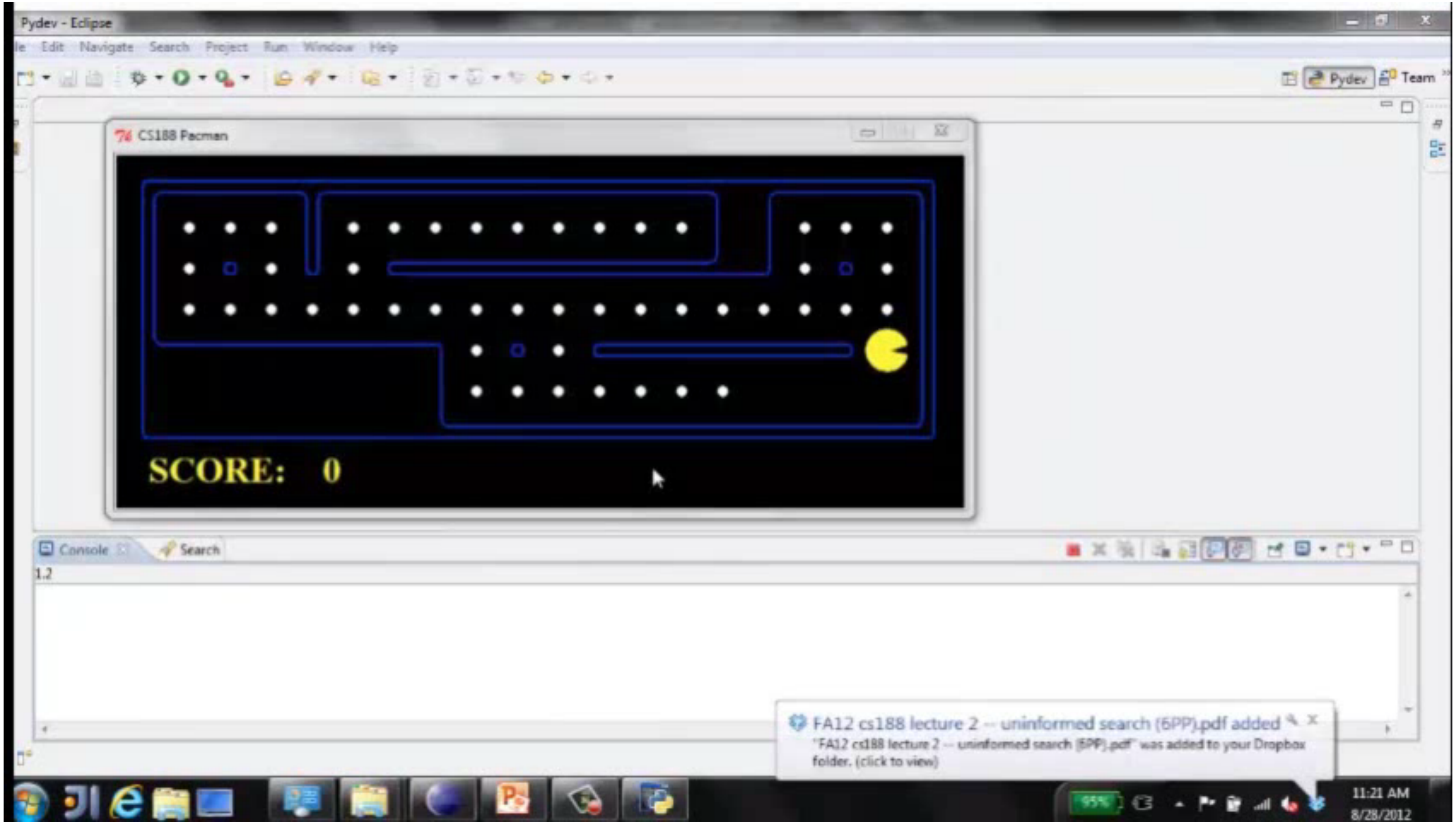

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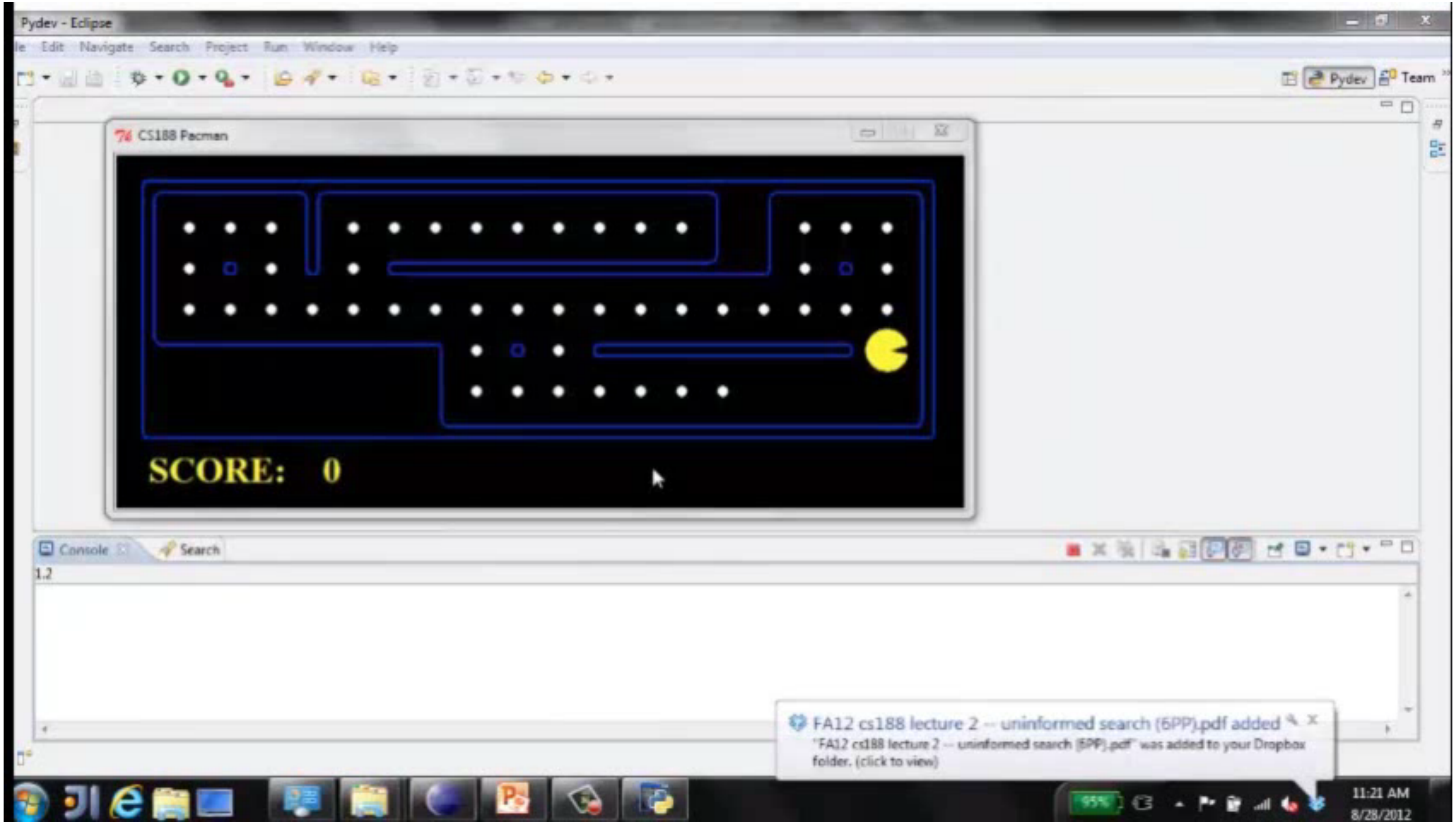

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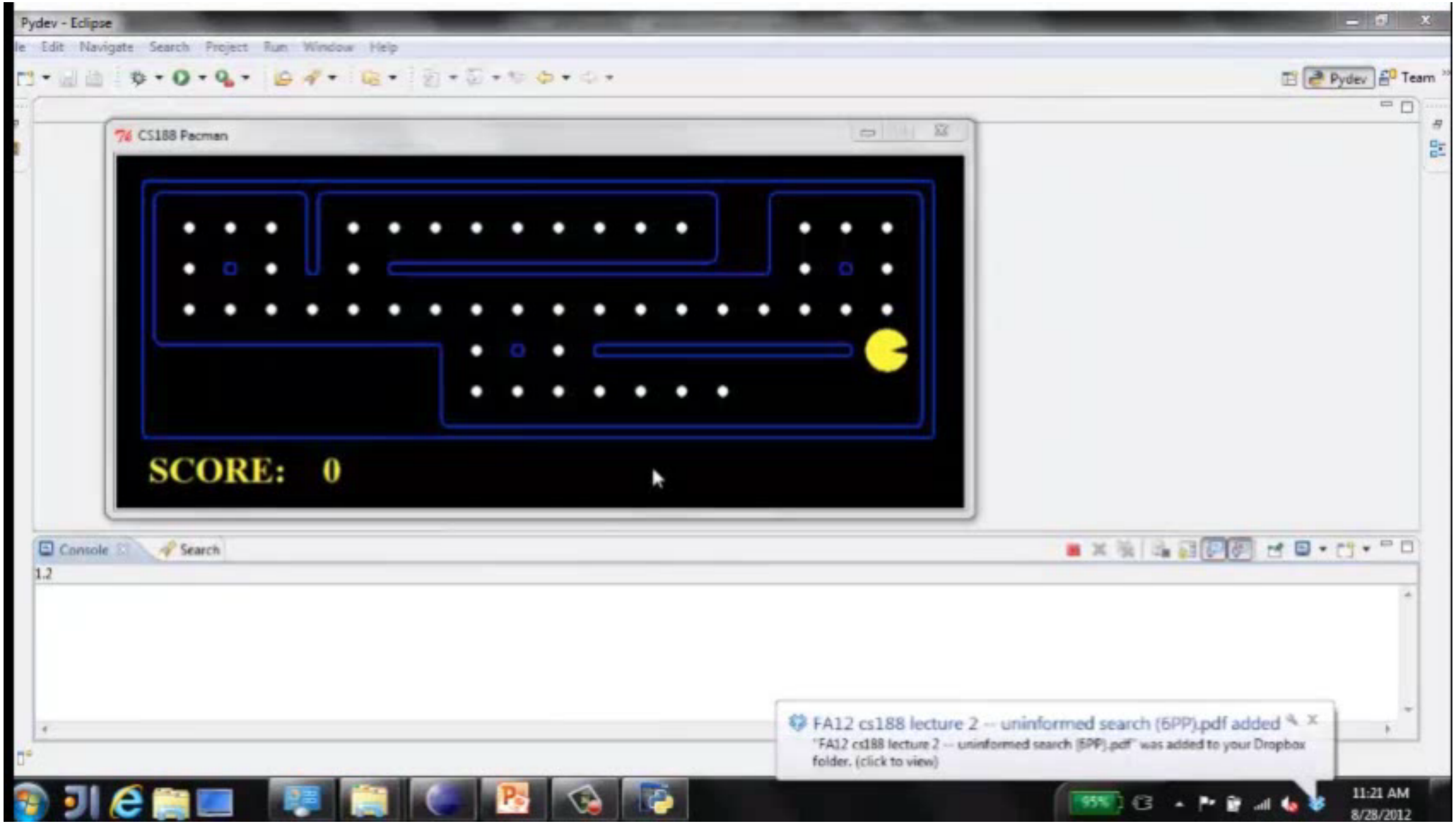
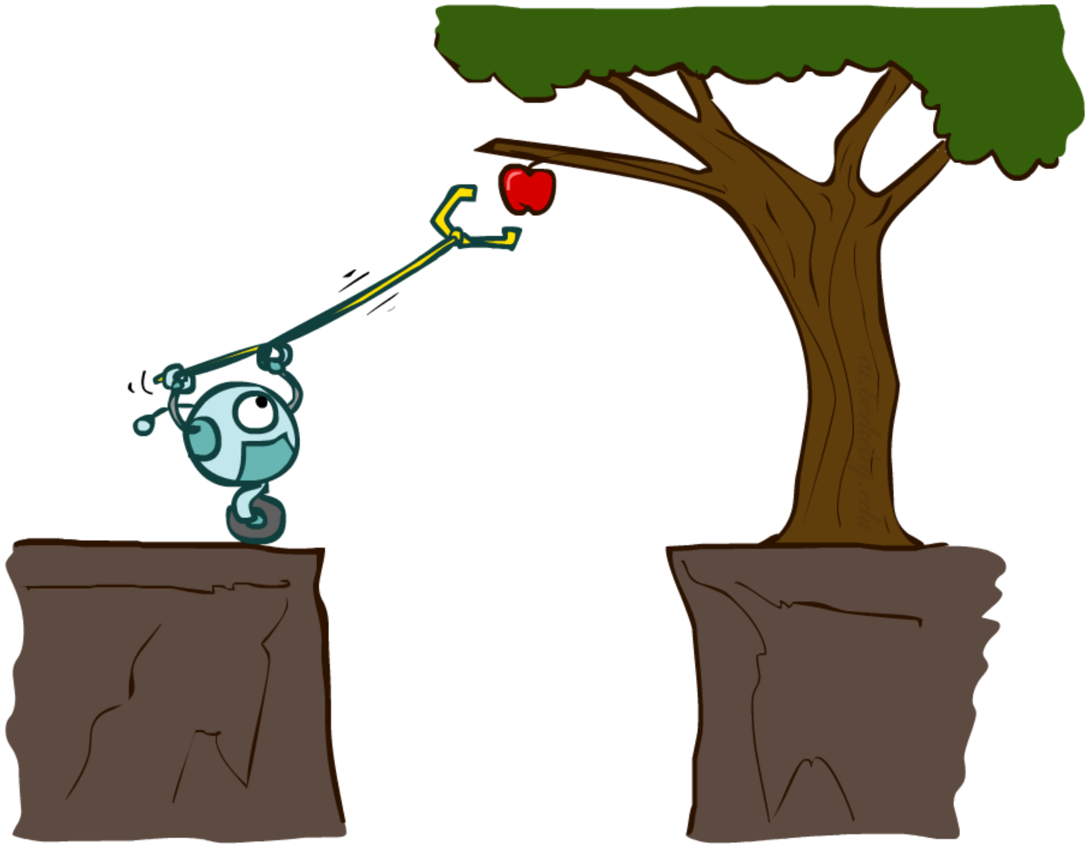


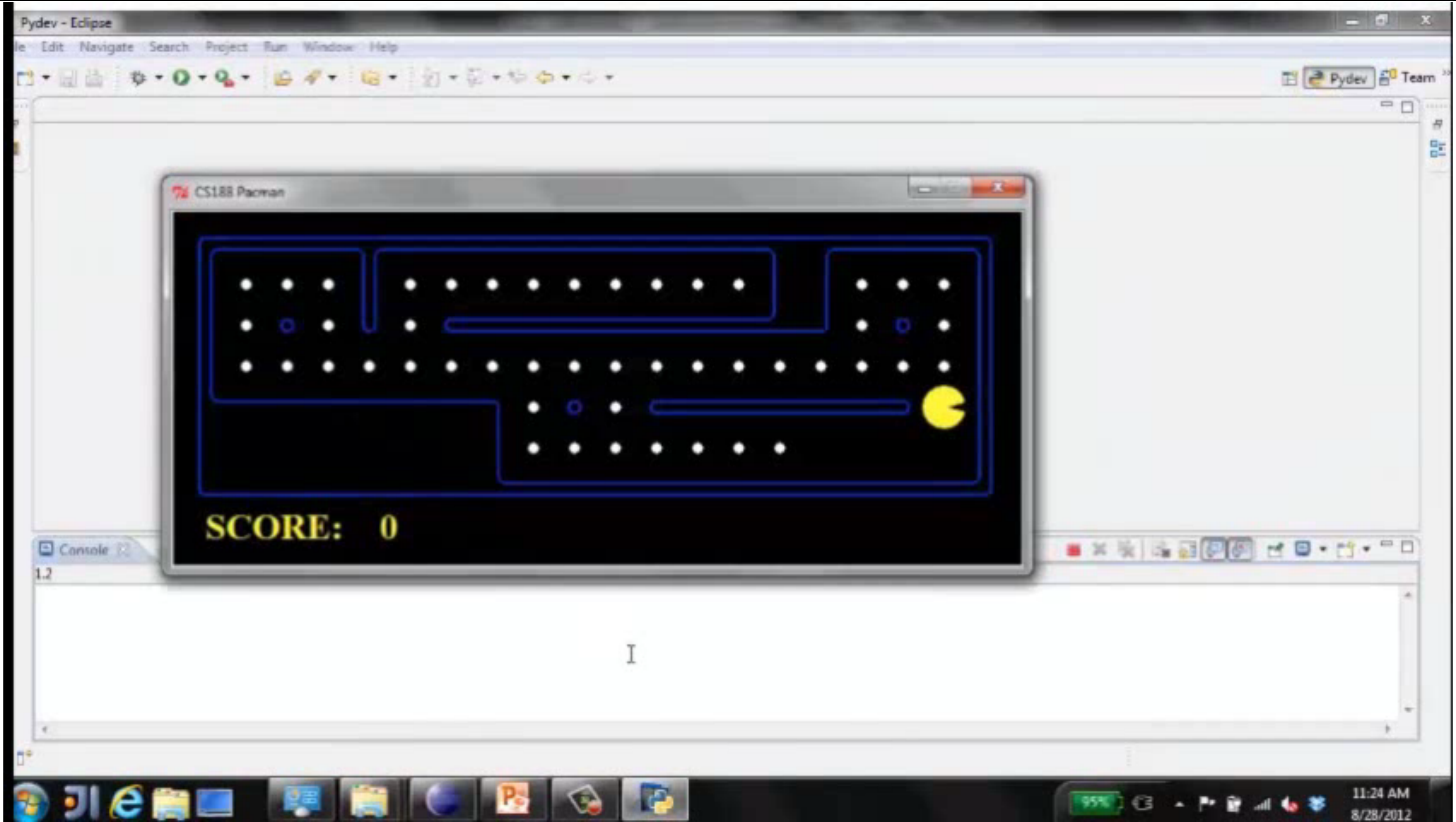
Planning Agents

- 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



[Demo: replanning (L2D3)]
[Demo: mastermind (L2D4)]

Video of Demo Replanning



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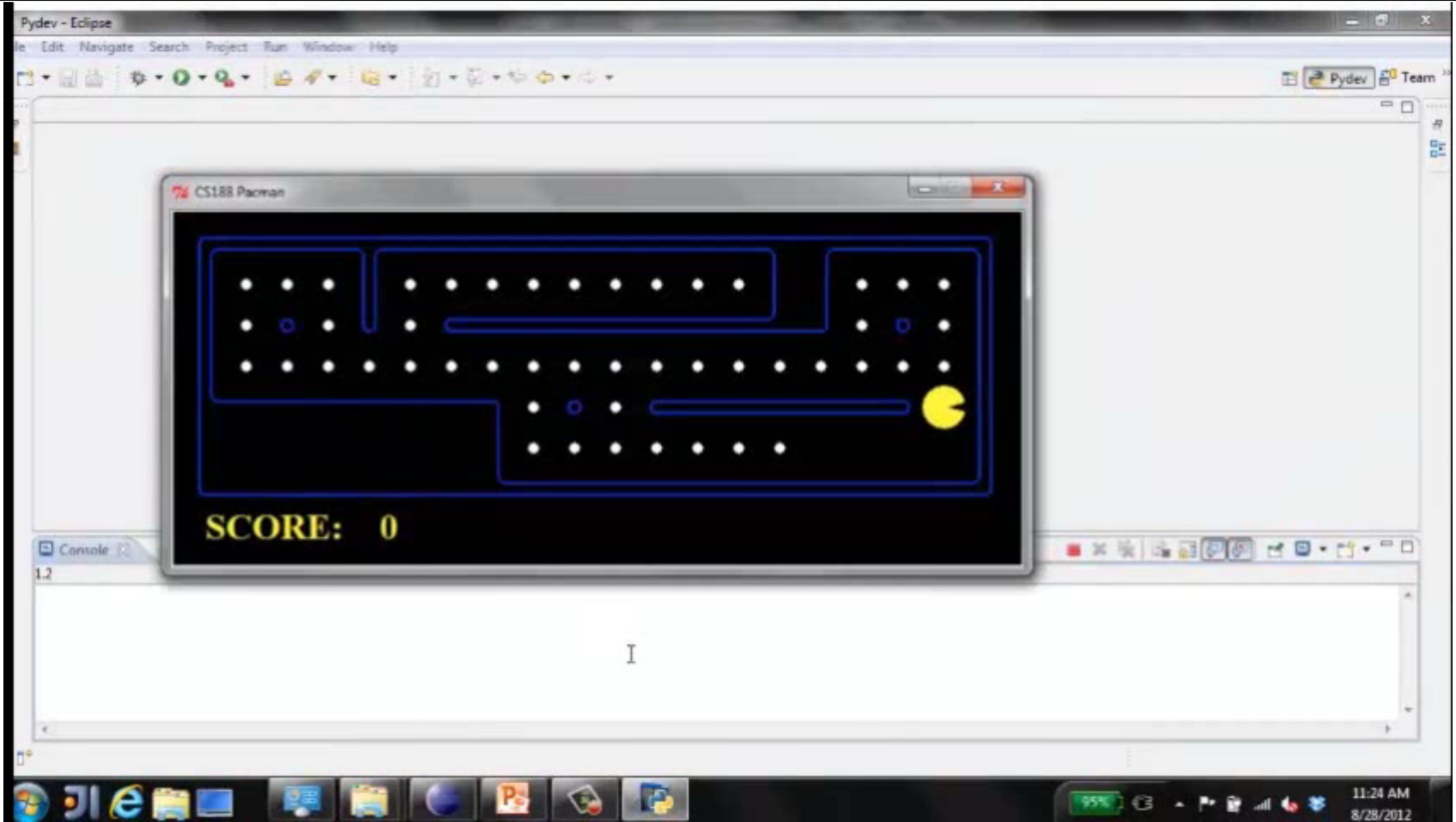

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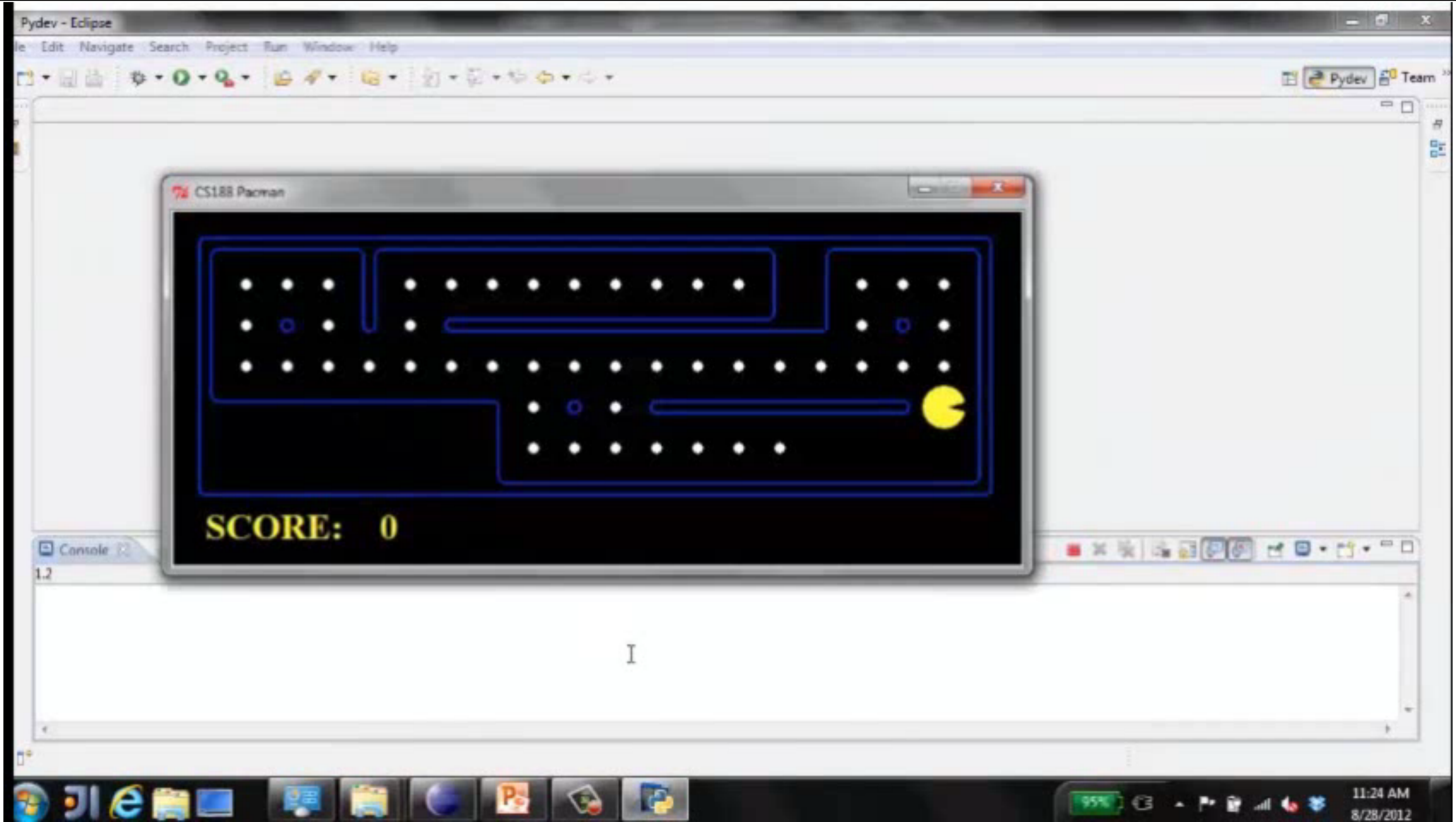
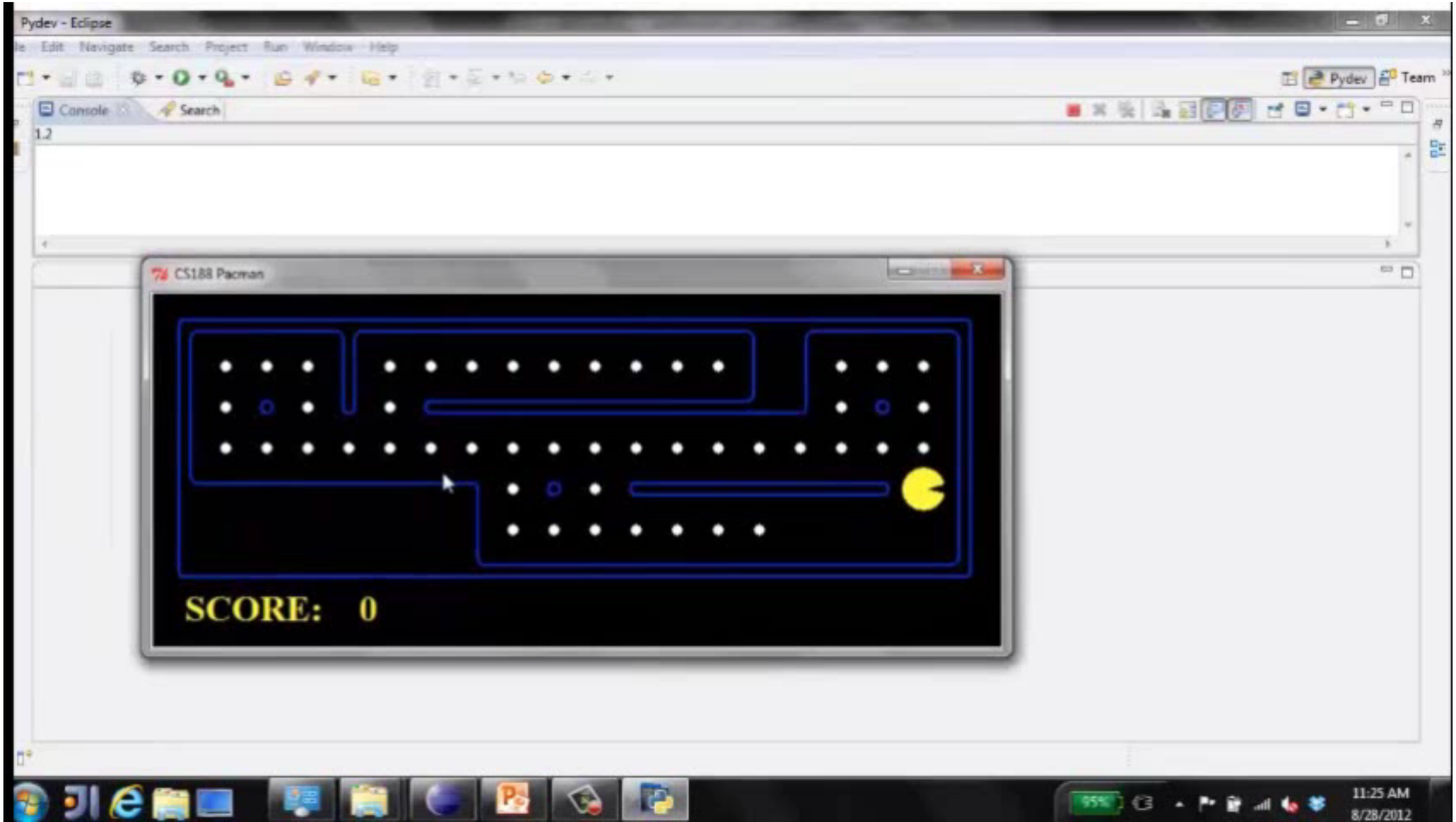


Video of Demo Mastermind



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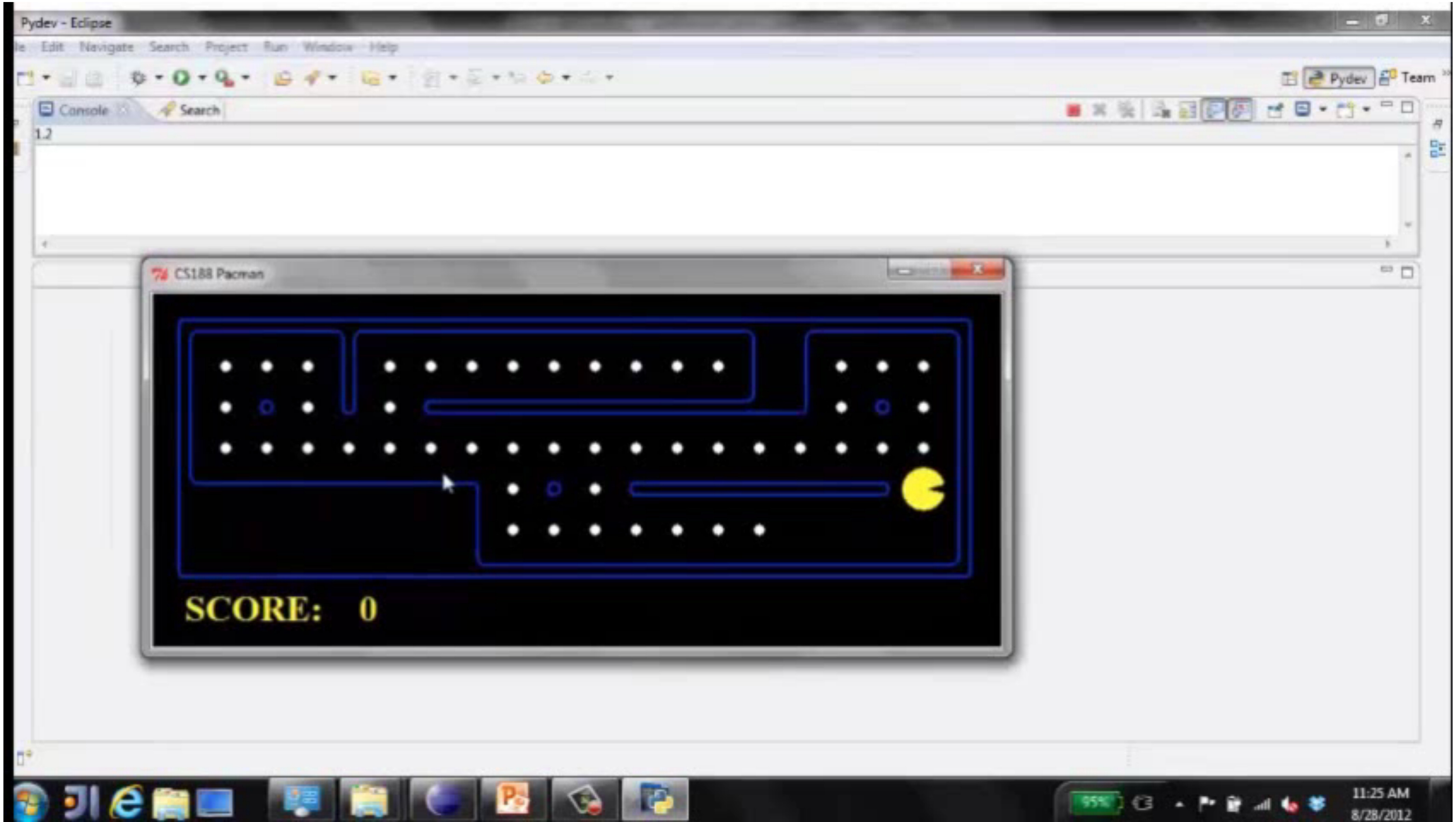

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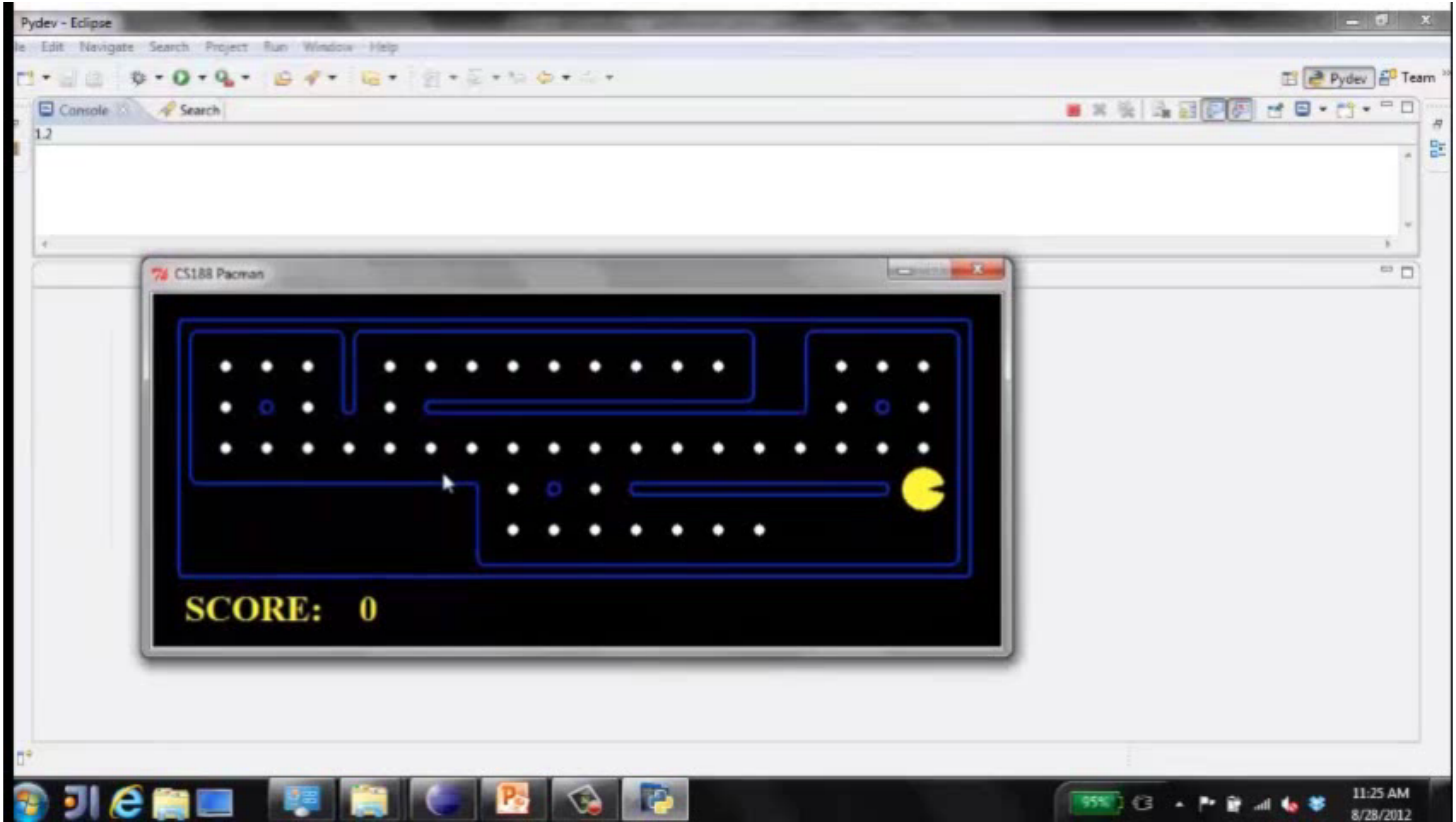

Search Problems

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- A search problem consists of:

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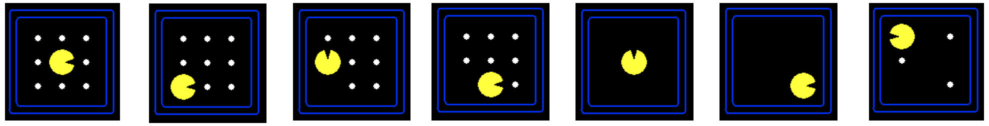
  - A state space



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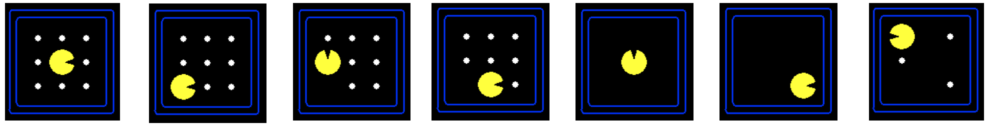
  - A state space 
  - A successor function
    (with actions, costs)

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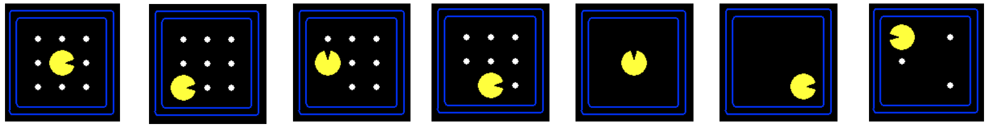

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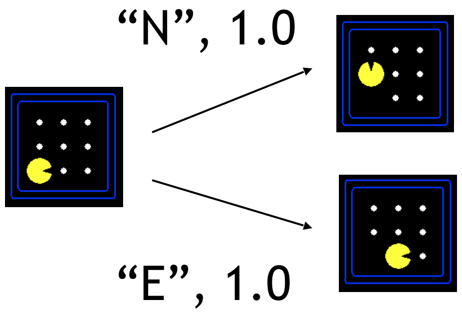

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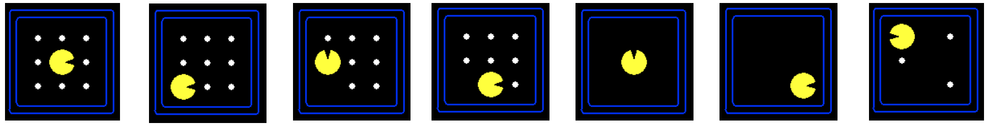

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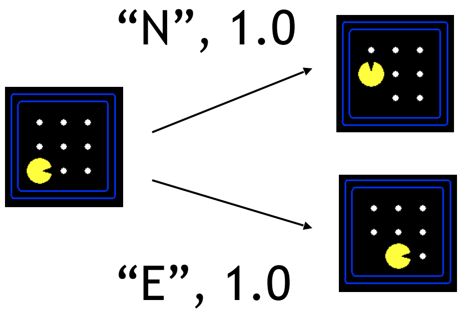

  - A start state and a goal test

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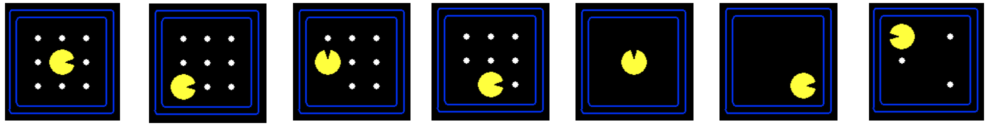

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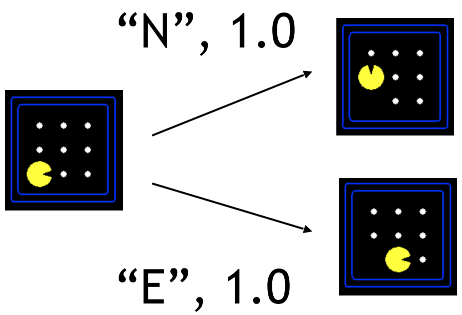

  - A start state and a goal test

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

Search Problems Are Models

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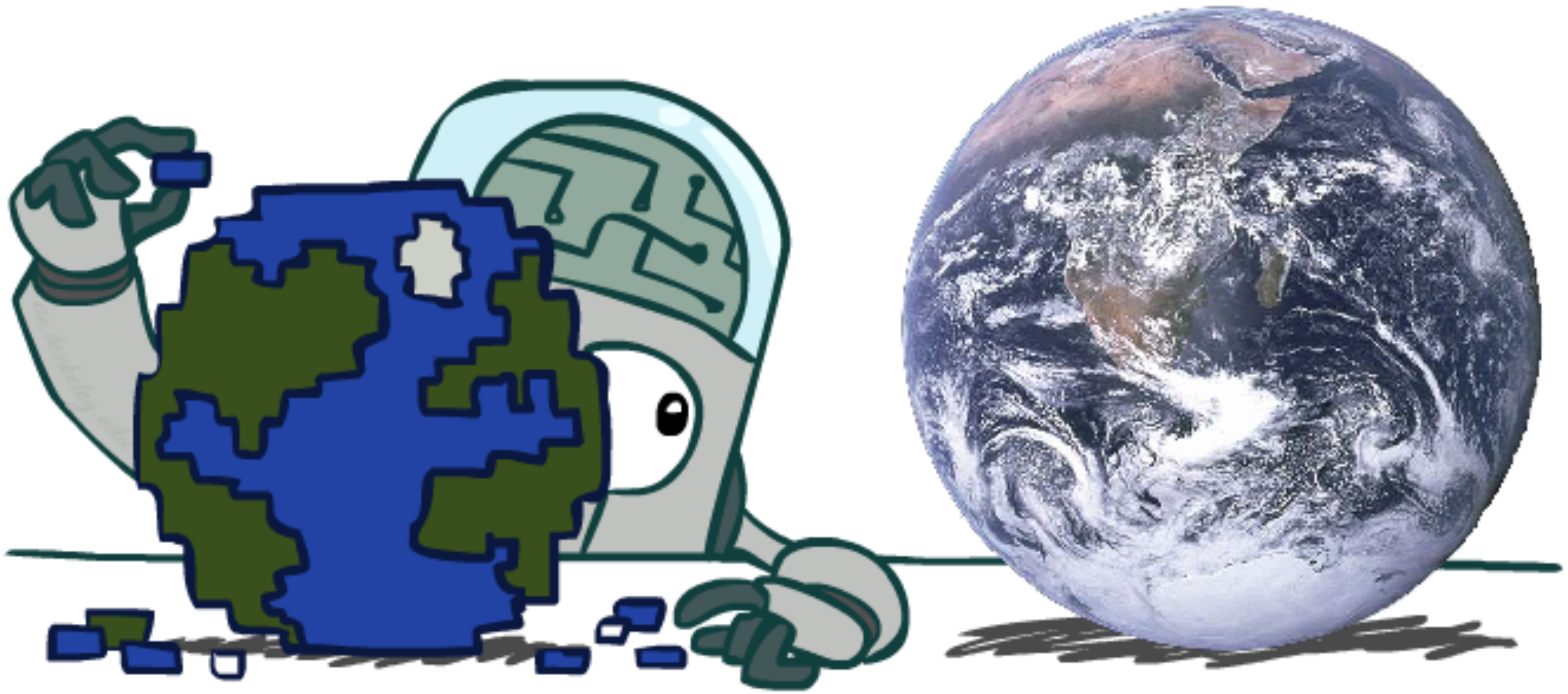
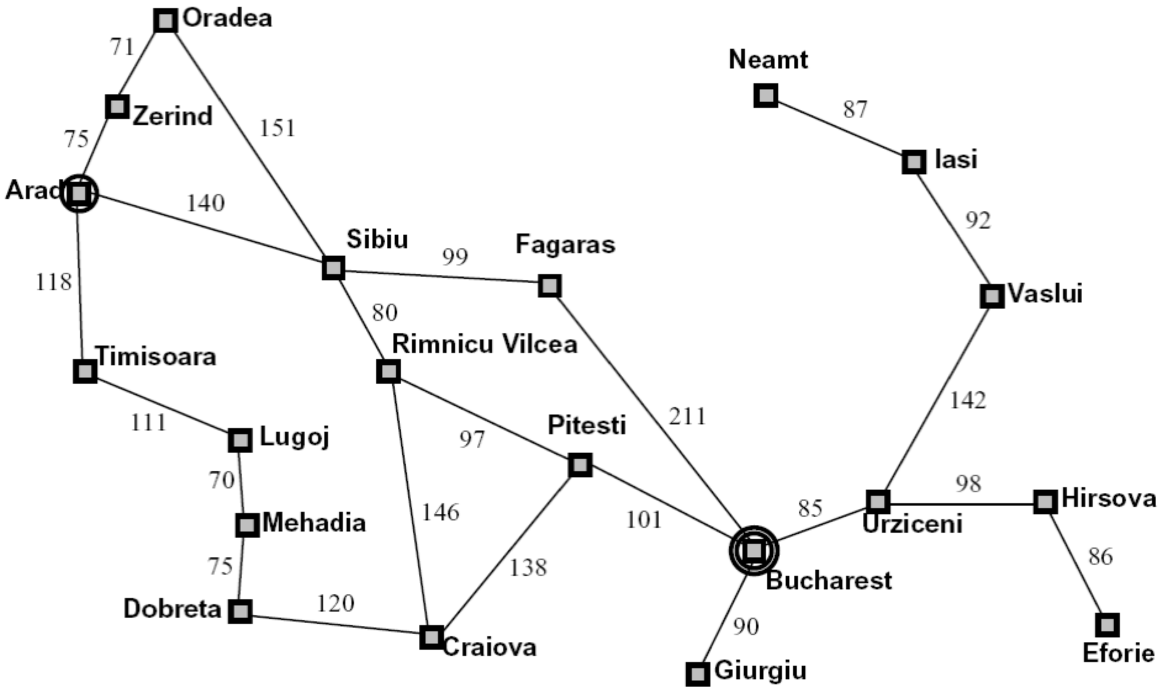


Example: Traveling in Romania



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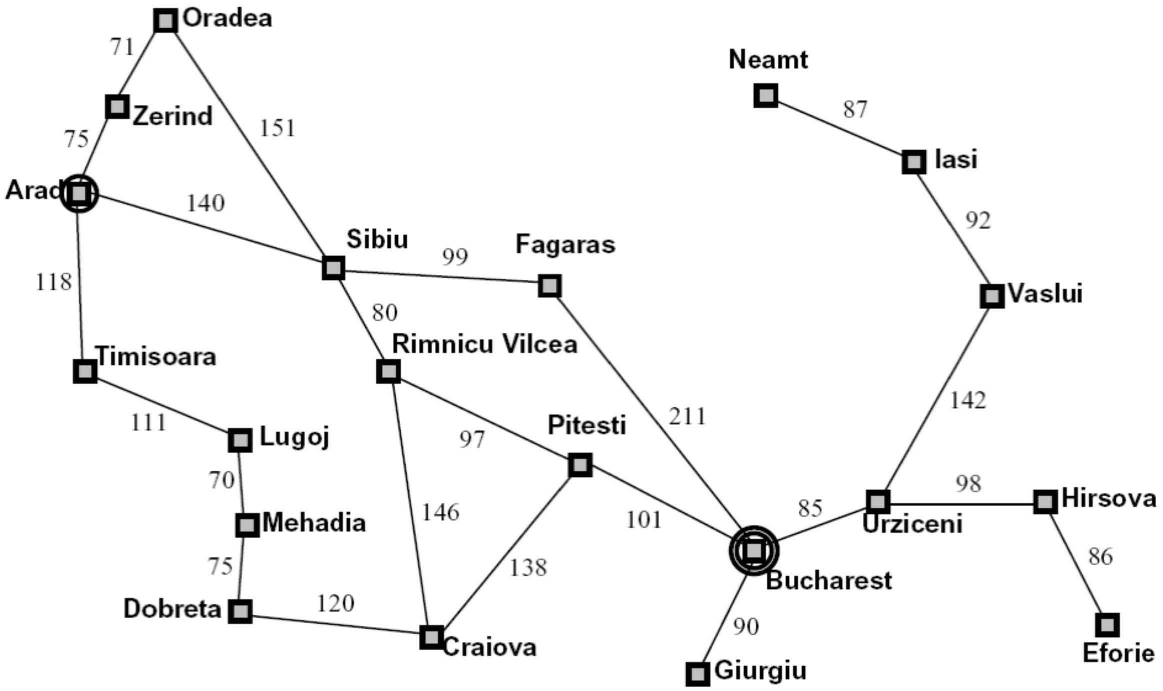

- State space:
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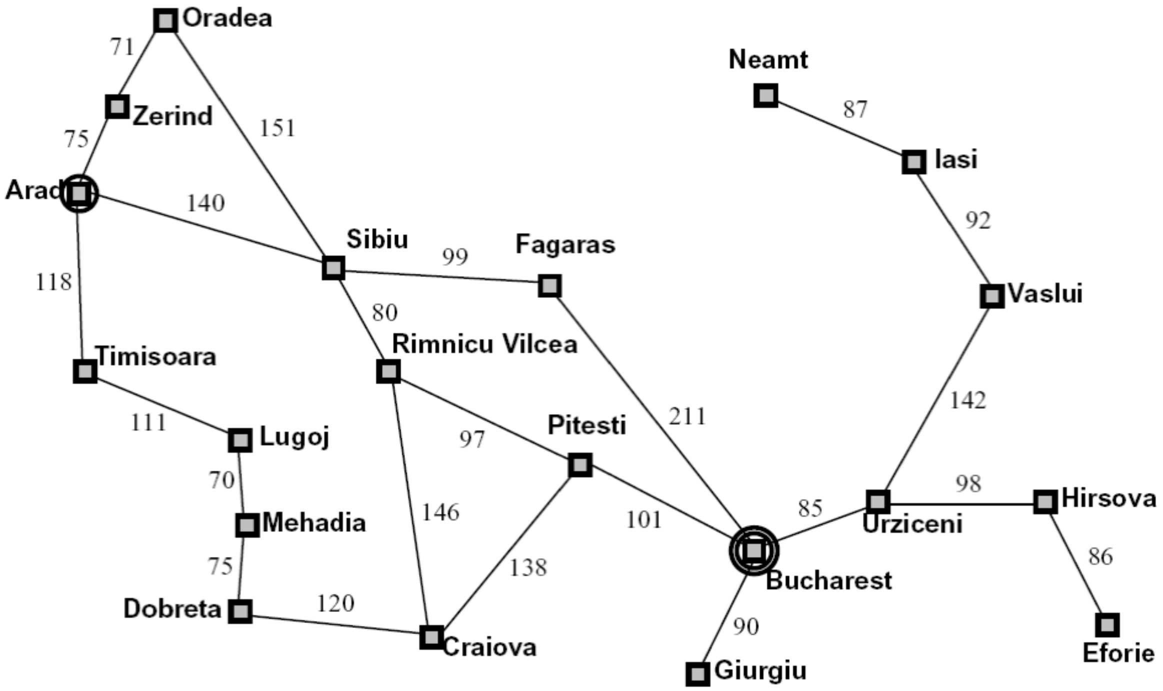

- State space:
  - Cities
- Successor function:
  - Roads: Go to adjacent city with cost = distance

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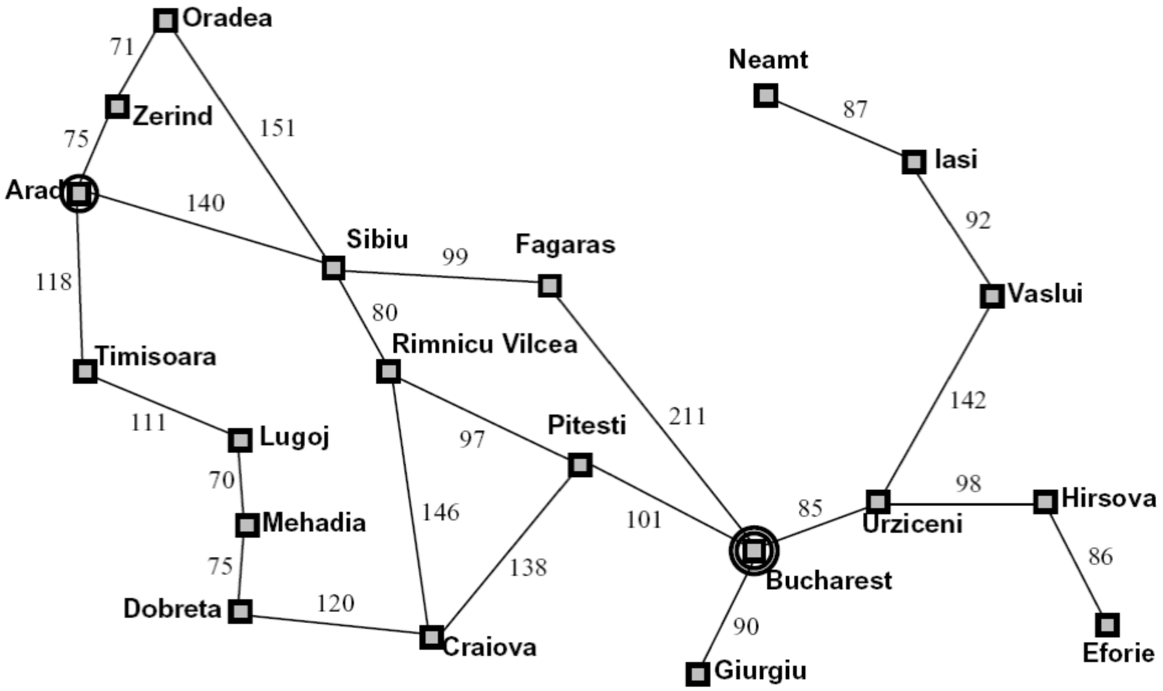

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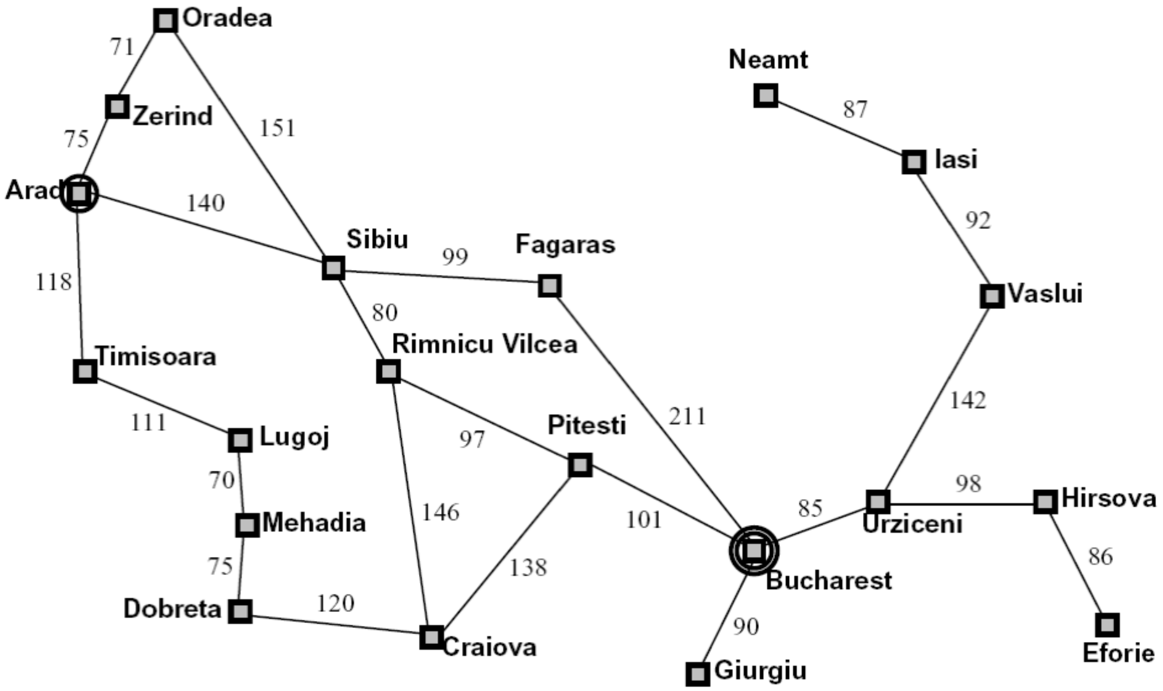

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  - Is state == Bucharest?

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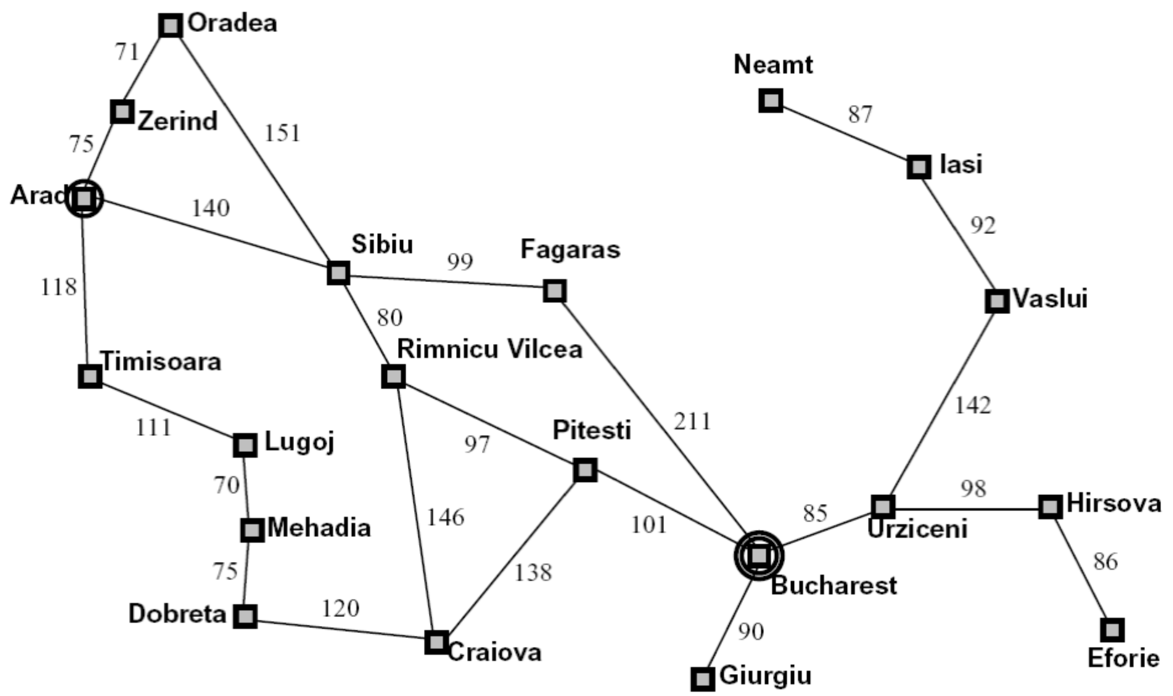

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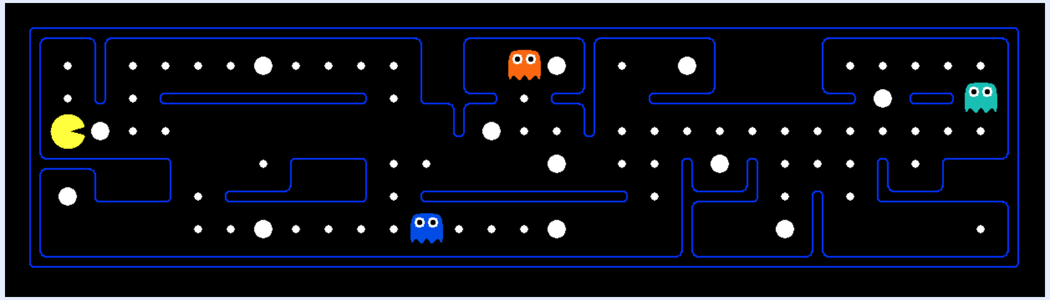
- Solution?

What's in a State Space?

The world state includes every last detail of the environment



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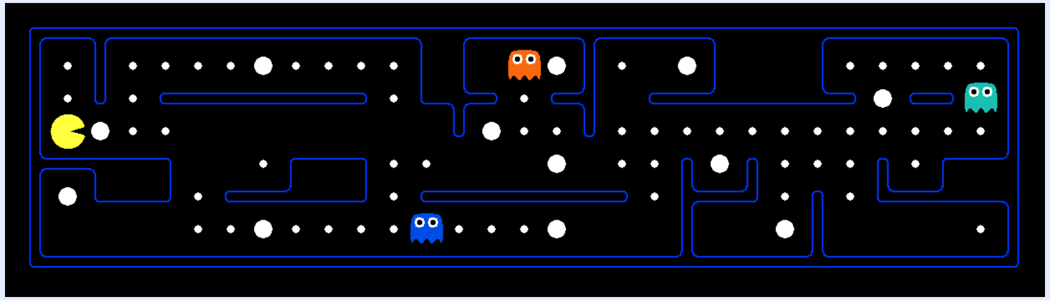

A search state keeps only the details needed for planning (abstraction)

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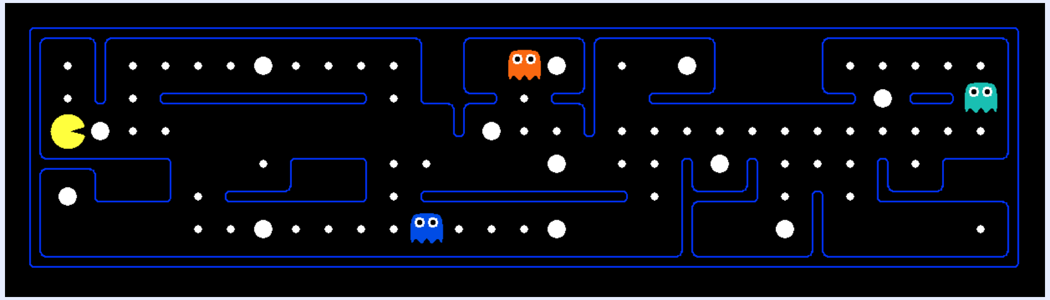

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  - States: (x,y) location
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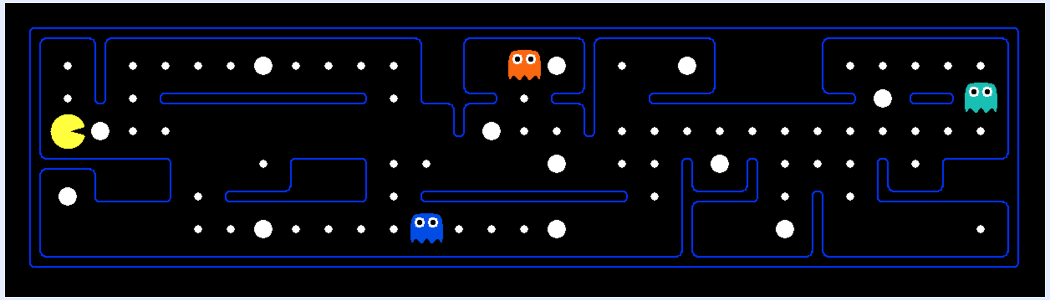

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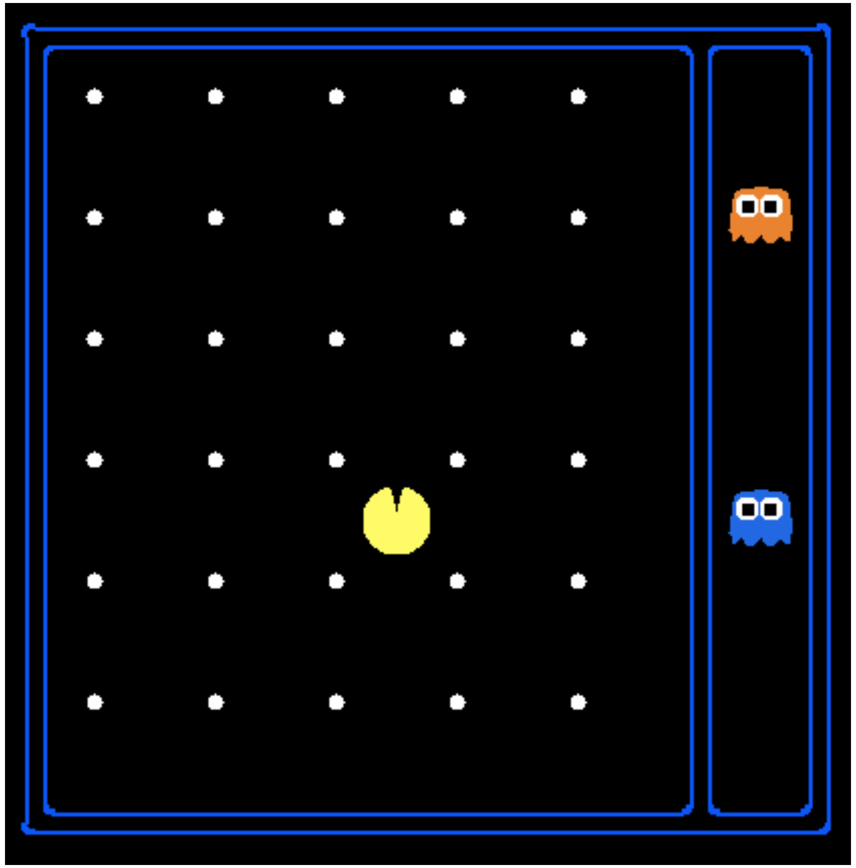
  - Goal test: is (x,y)=END
- Problem: Eat-All-Dots
  - States: {(x,y), dot booleans}
  - Actions: NSEW
  - Successor: update location and possibly a dot boolean
  - Goal test: dots all false

State Space Sizes?

- World state:
  - Agent positions: 120
  - Food count: 30
  - Ghost positions: 12
  - Agent facing: NSEW



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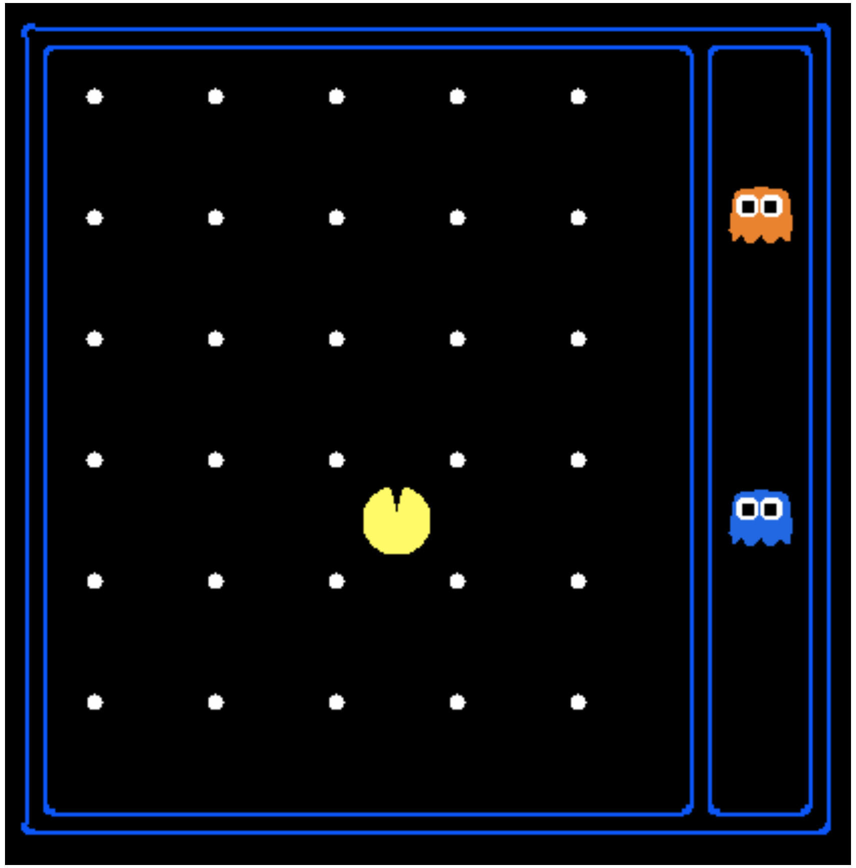

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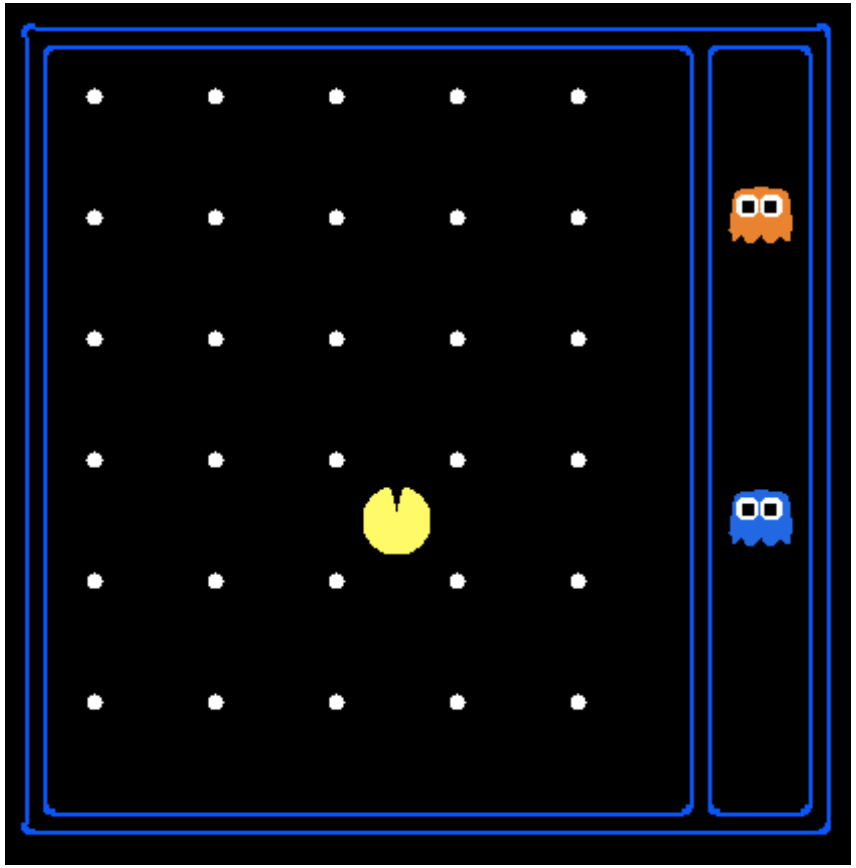

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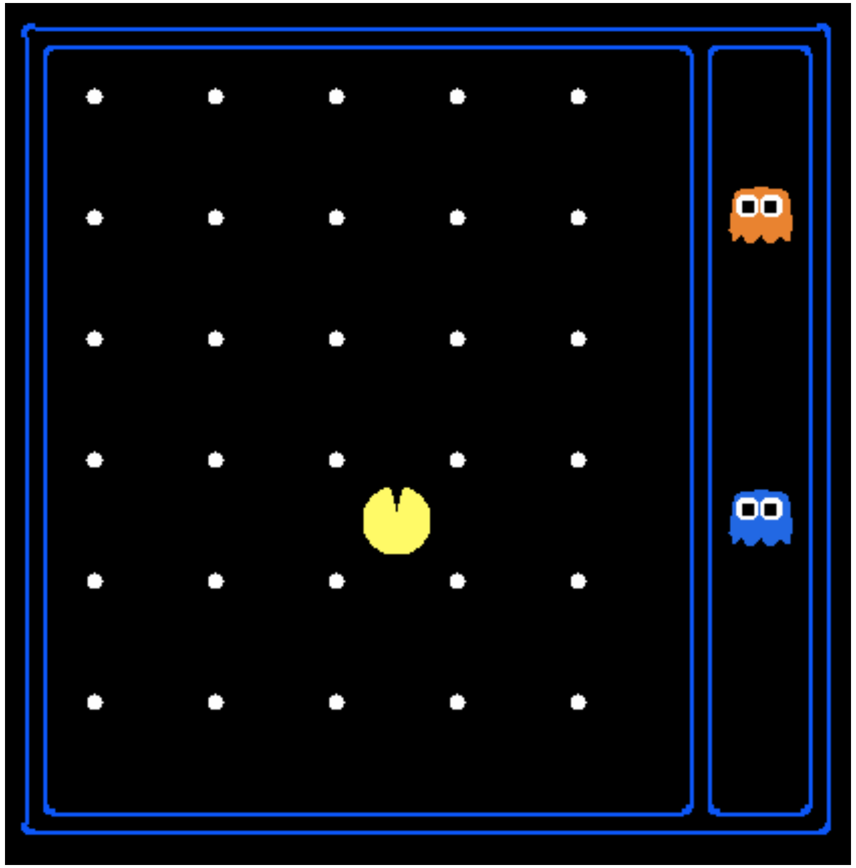

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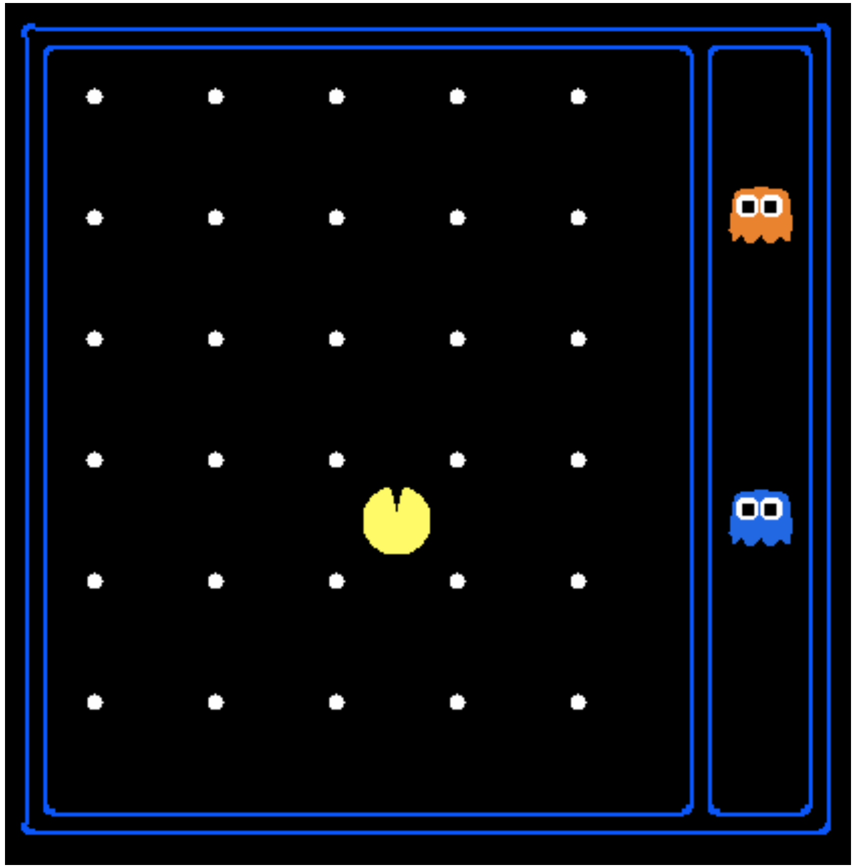

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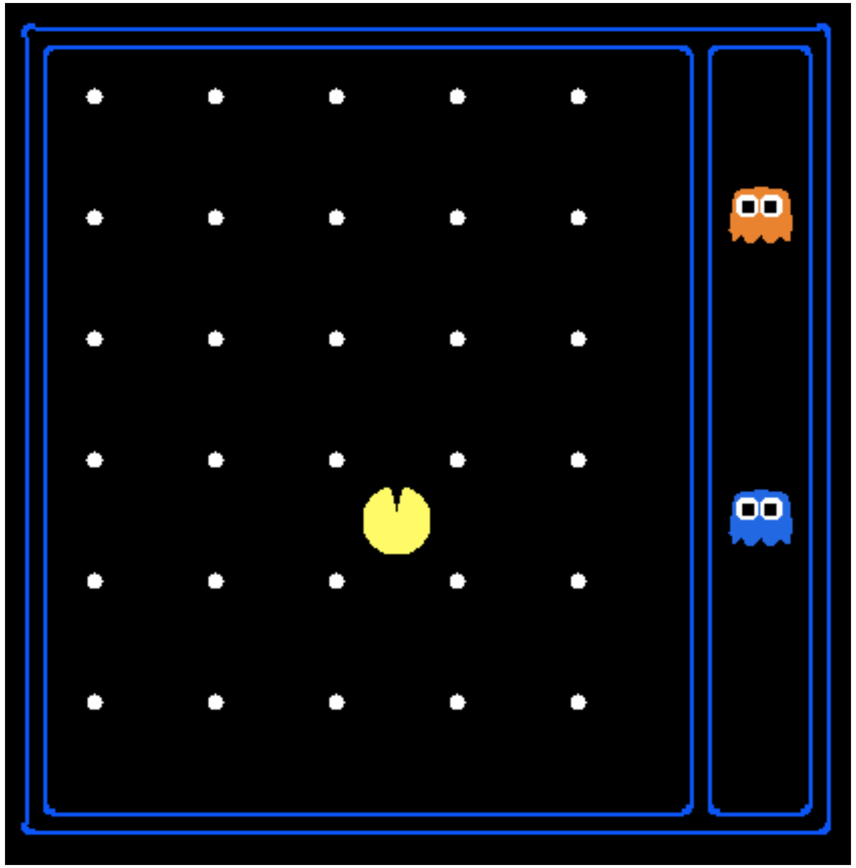

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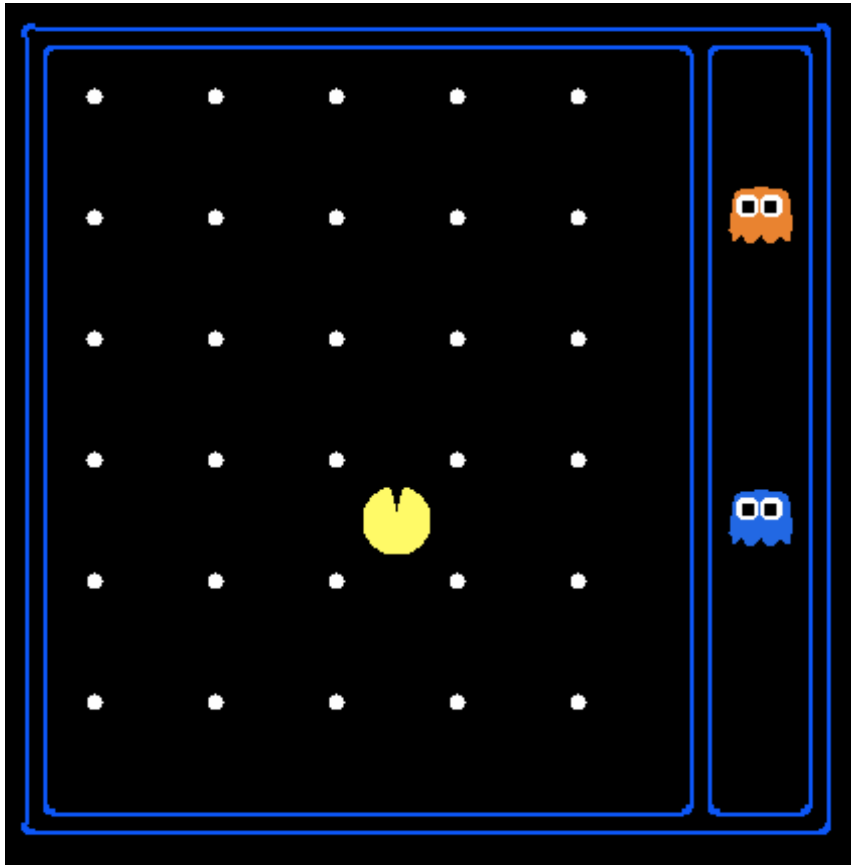

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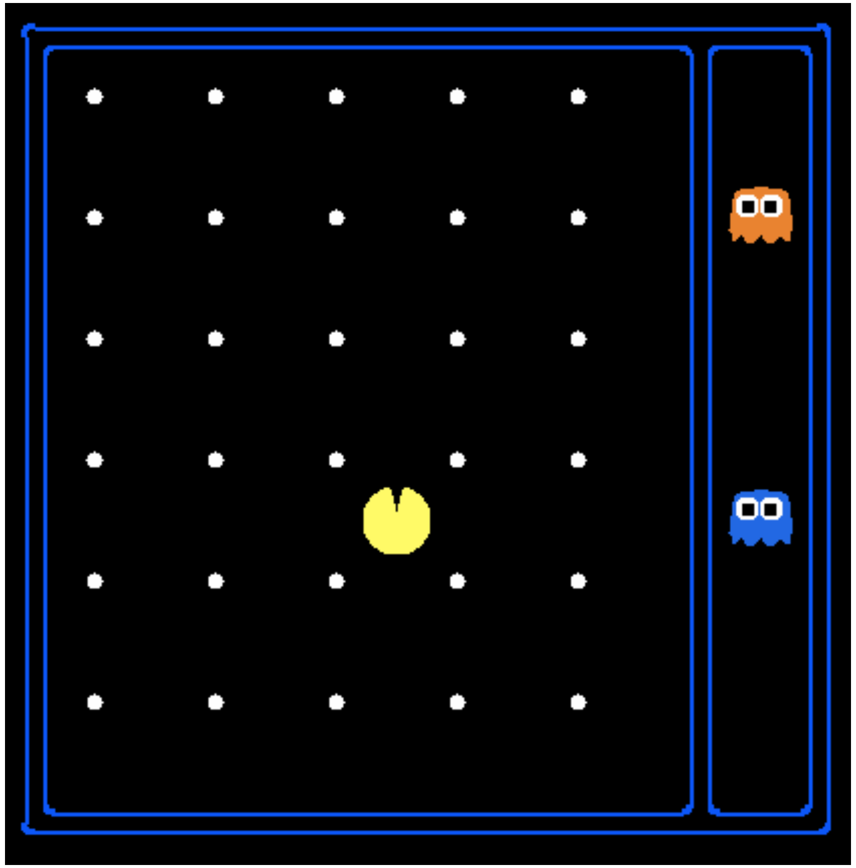
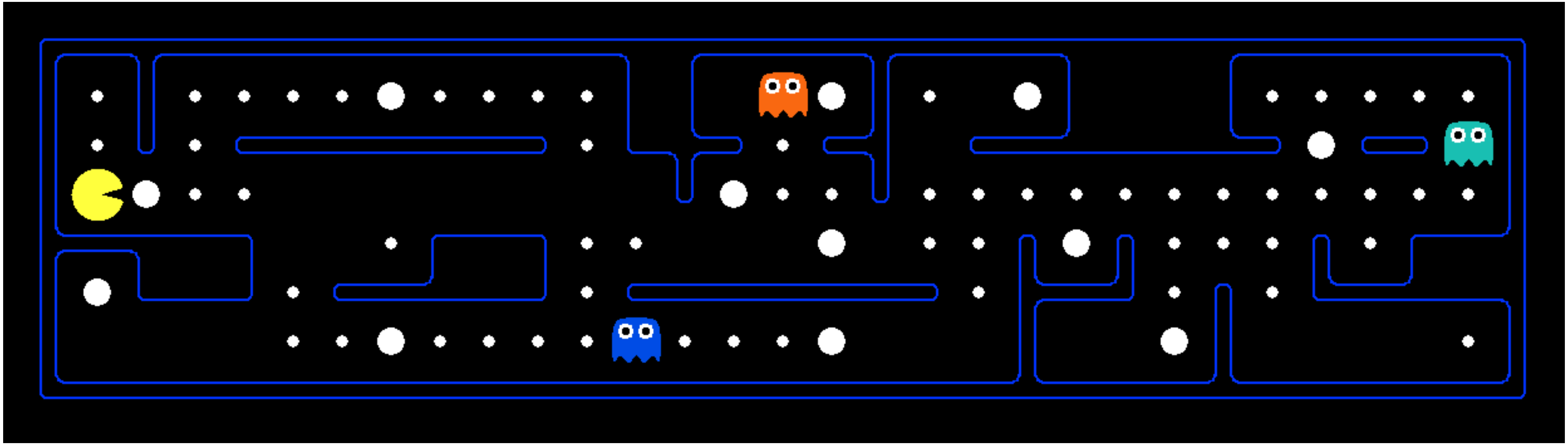


Quiz: Safe Passage



- Problem: eat all dots while keeping the ghosts perma-scared

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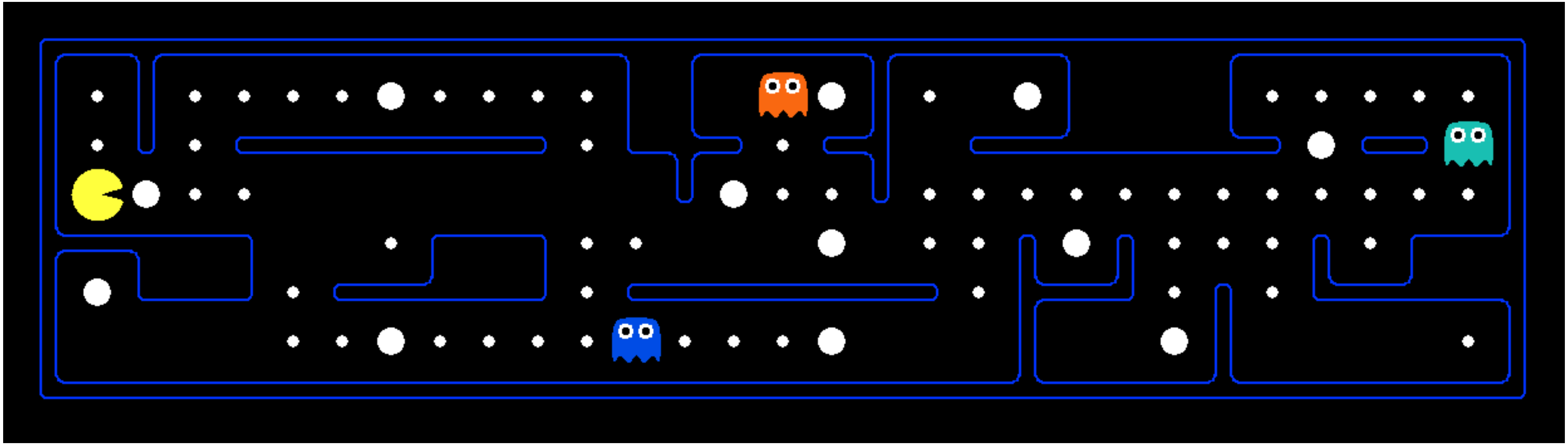

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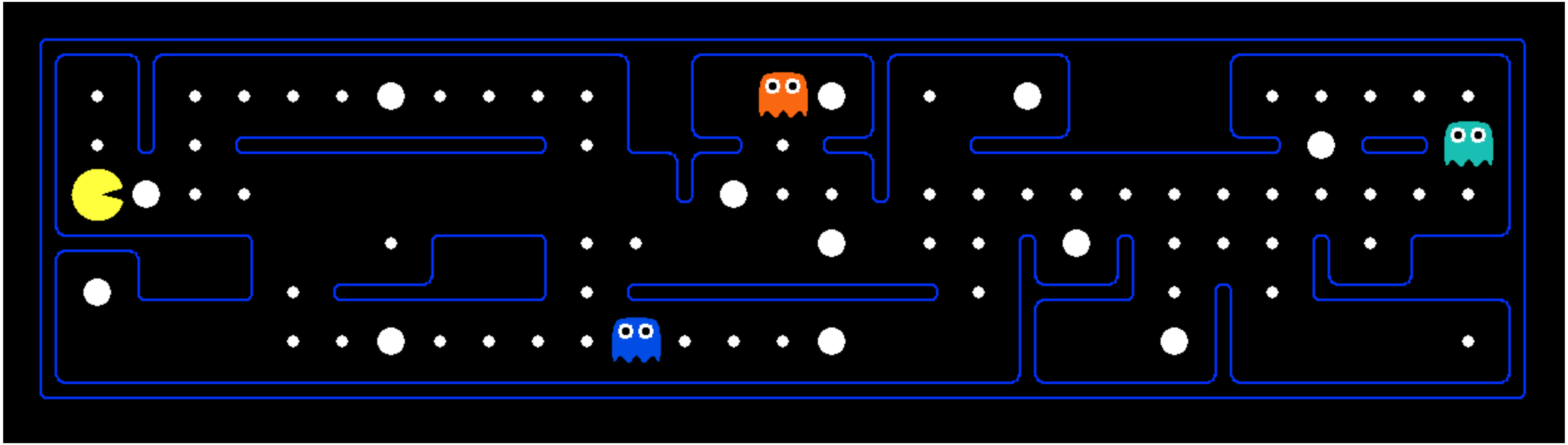
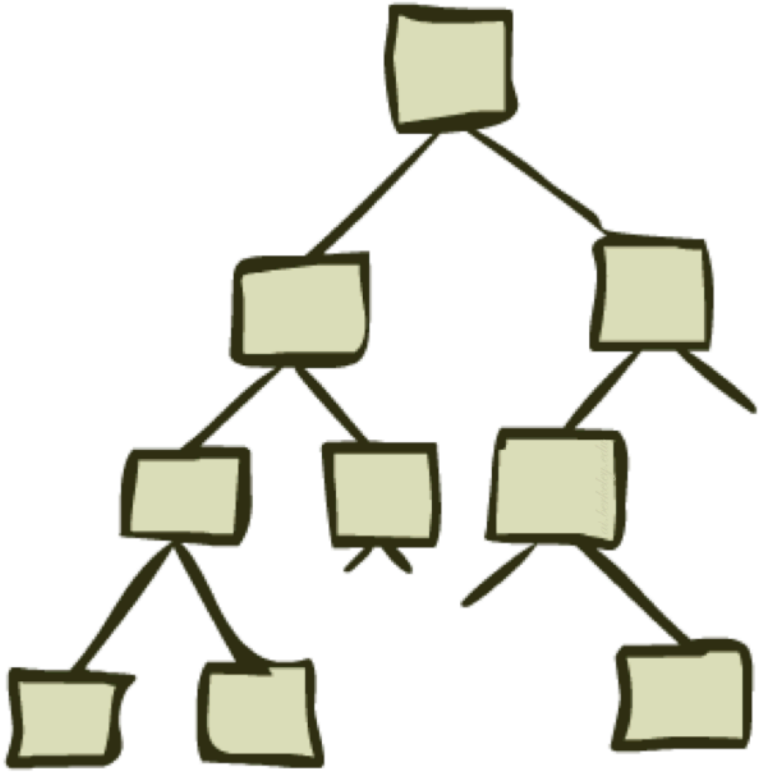


- Problem: eat all dots while keeping the ghosts perma-scared
- What does the state space have to specify?
  - (agent position, dot booleans, power pellet booleans, remaining scared time)

State Space Graphs and Search Trees



State Space Graphs

- State space graph: A mathematical representation of a search problem

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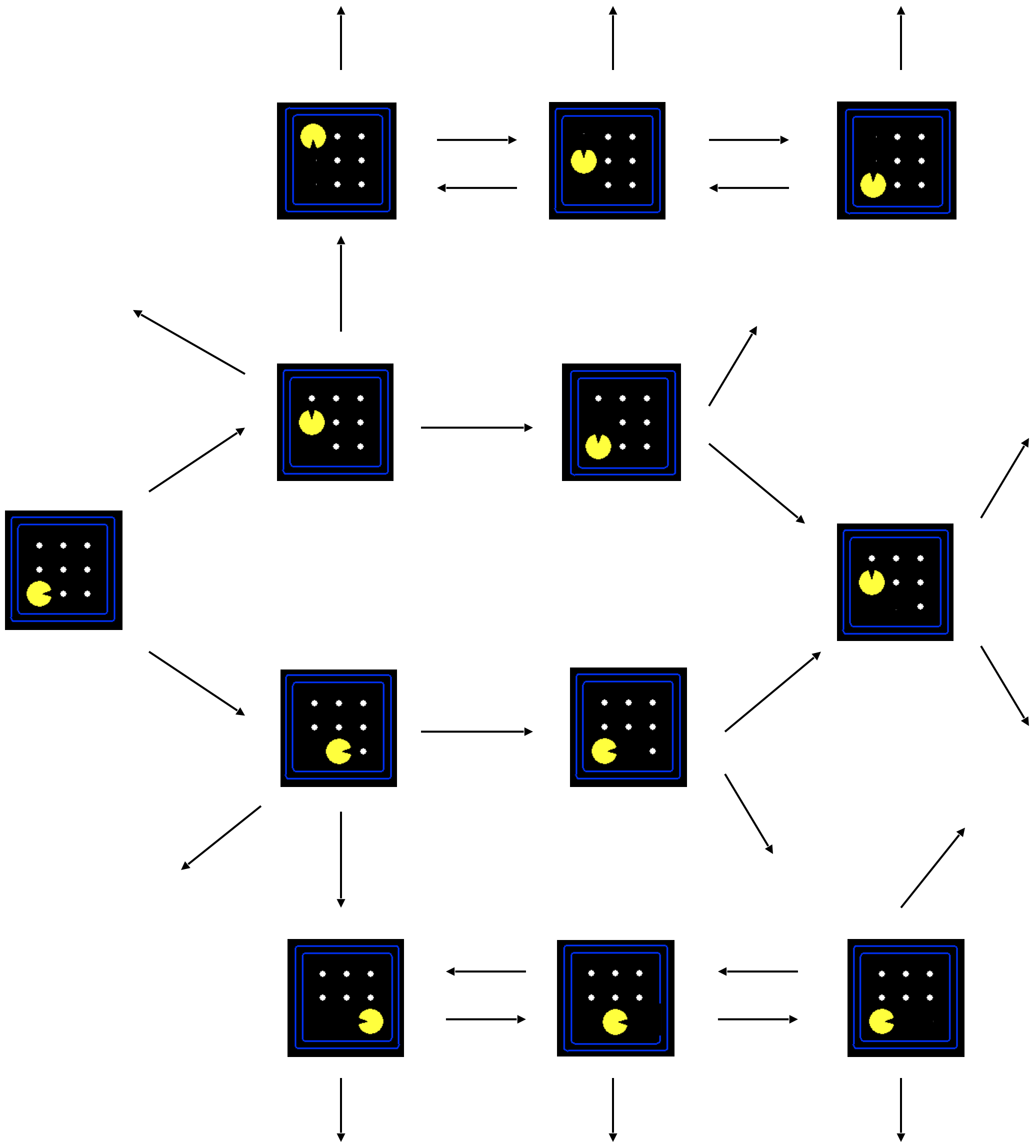

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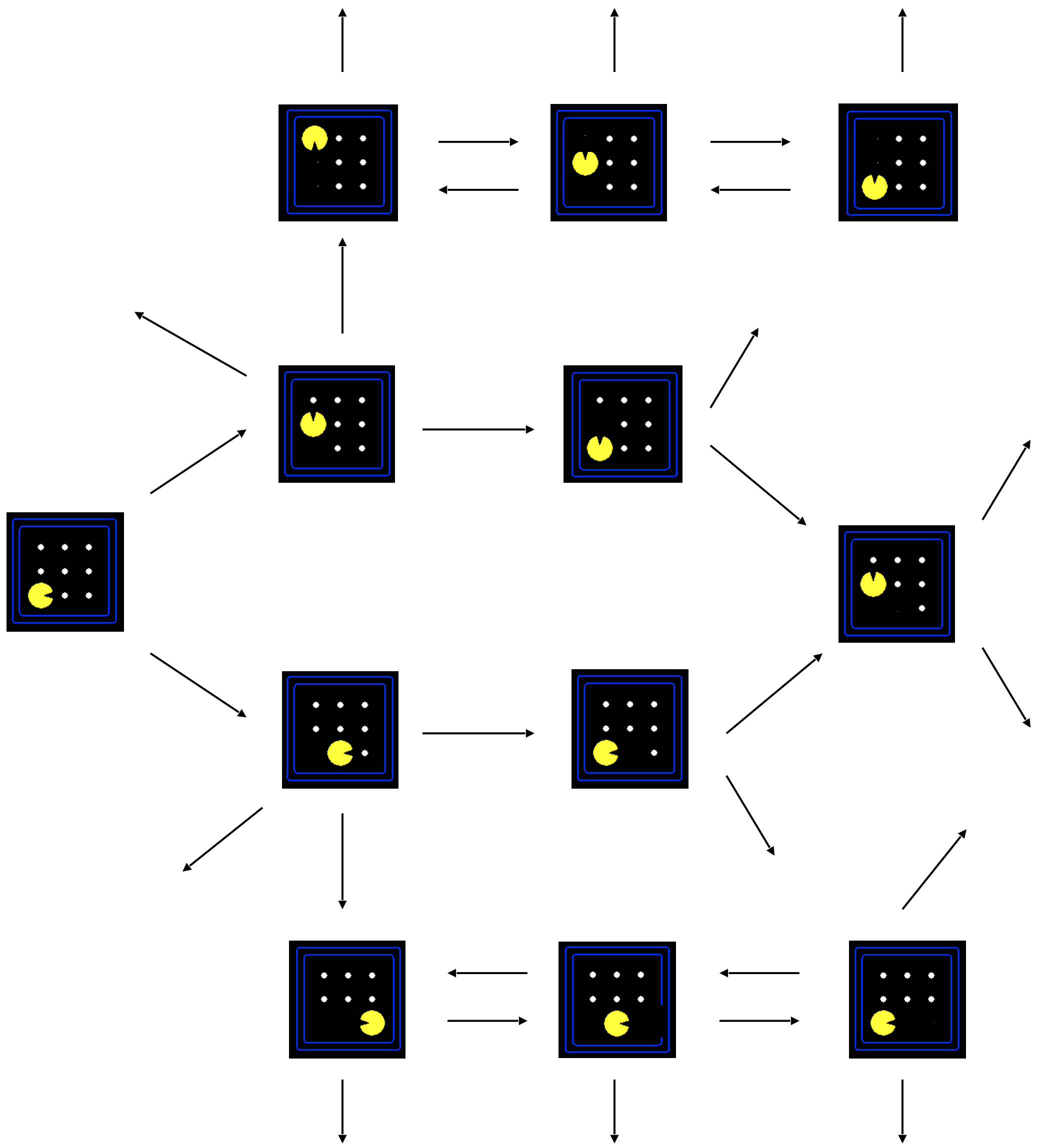

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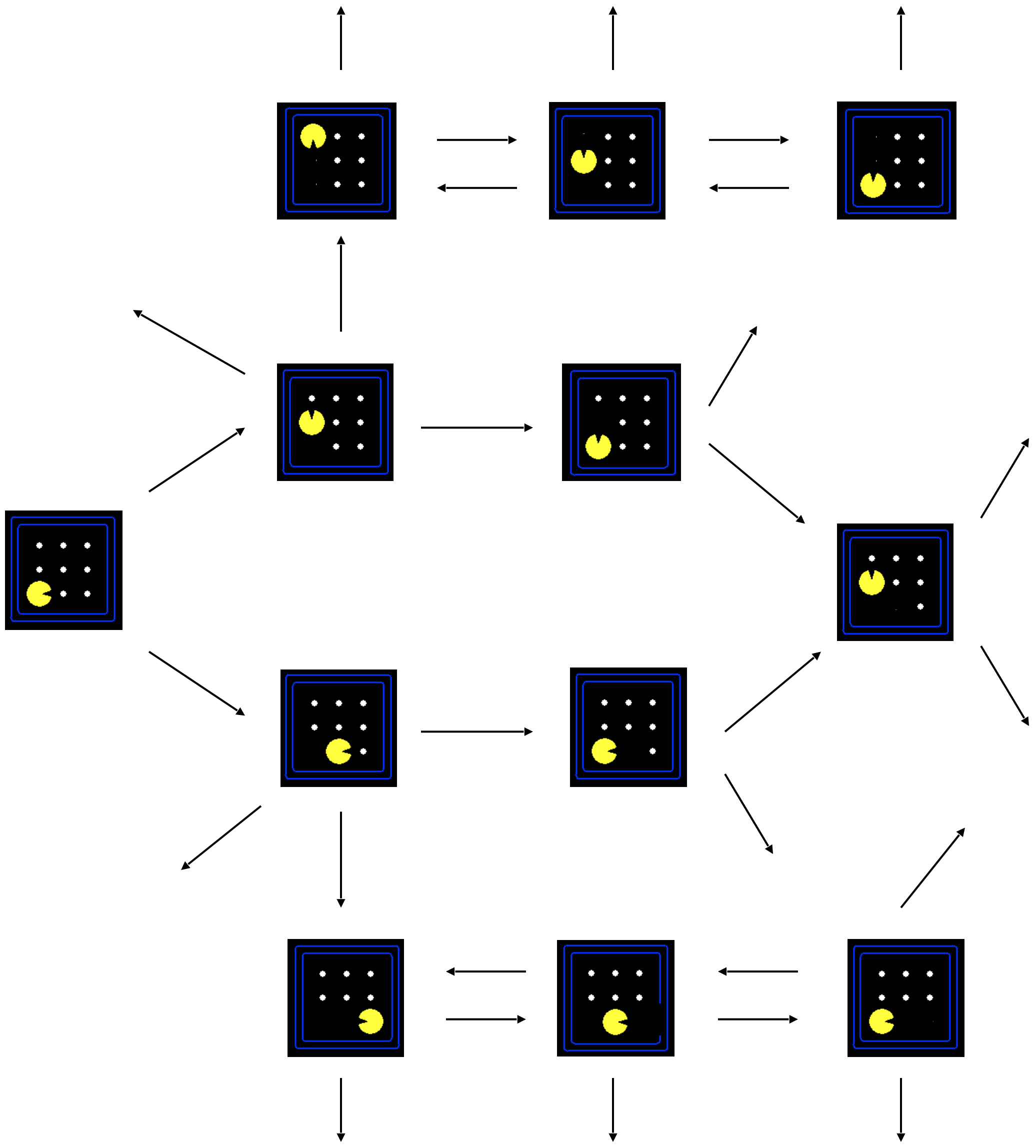

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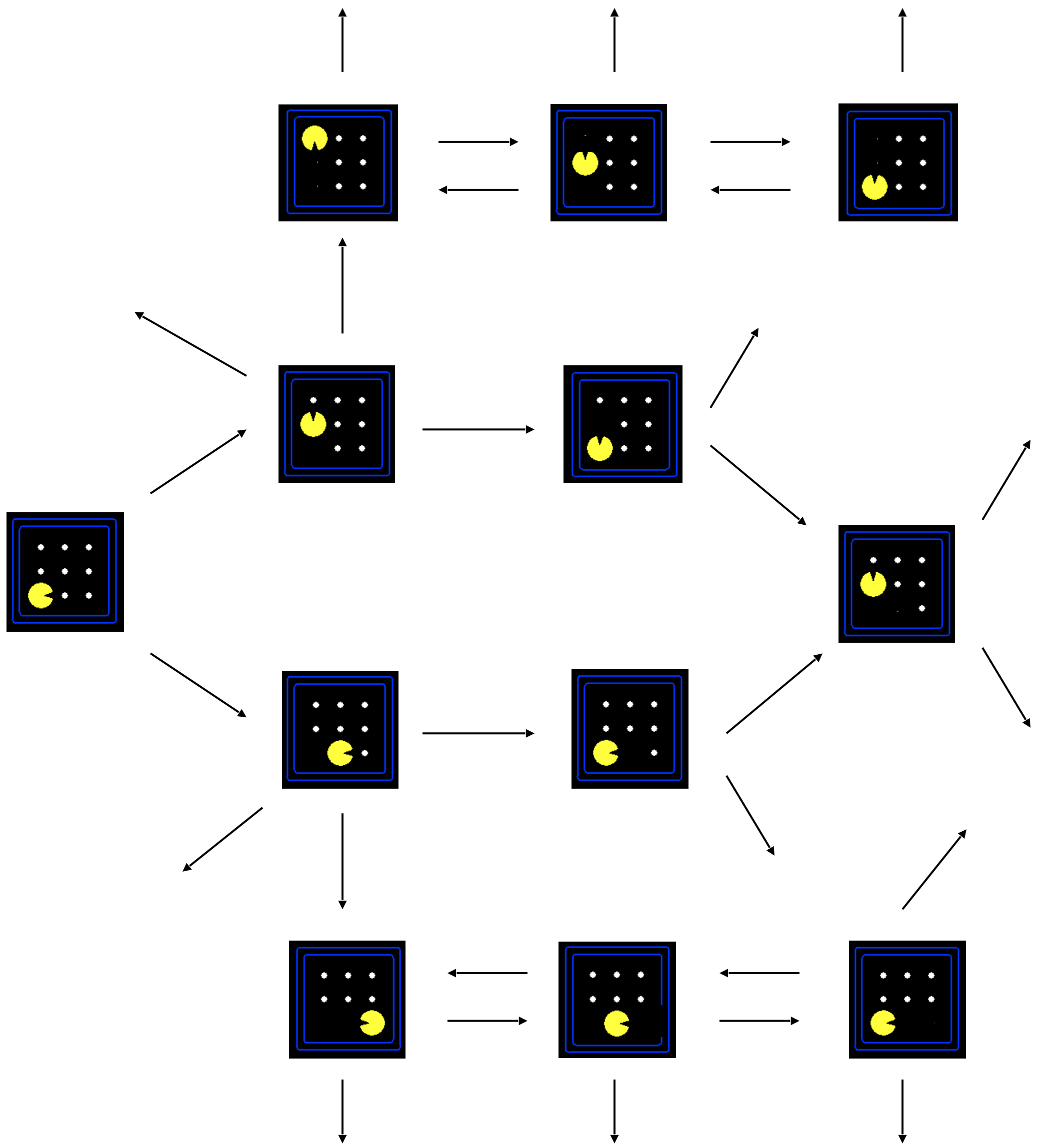

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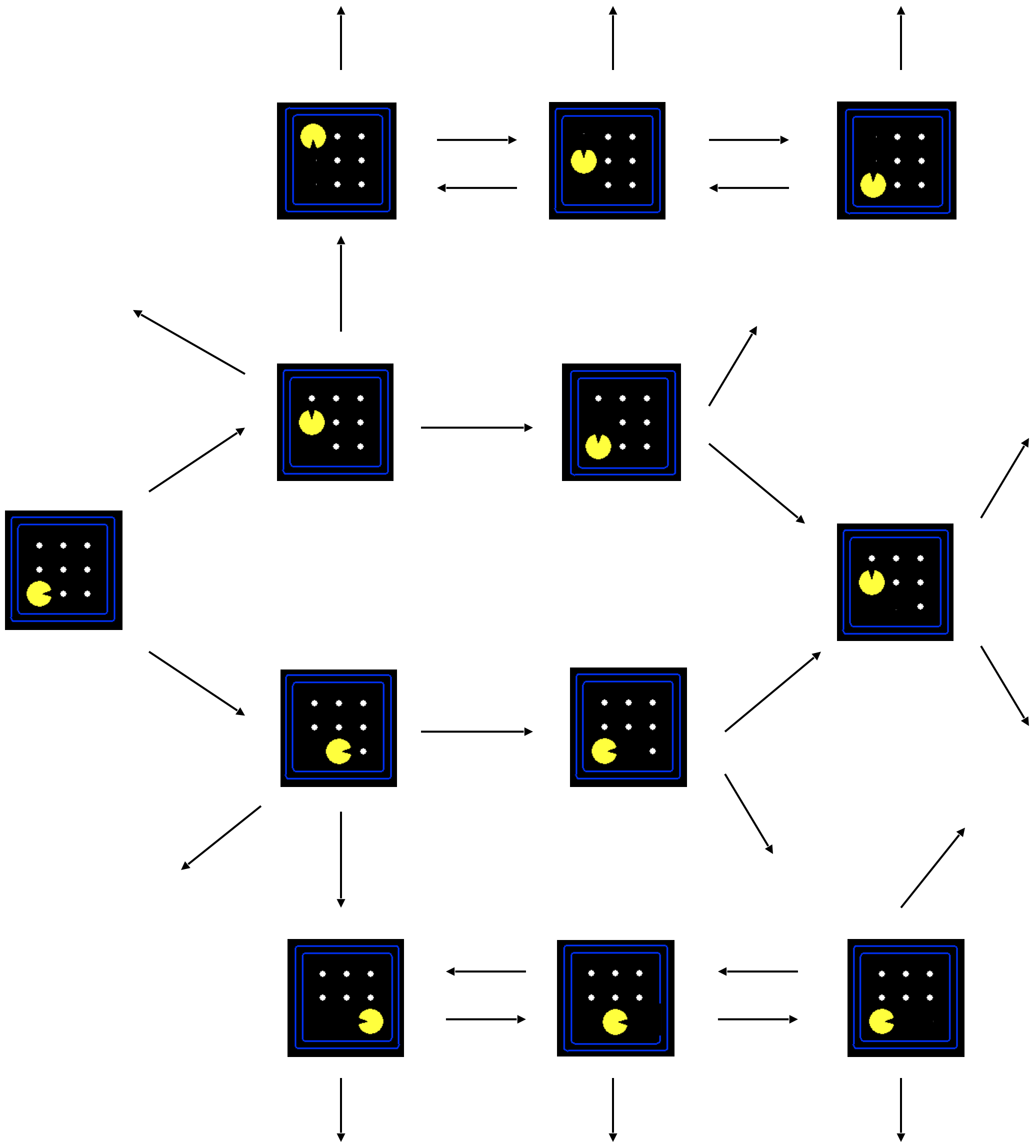

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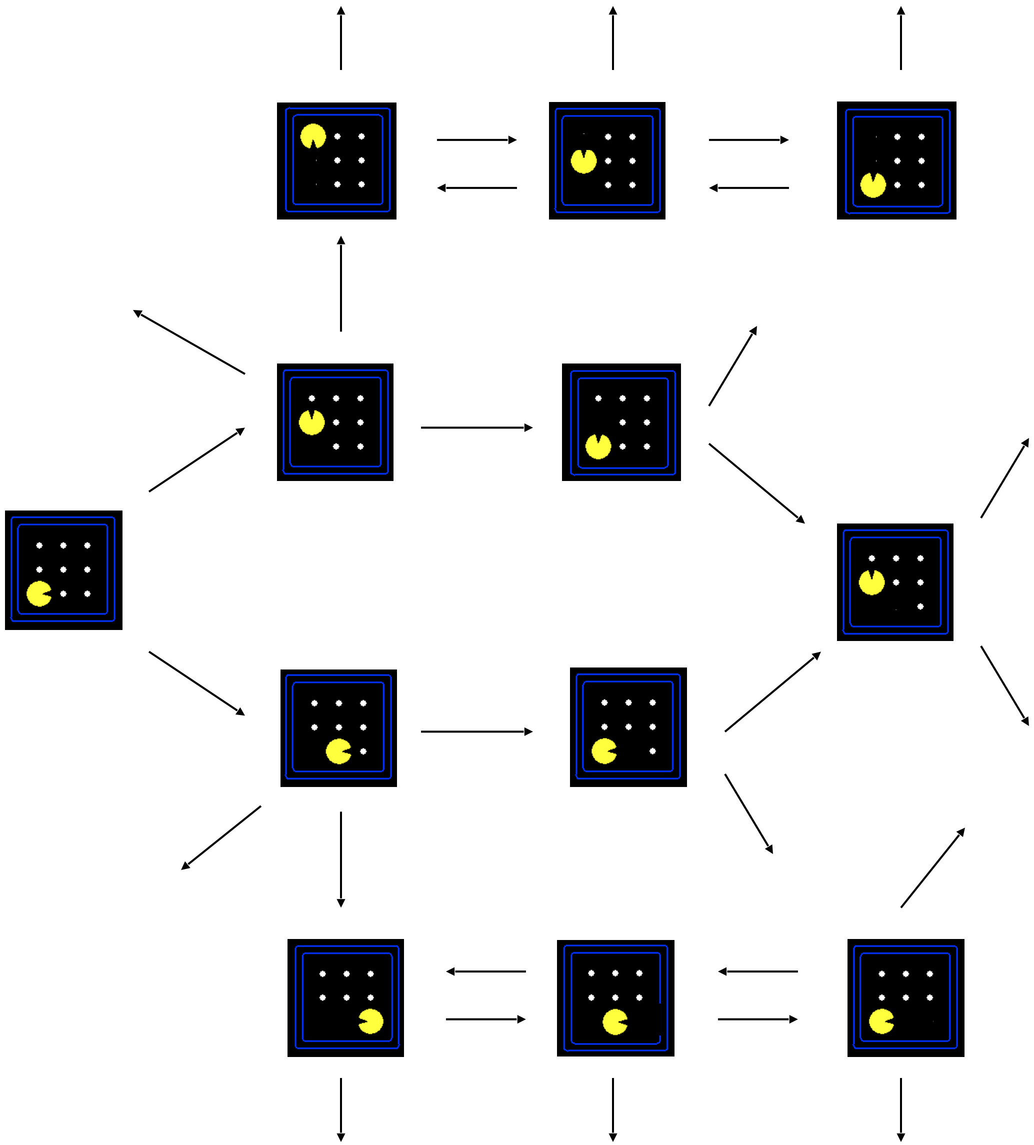

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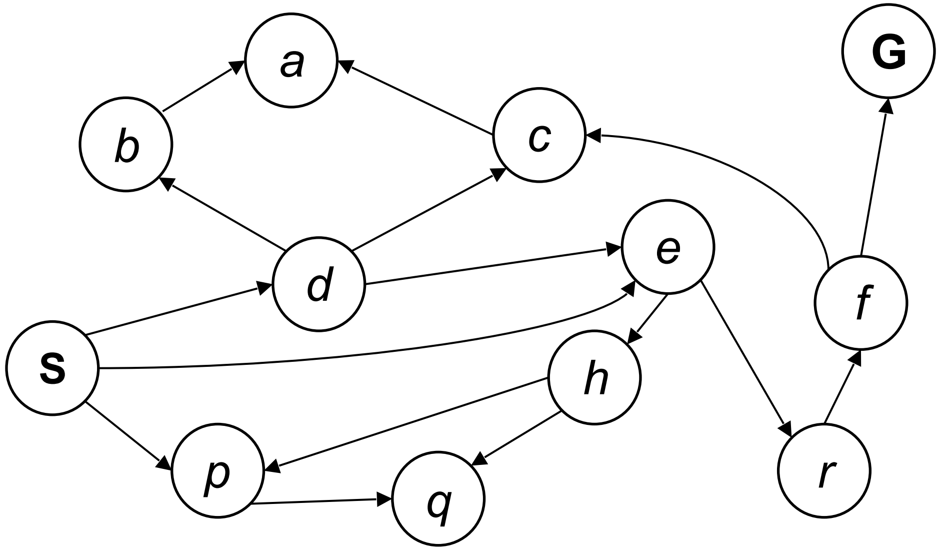
- In a search graph, each state occurs only once!

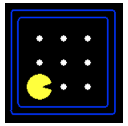
- We can rarely build this full graph in memory (it's too big), but it's a useful idea



Tiny search graph for a tiny search problem

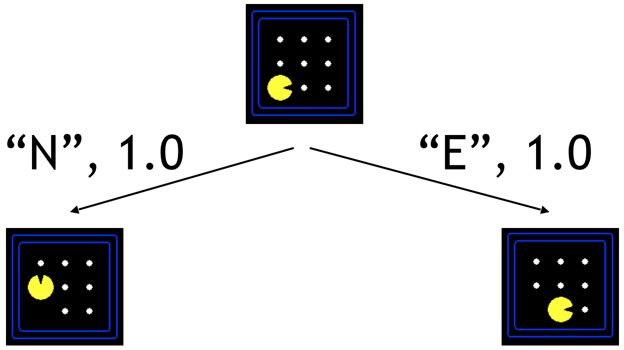
Search Trees

Search Trees



This is now / start

Search Trees



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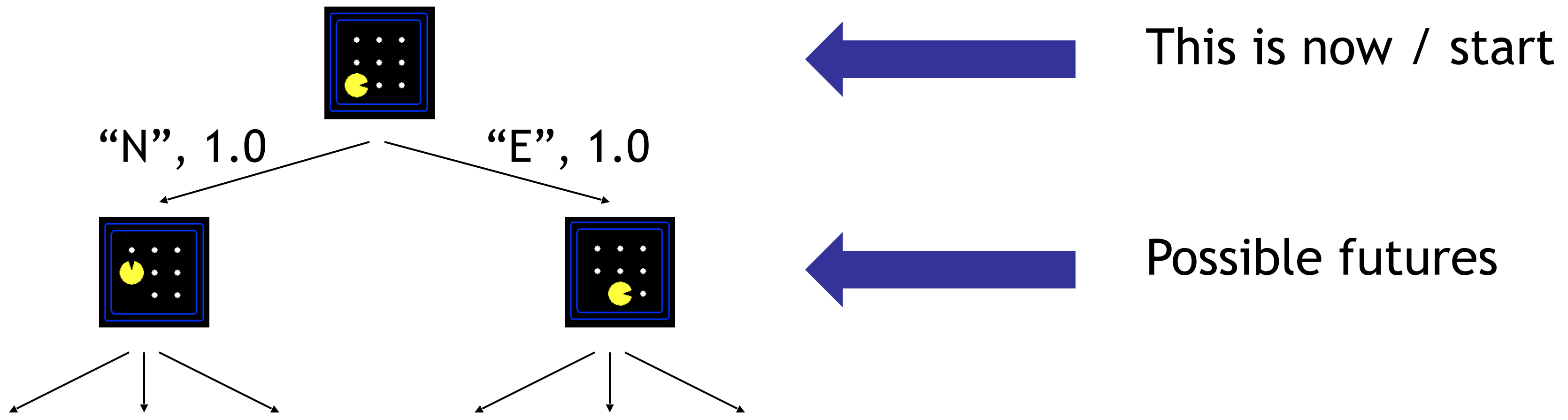
Possible futures

Search Trees



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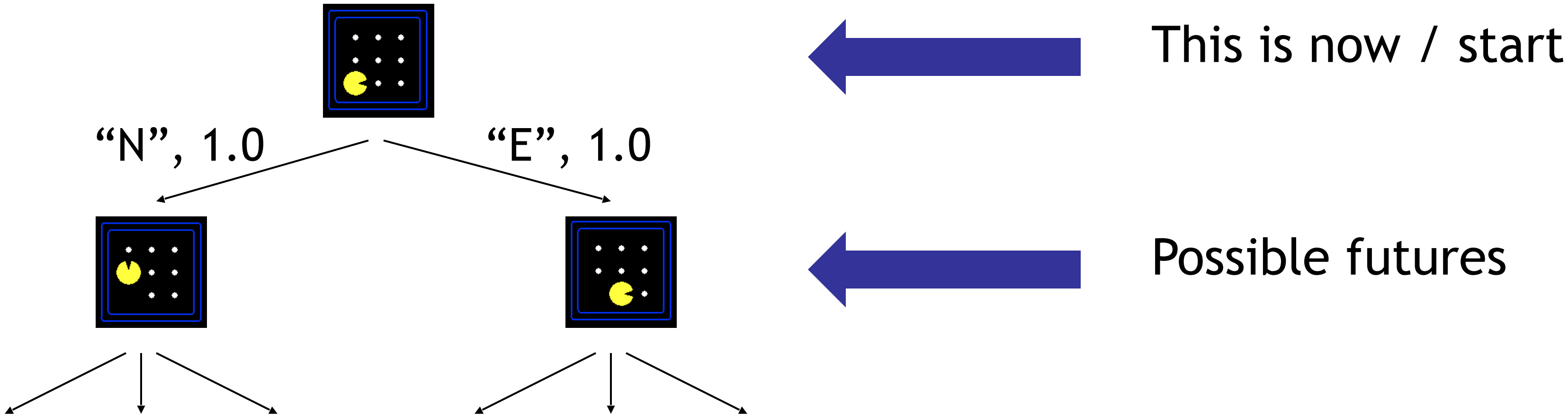
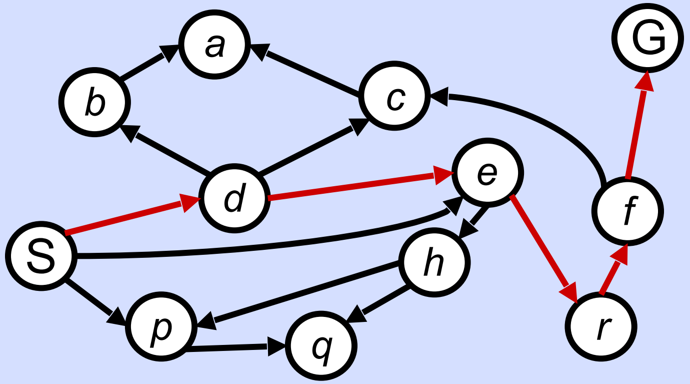


- A search tree:
  - A “what if” tree of plans and their outcomes
  - The start state is the root node
  - Children correspond to successors
  - Nodes show states, but correspond to PLANS that achieve those states
  - For most problems, we can never actually build the whole tree

State Space Graphs vs. Search Trees

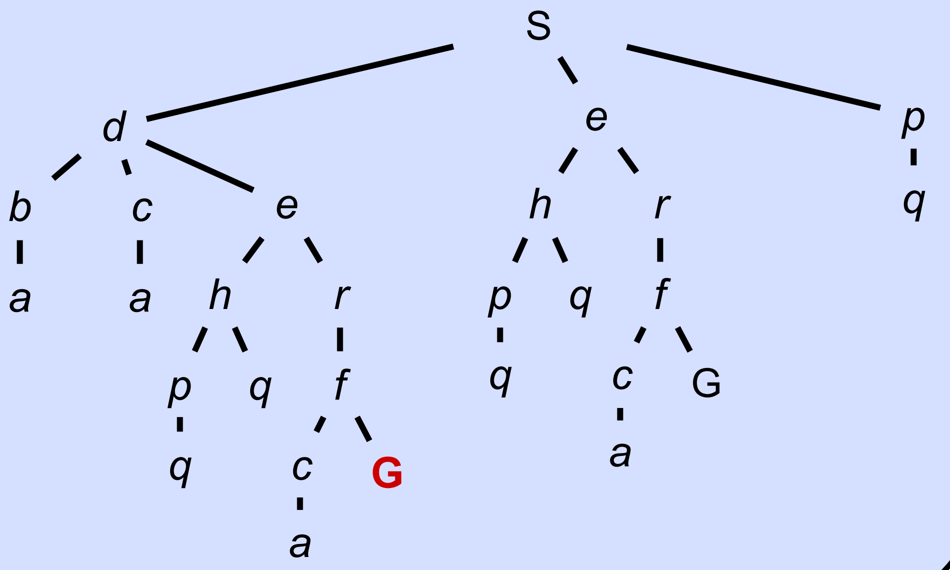
State Space Graph



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

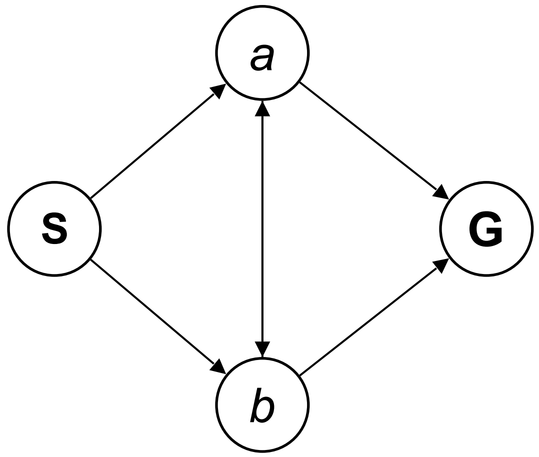
We construct both on demand – and we construct as little as possible.

Search Tree



Quiz: State Space Graphs vs. Search Trees

Consider this 4-state graph:



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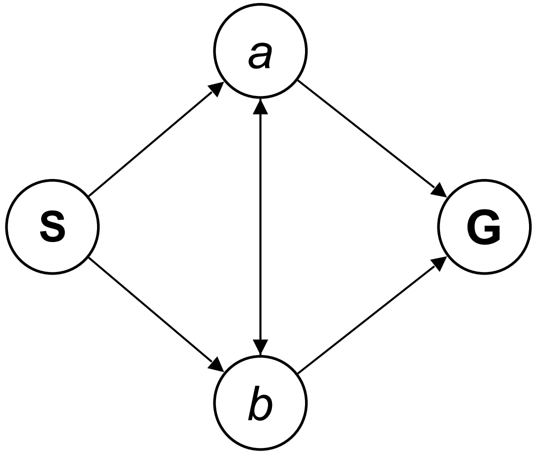

How big is its search tree (from S)?

Quiz: State Space Graphs vs. Search Trees

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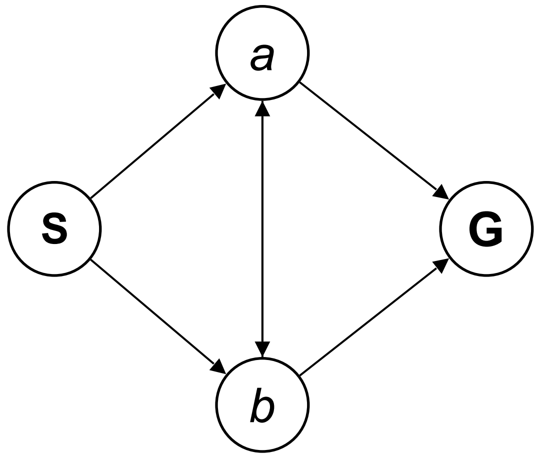

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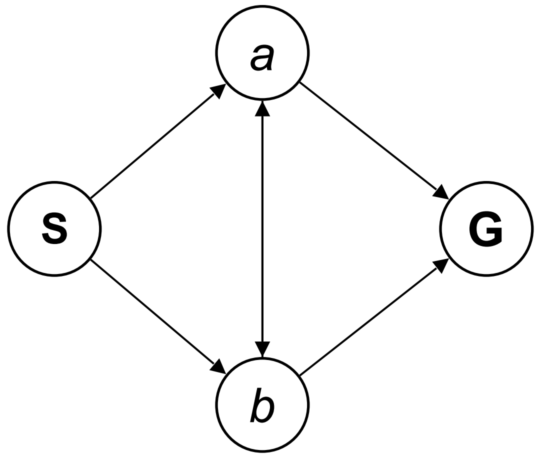
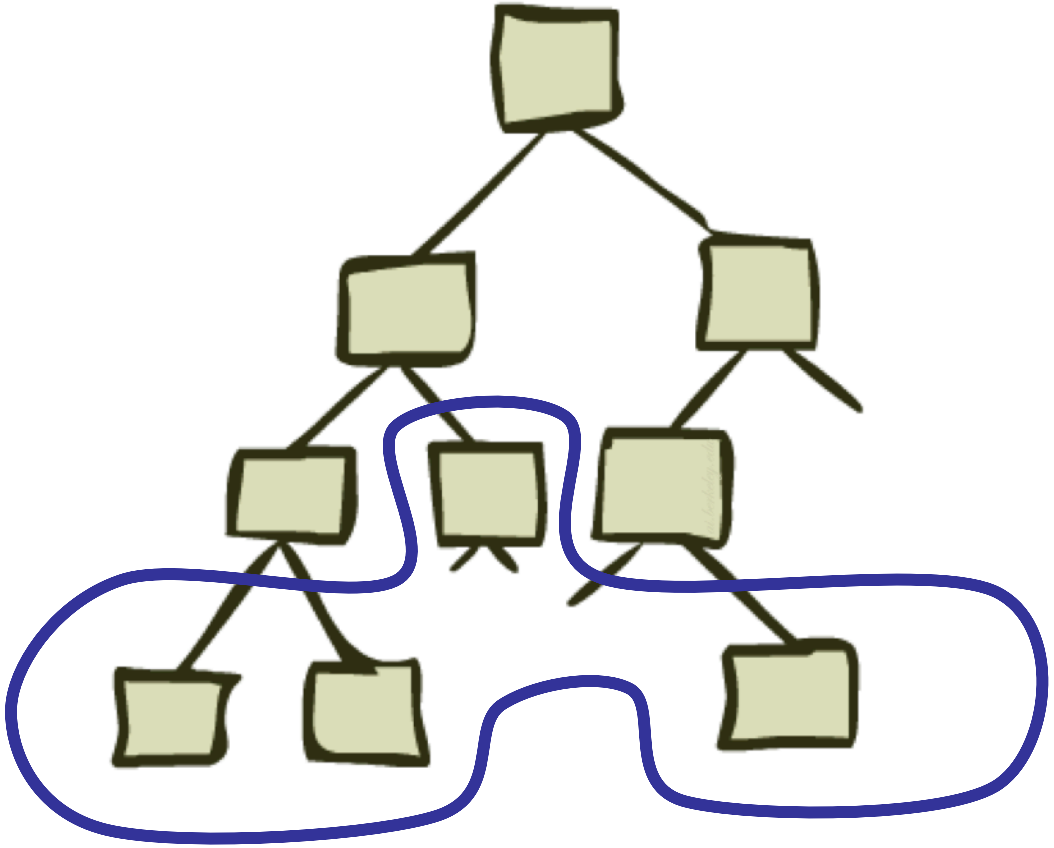


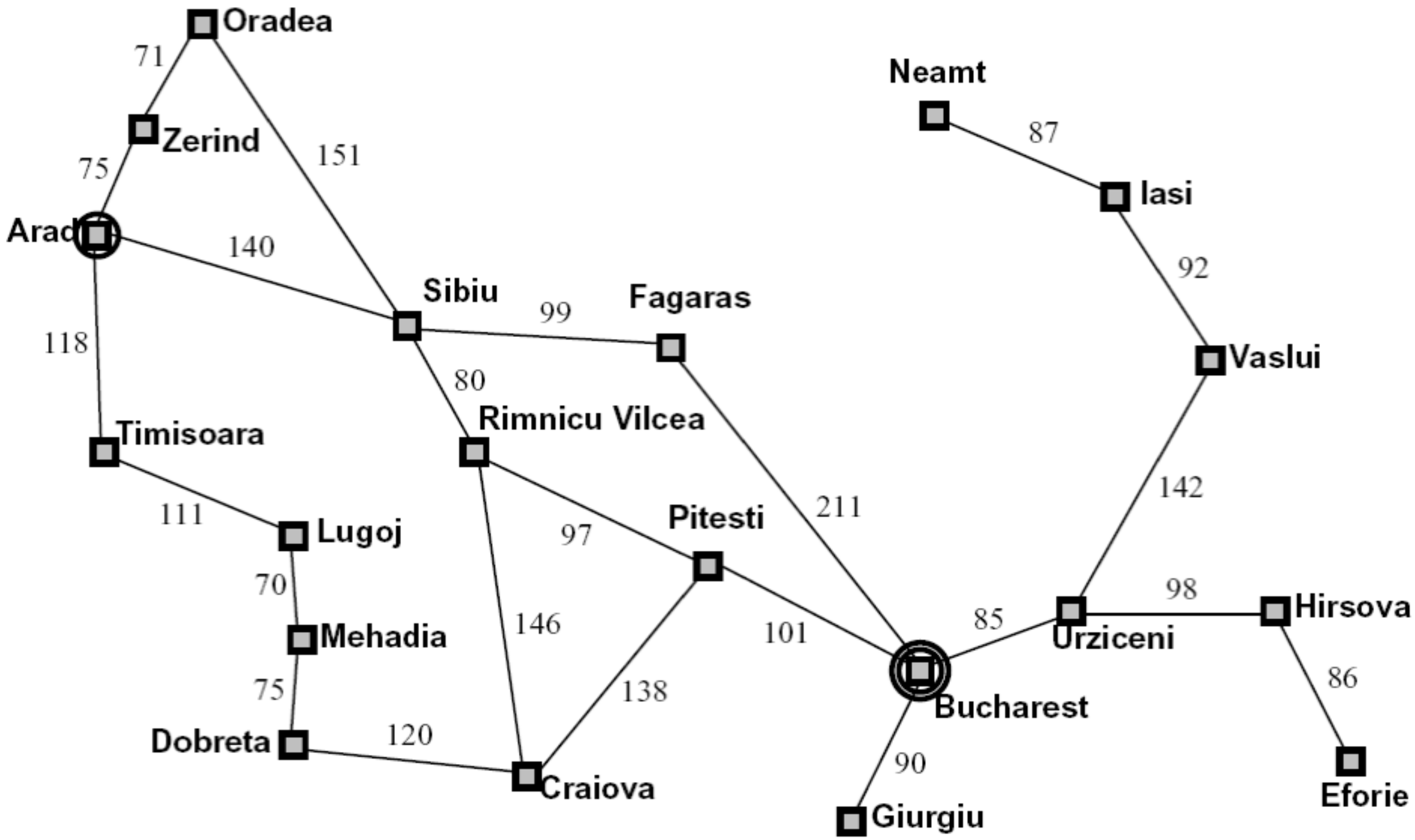
How big is its search tree (from S)?

Important: Lots of repeated structure in the search tree!

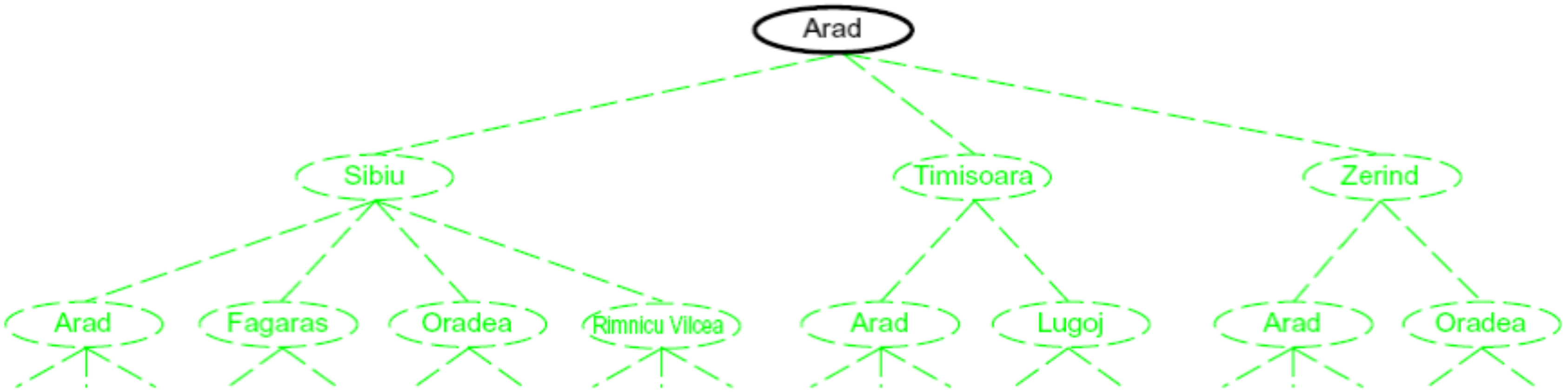
Tree Search



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

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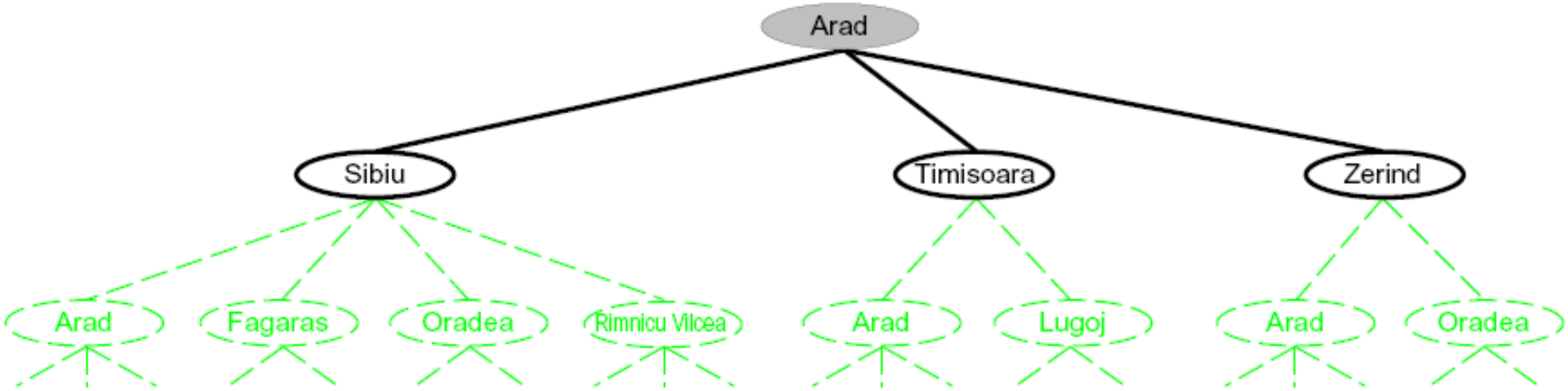

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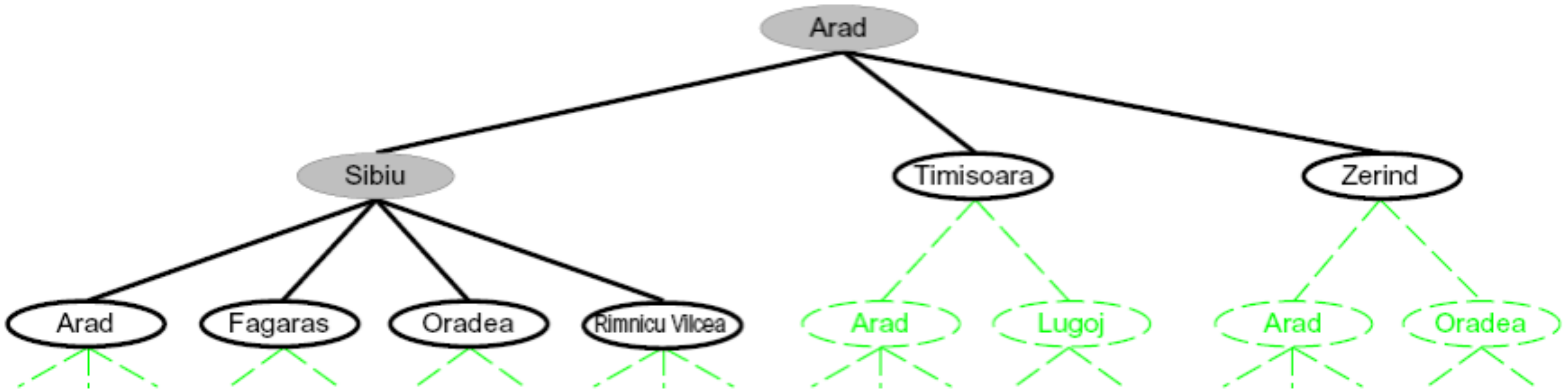

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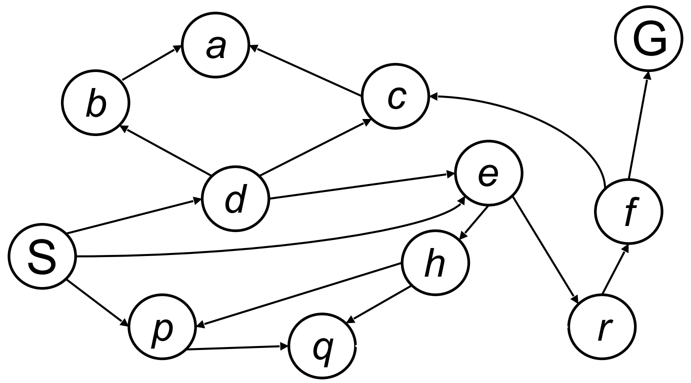
General Tree Search

```
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
- Main question: which fringe nodes to explore?

Example: Tree Search

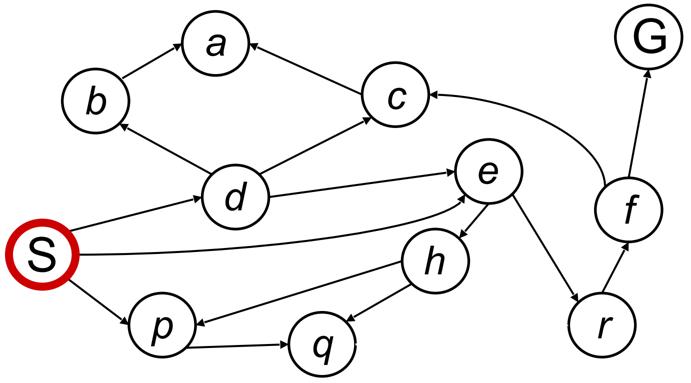


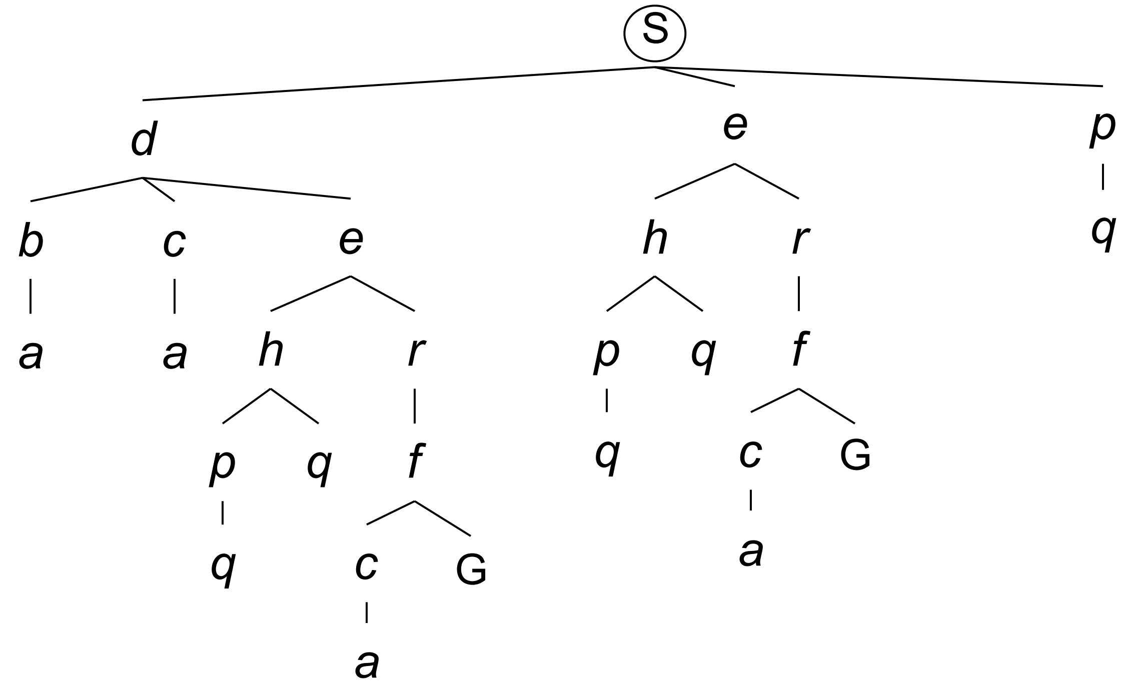
Depth-First Search

Depth-First Search

Strategy: expand a deepest node first

Implementation: Fringe is a LIFO stack





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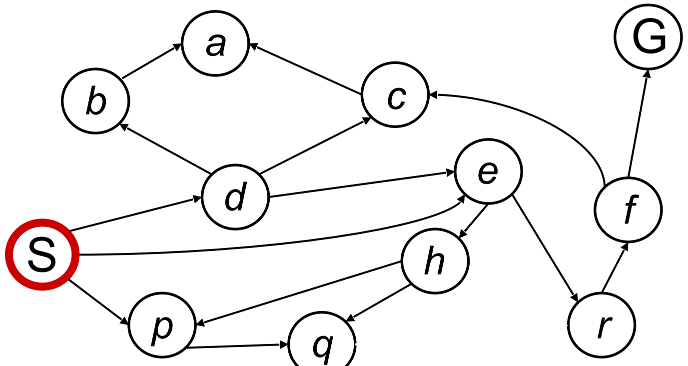

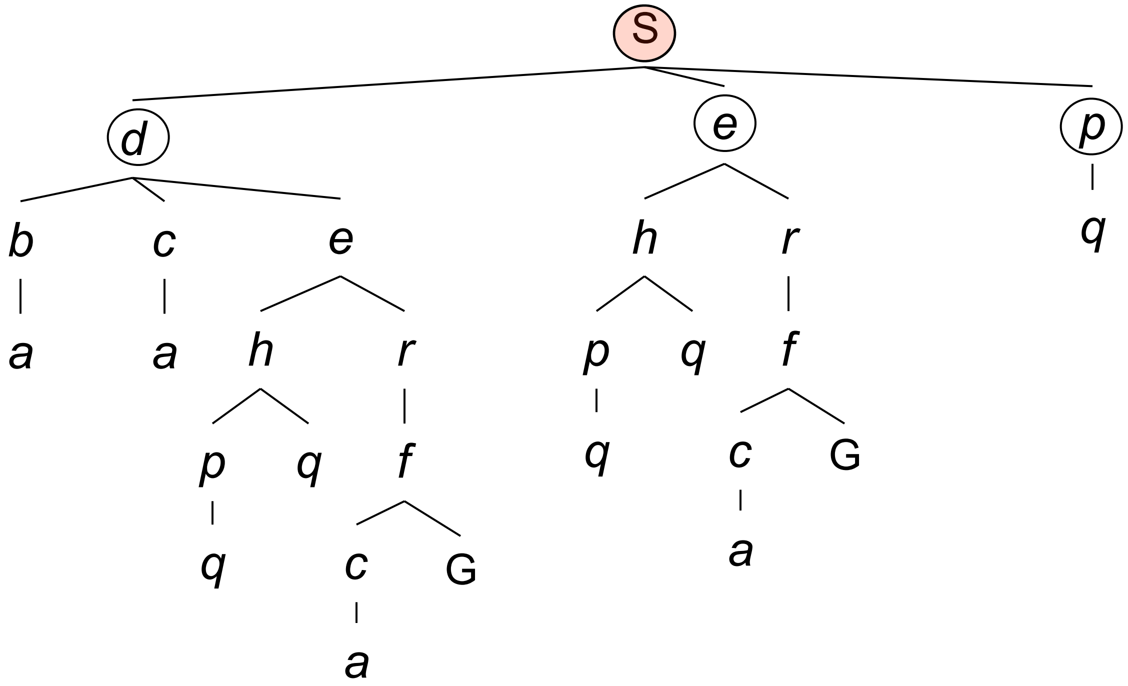

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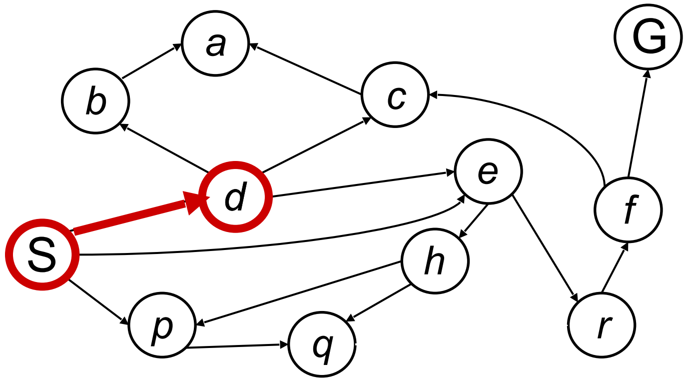

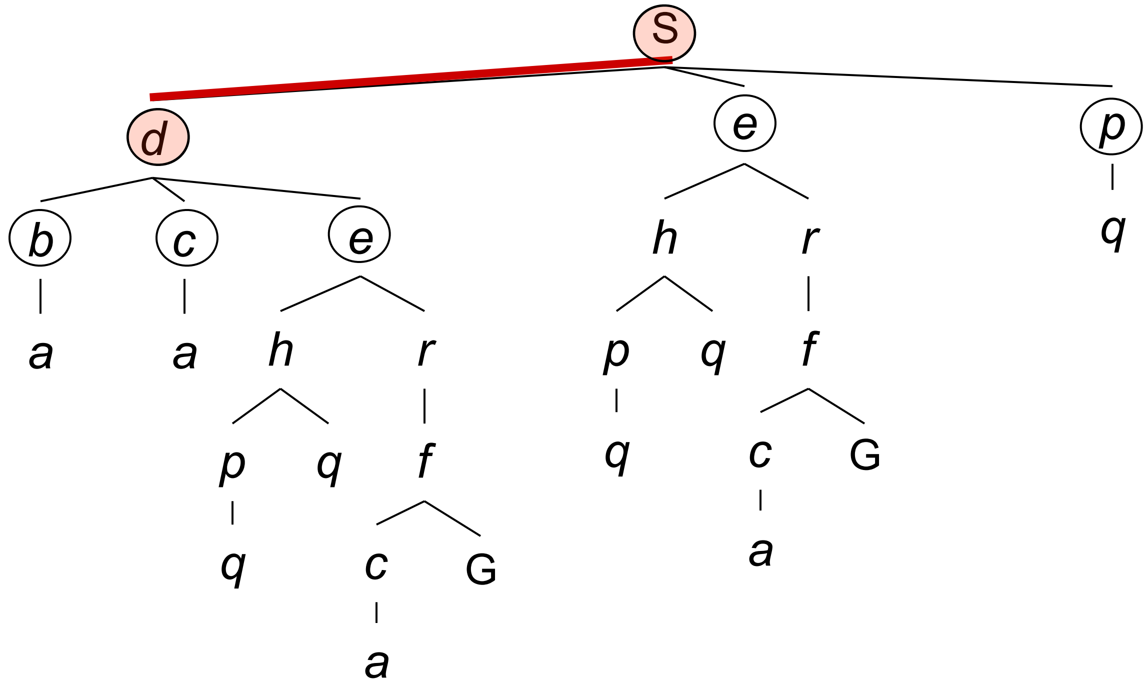

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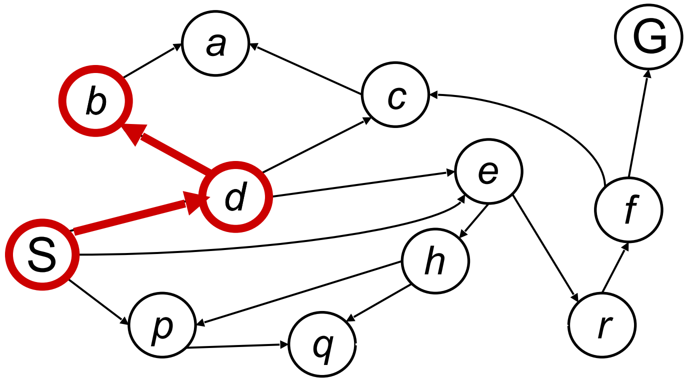

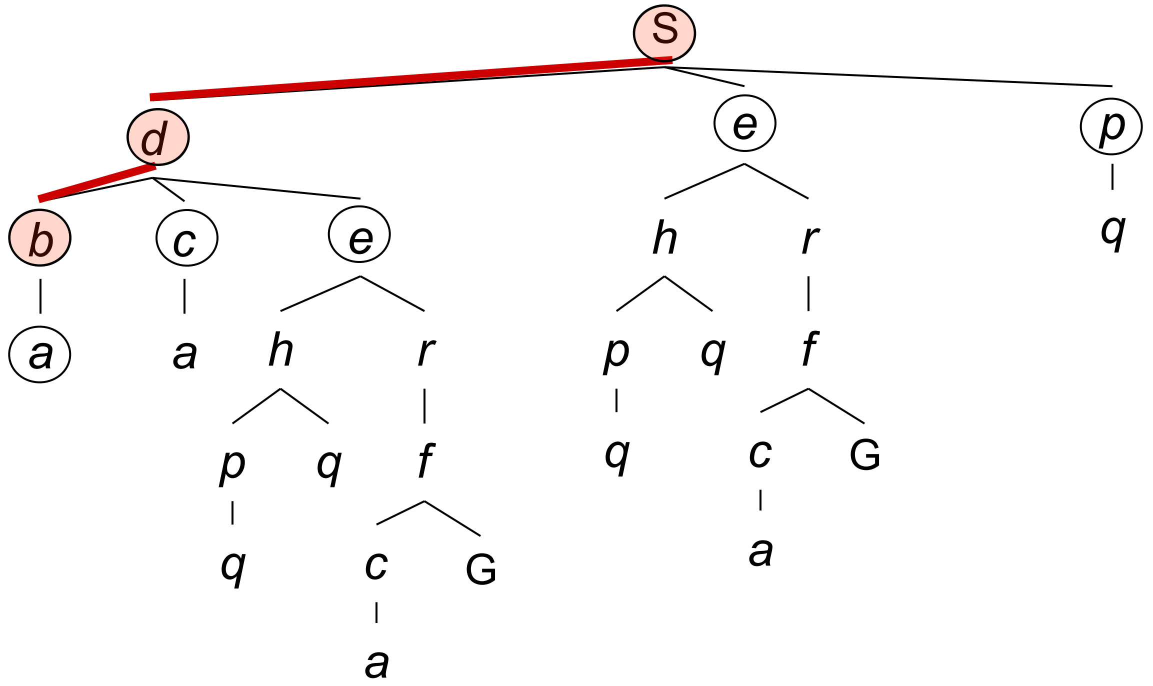

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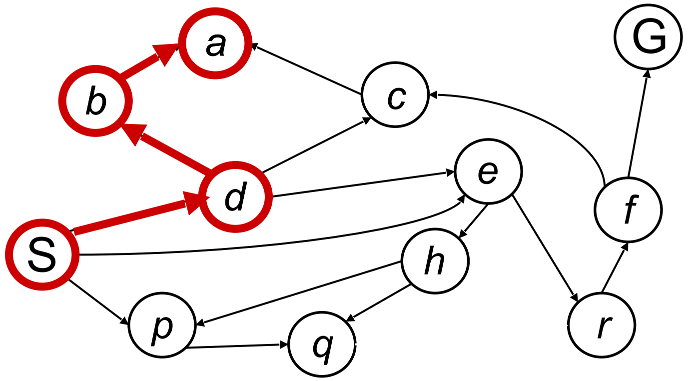

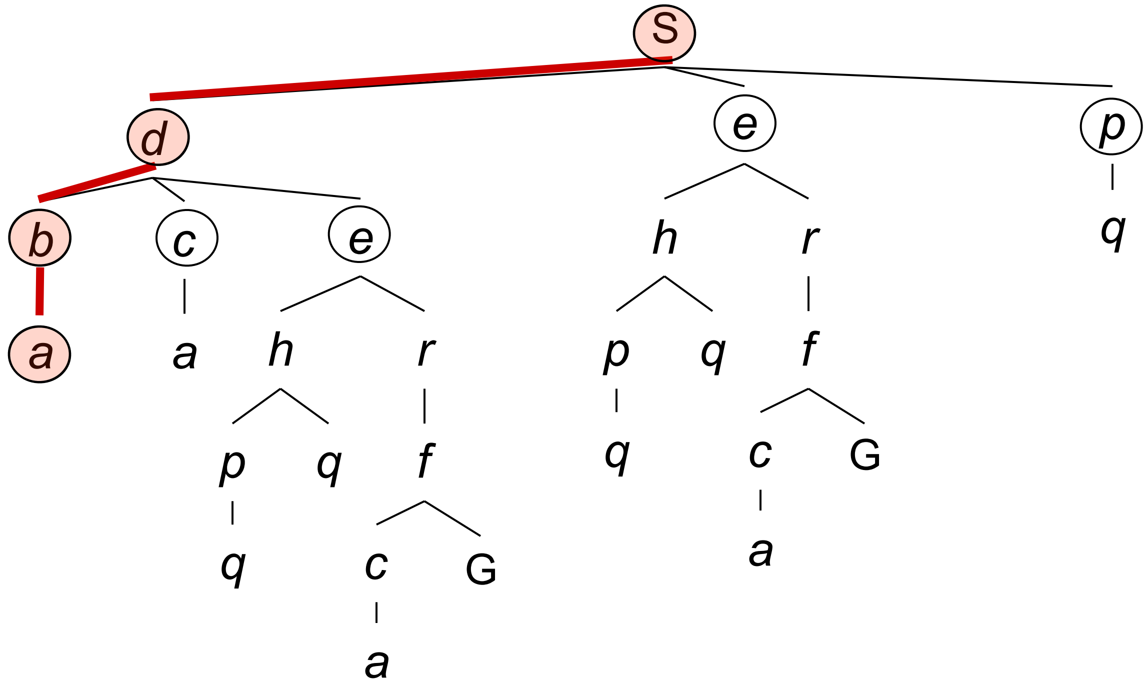

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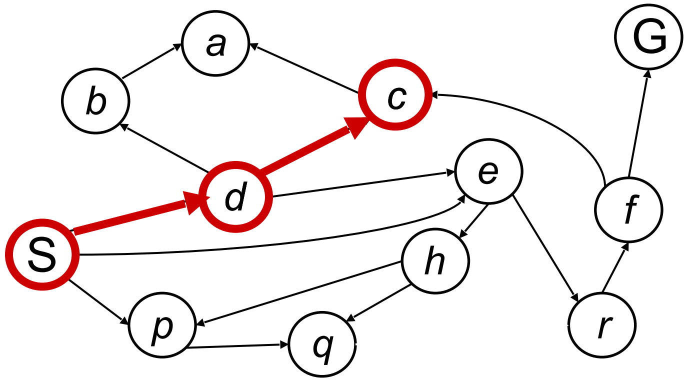

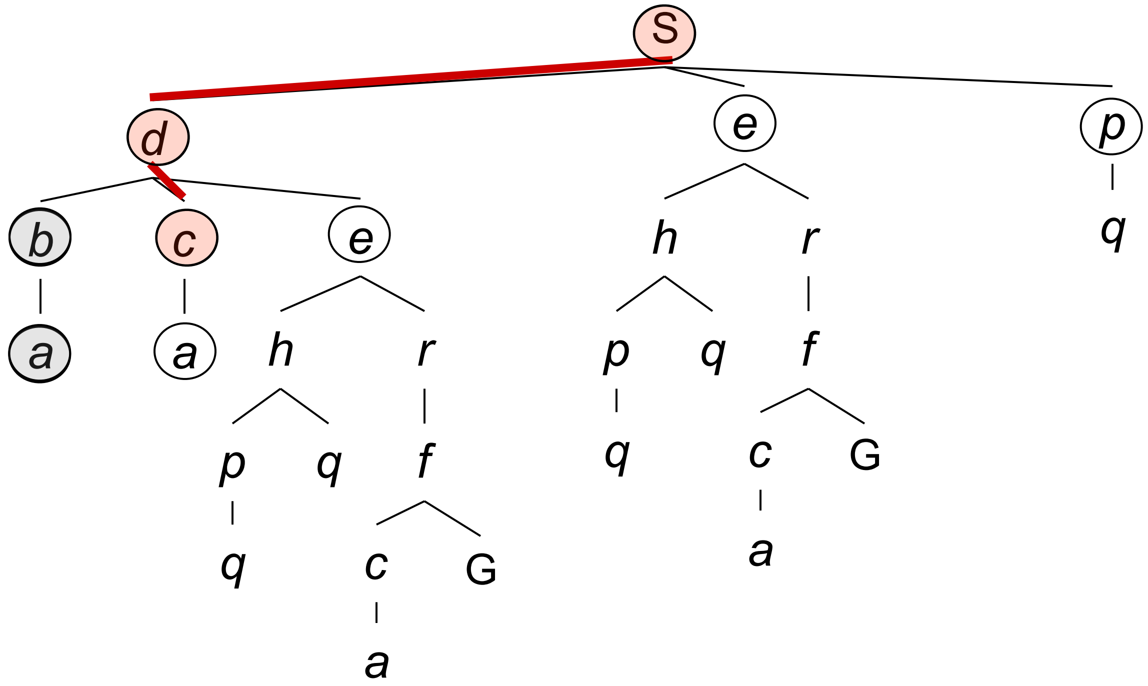

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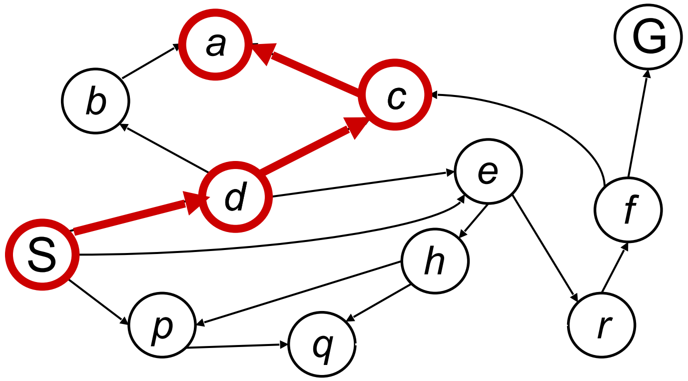

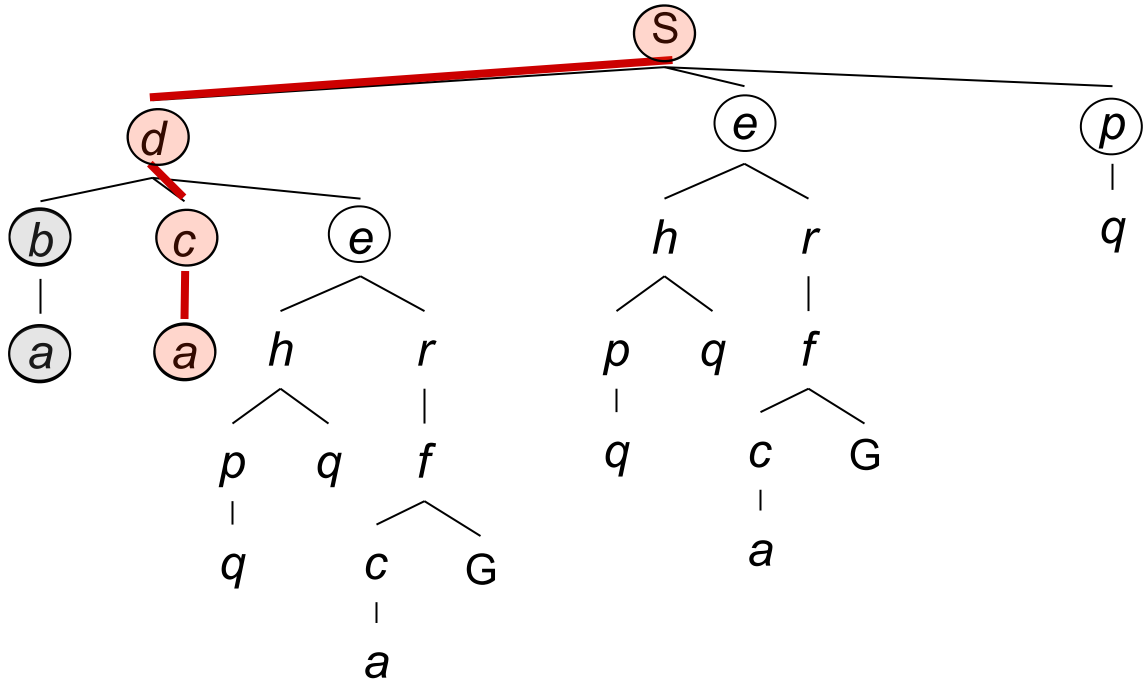

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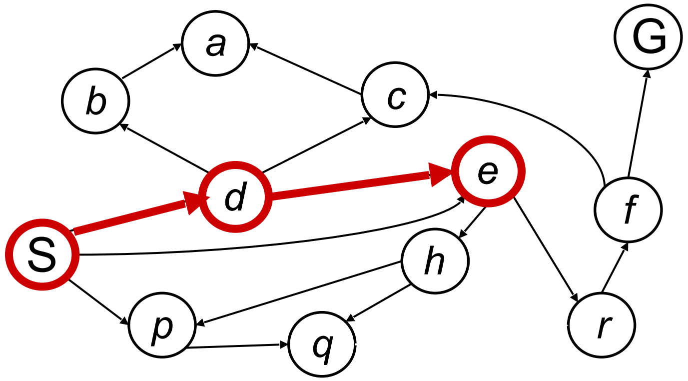

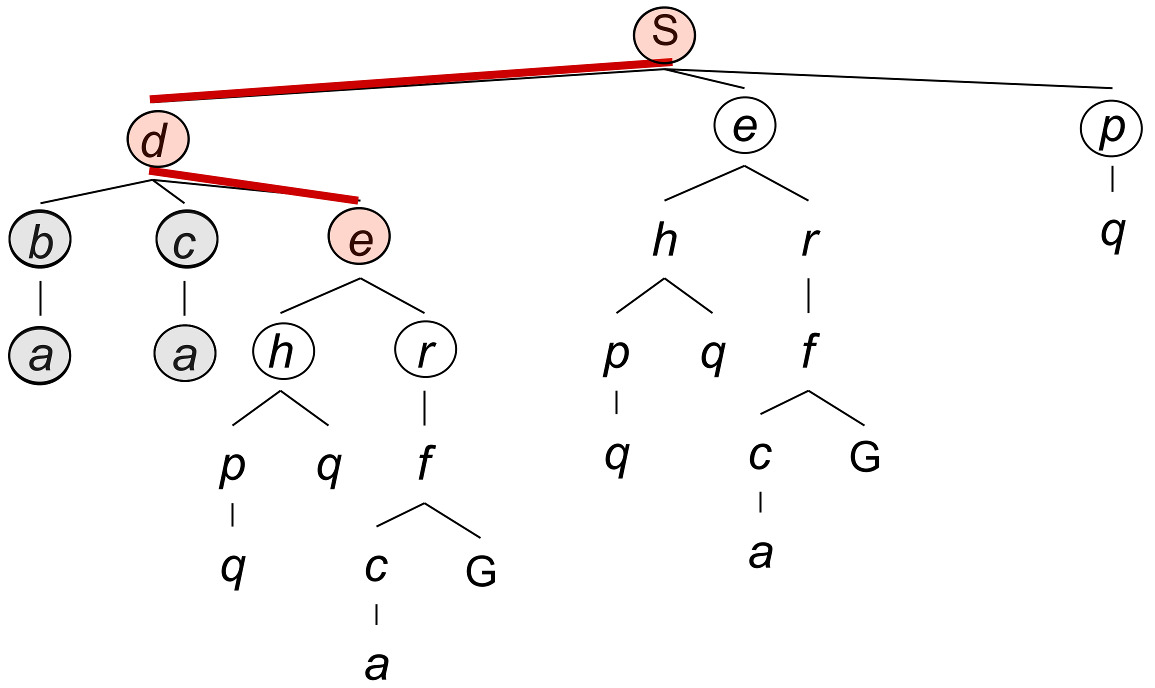

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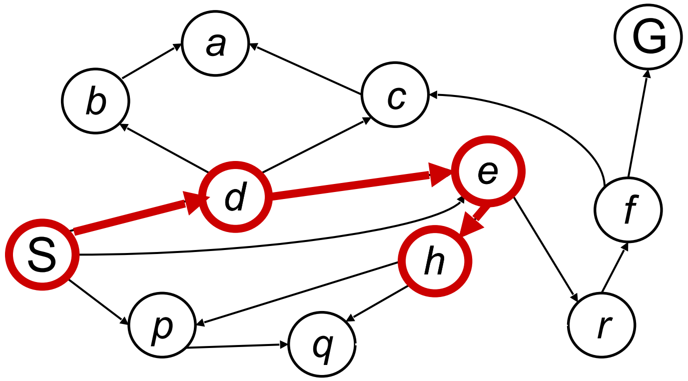

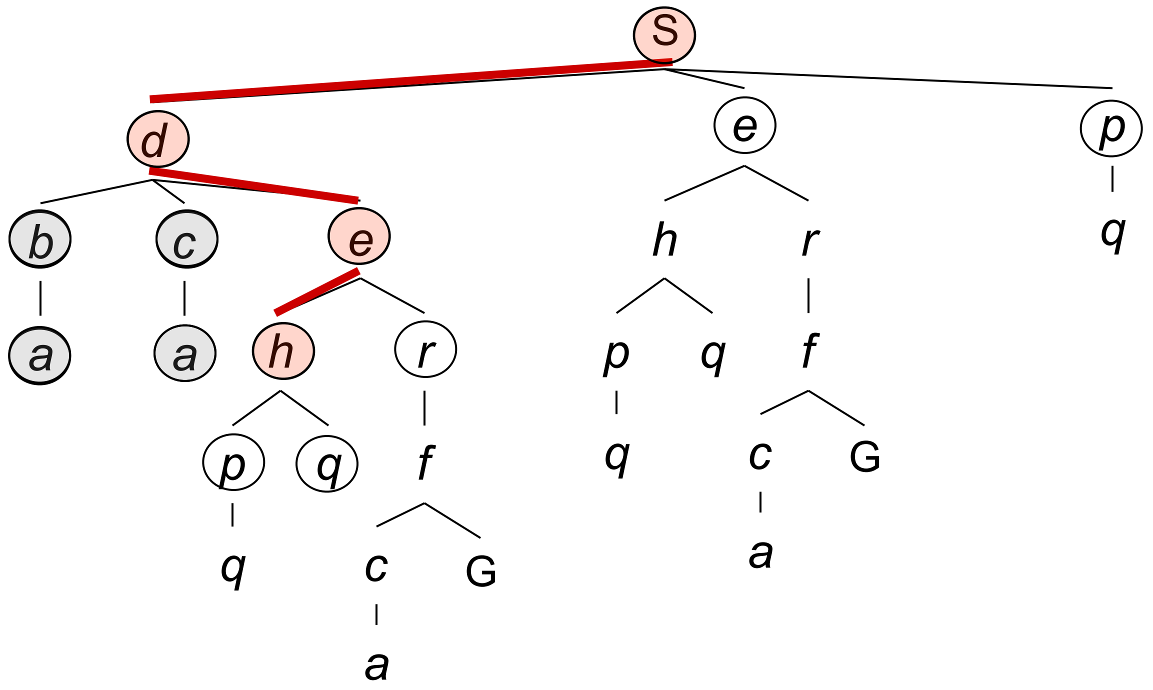

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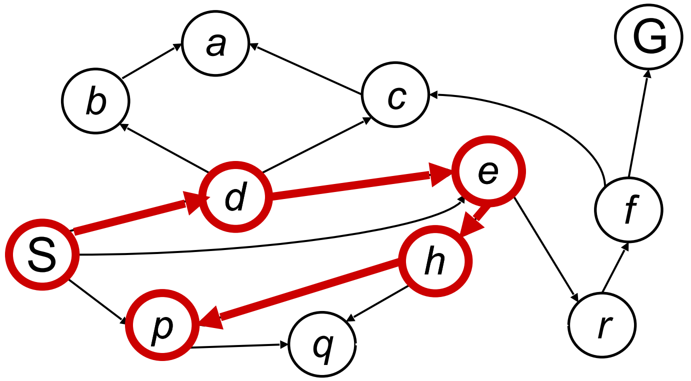

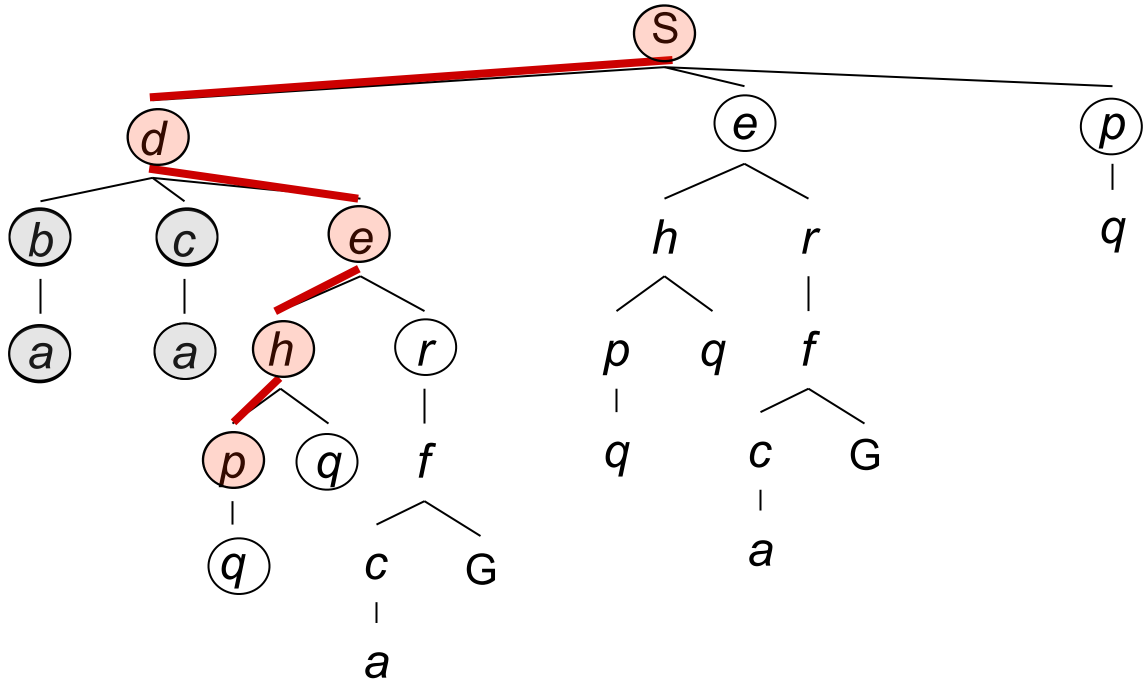

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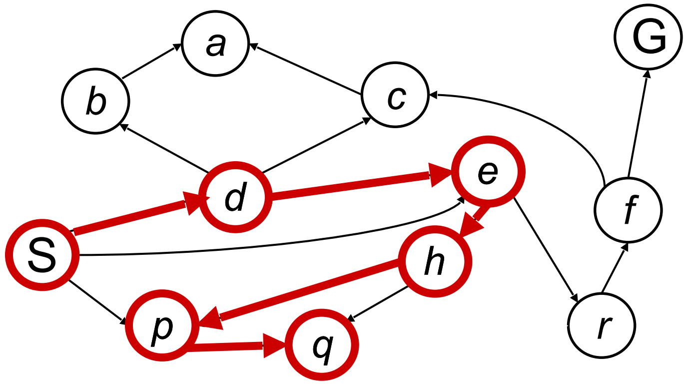

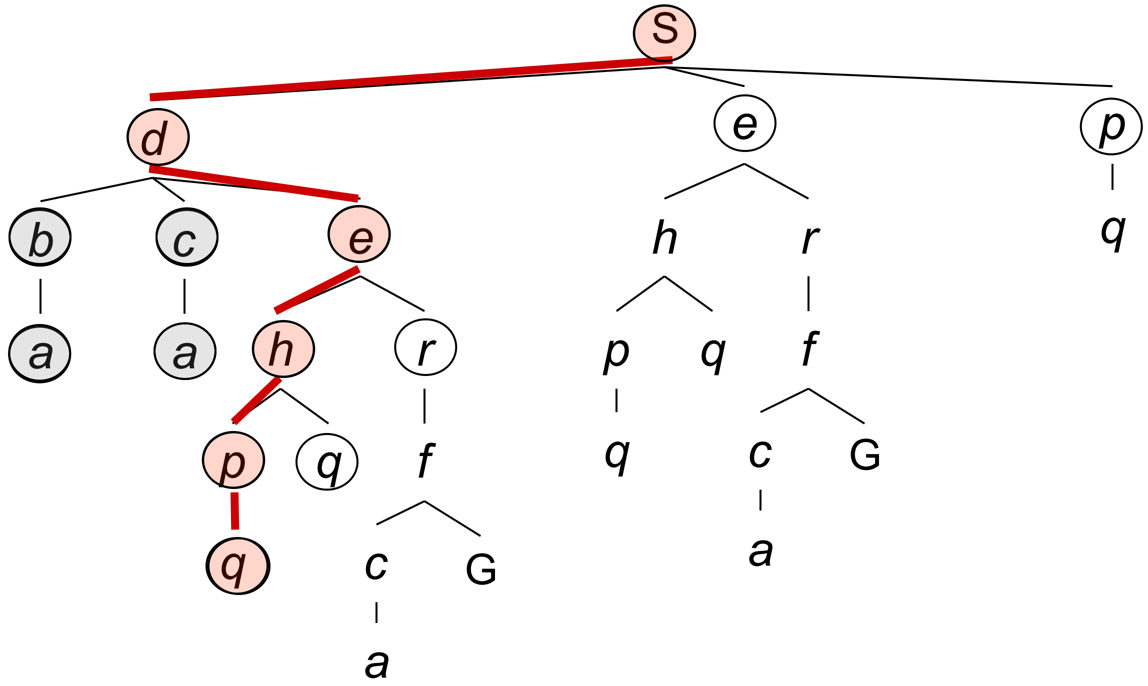

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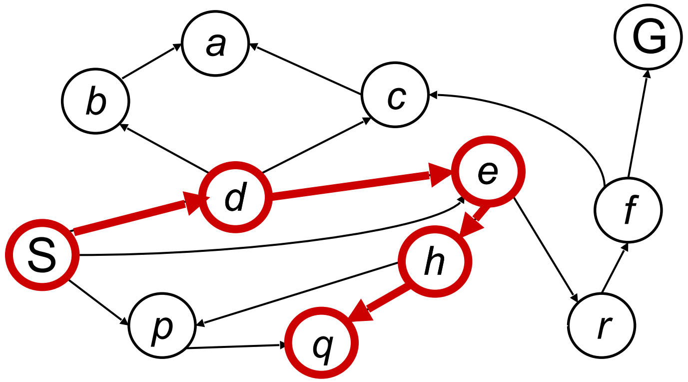

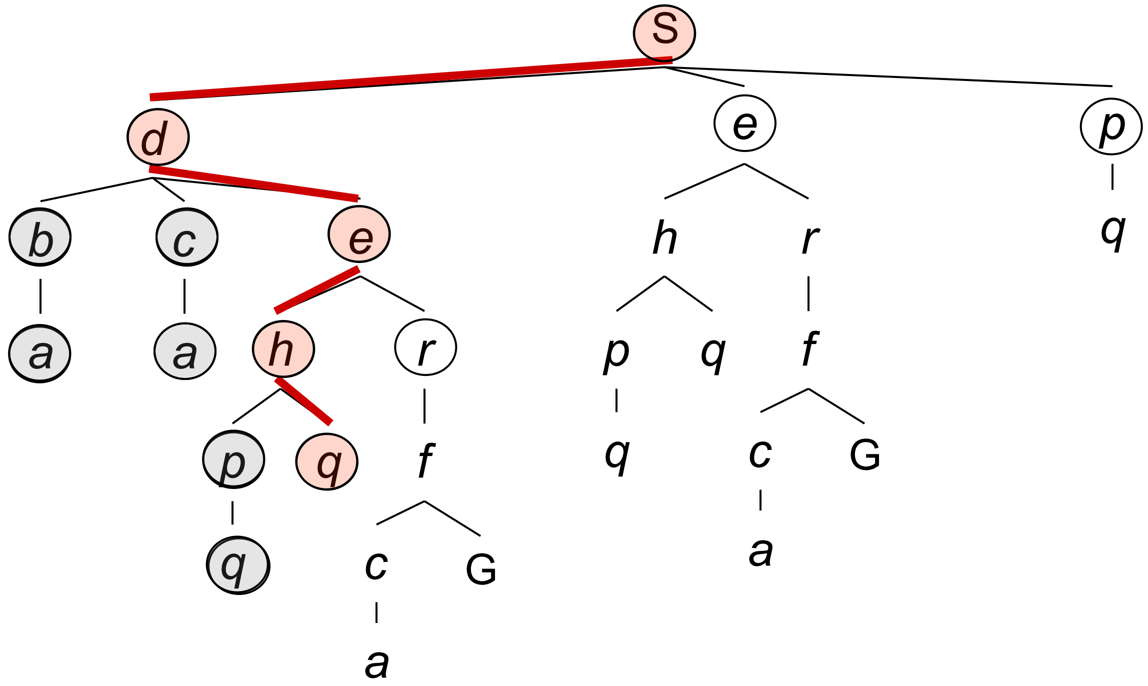

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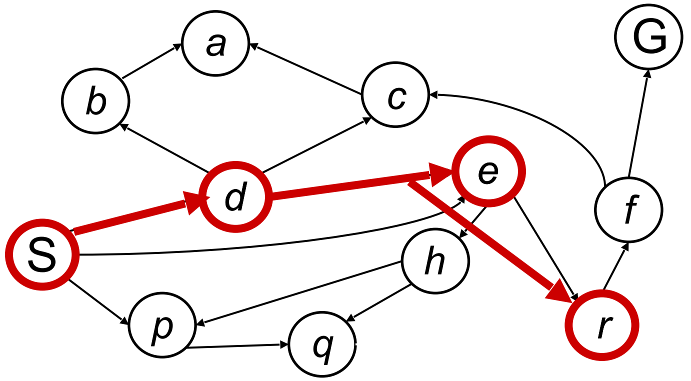

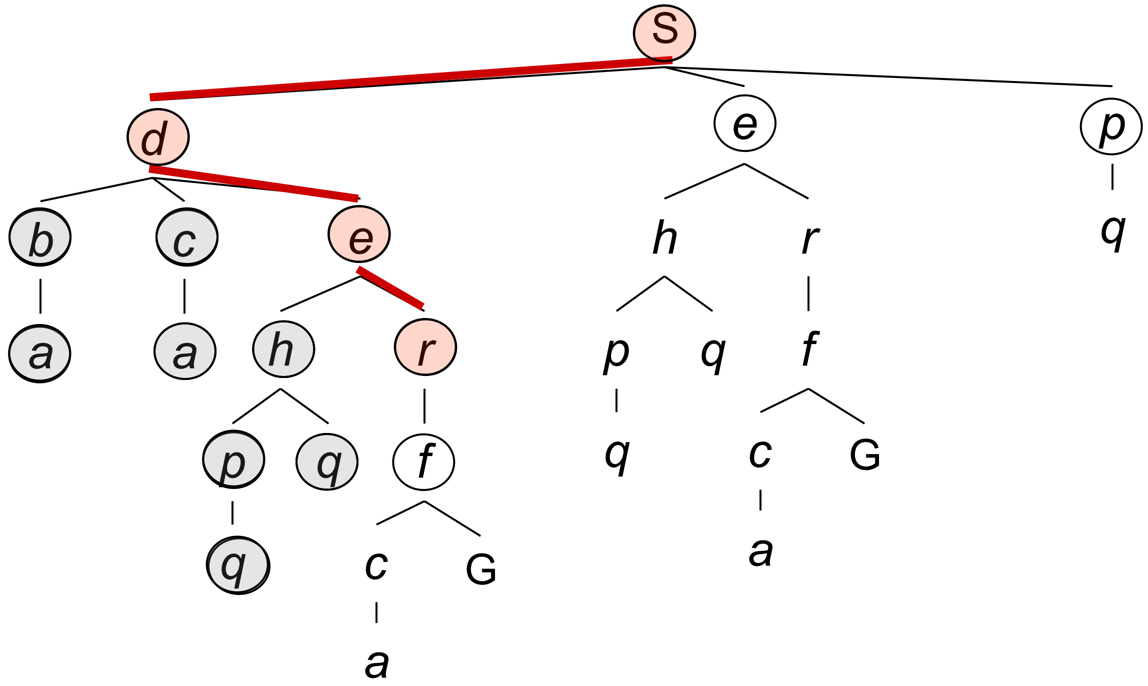

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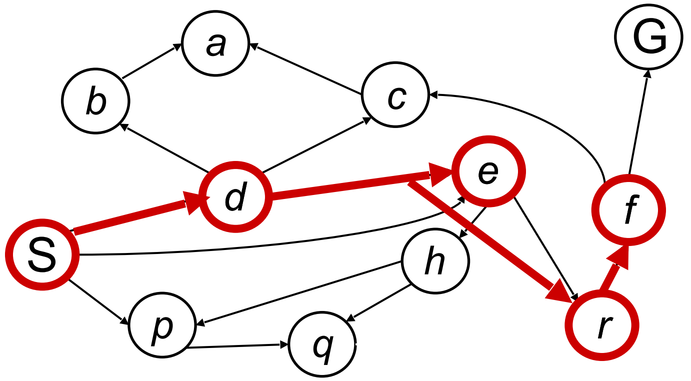

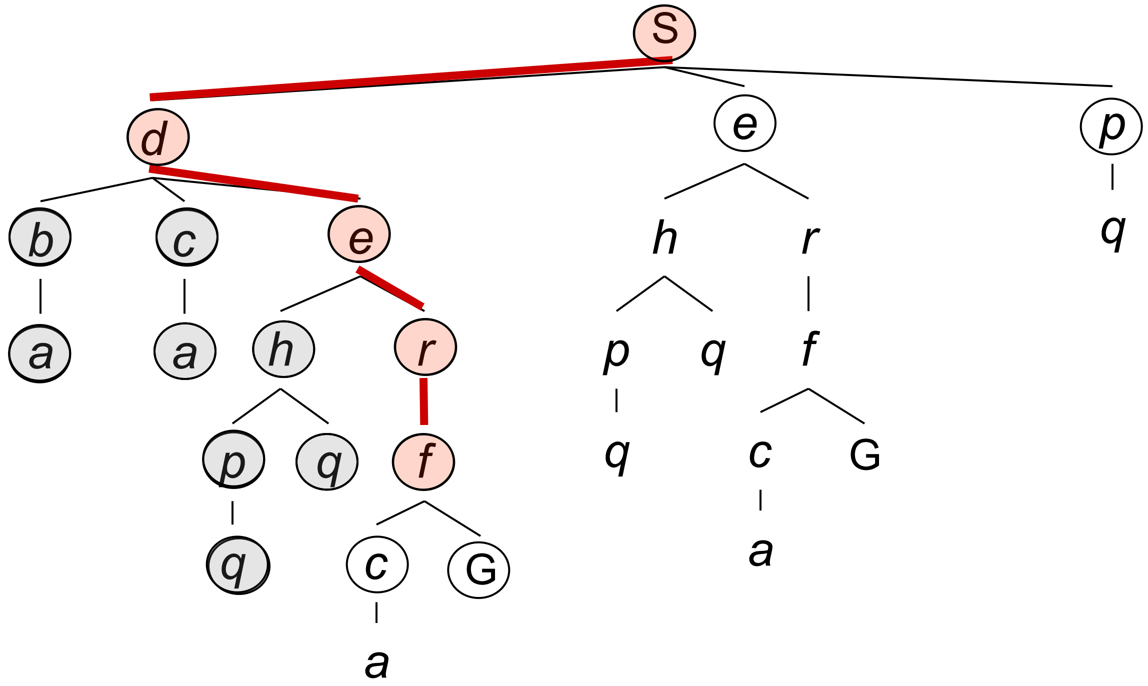

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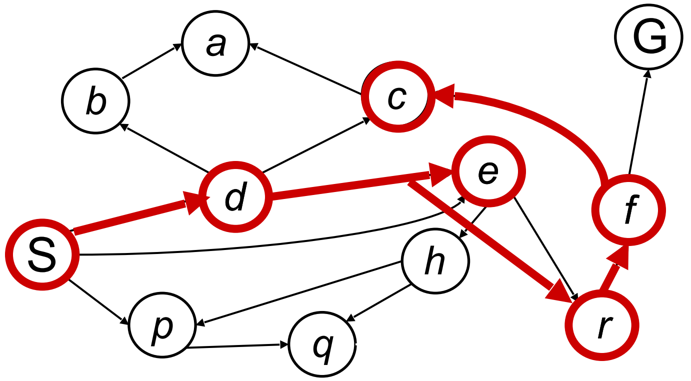

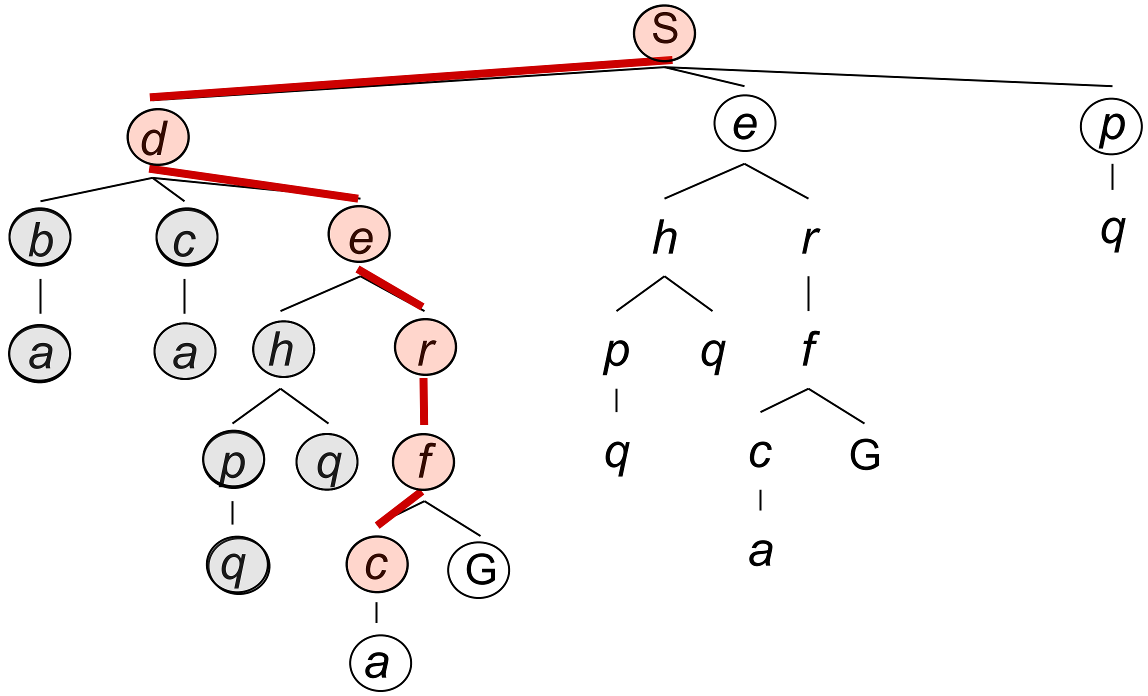

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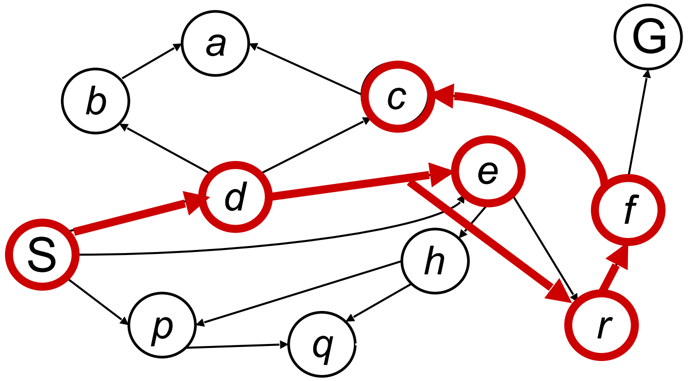

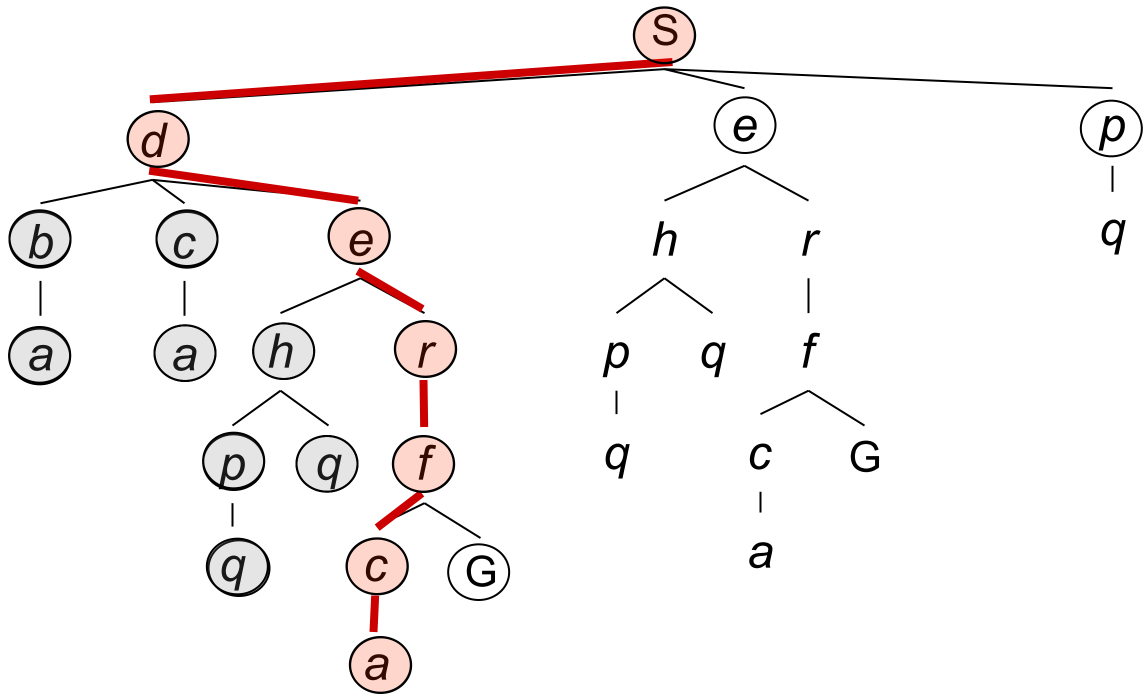

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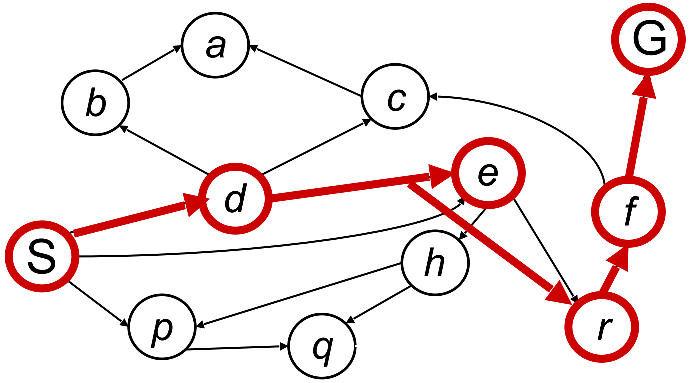
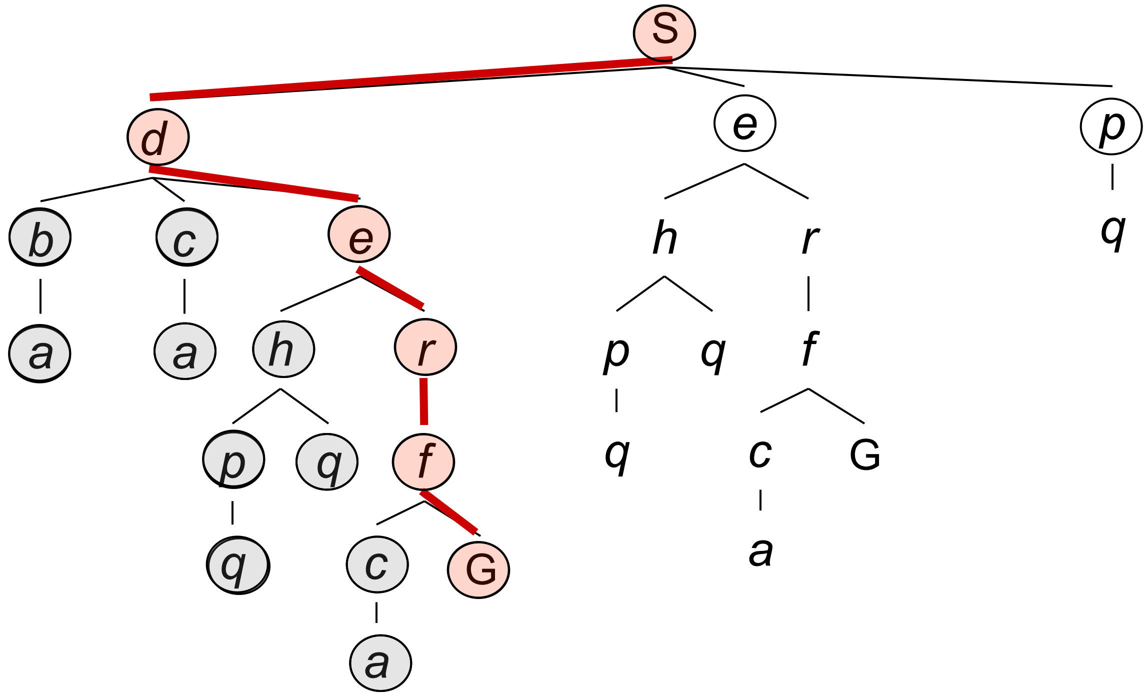
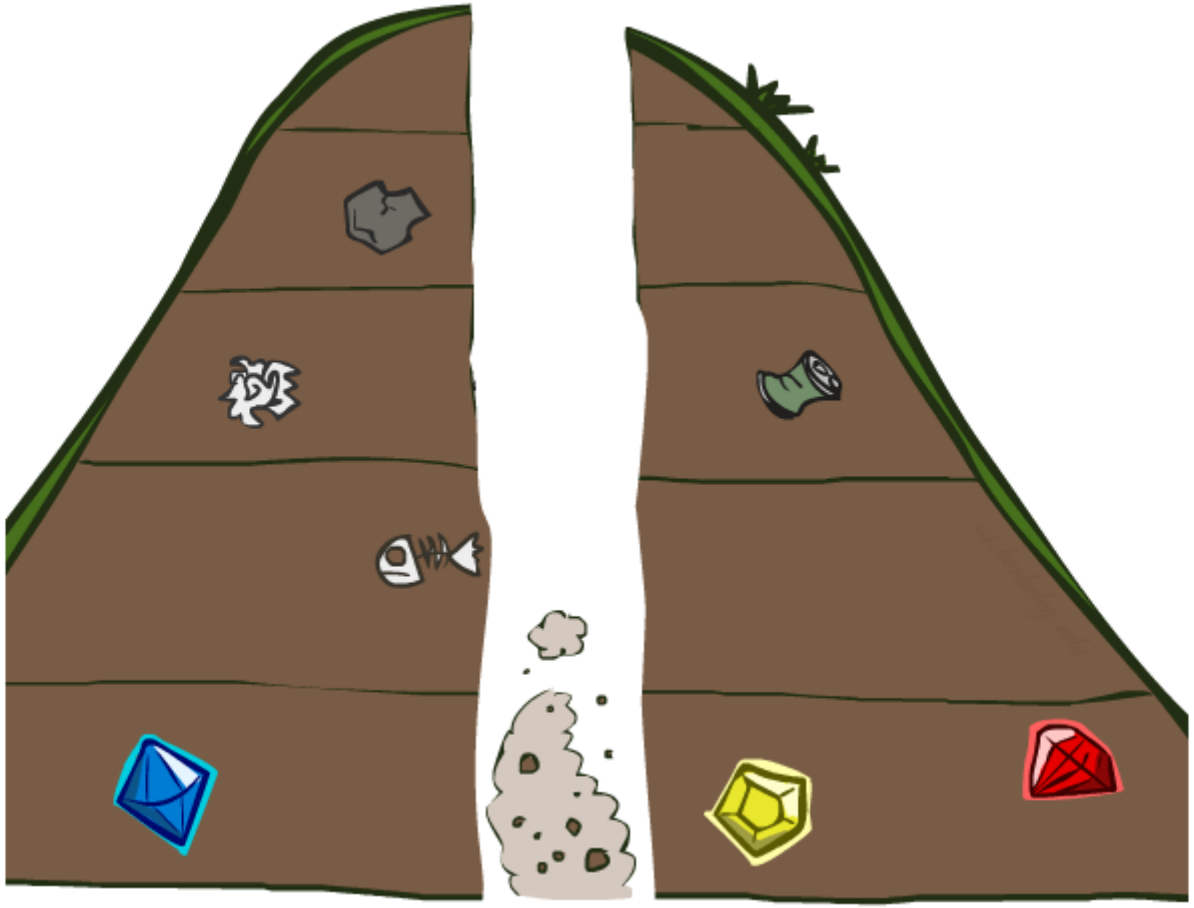




Search Algorithm Properties



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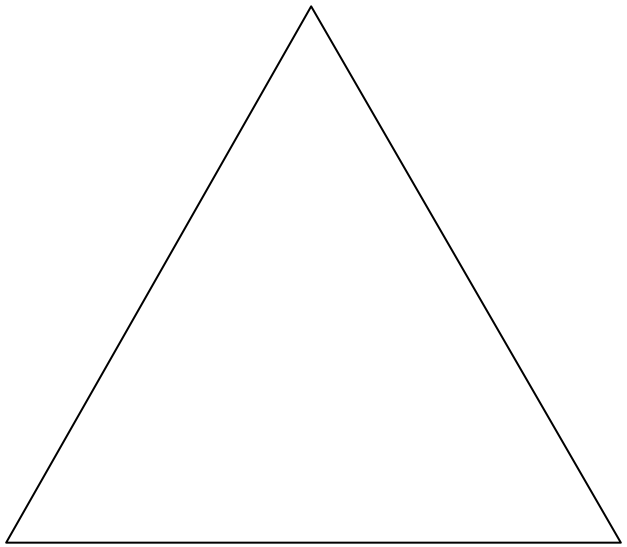

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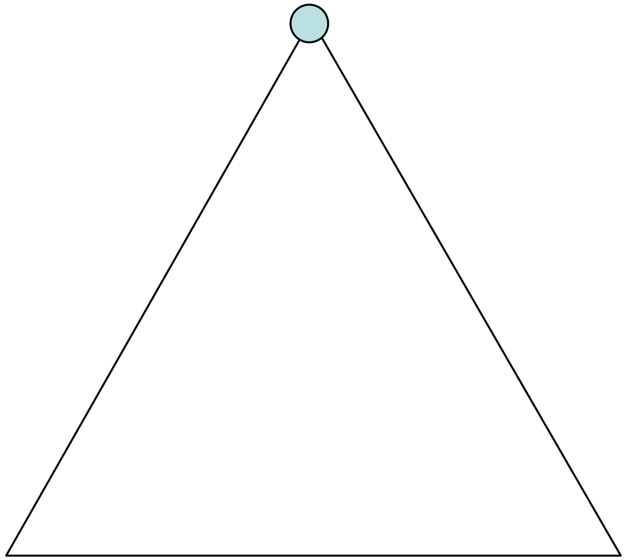

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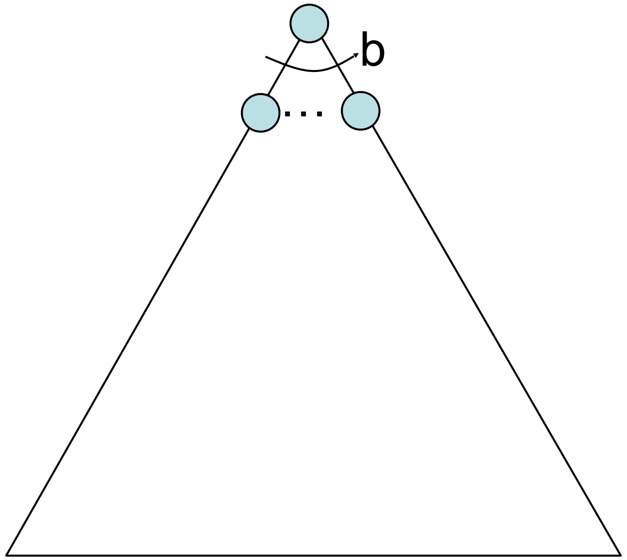

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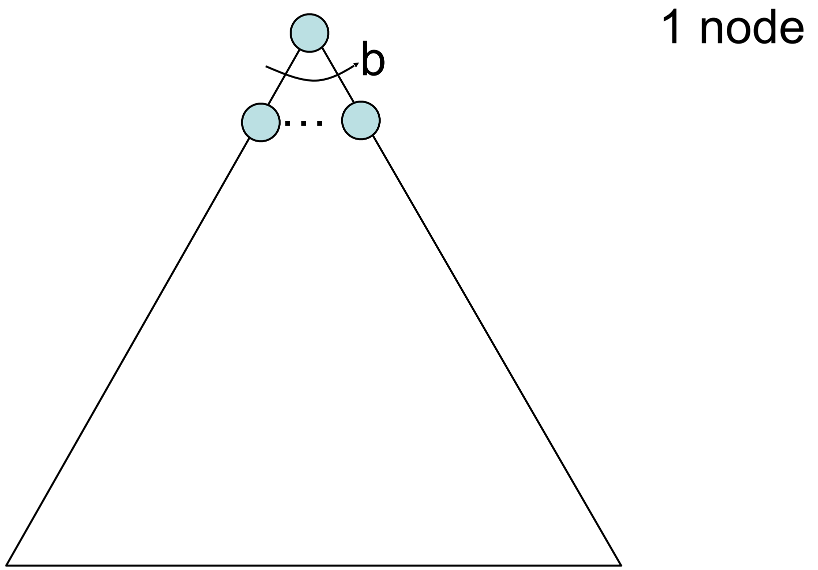

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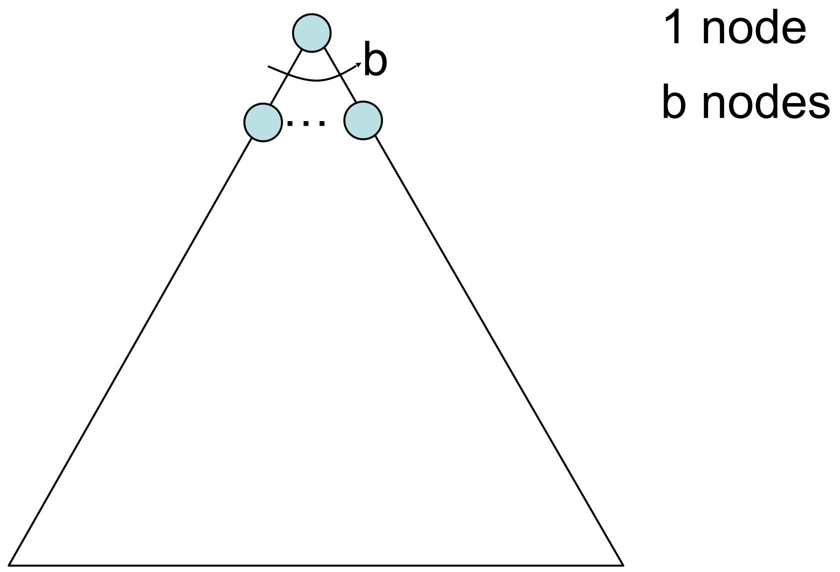

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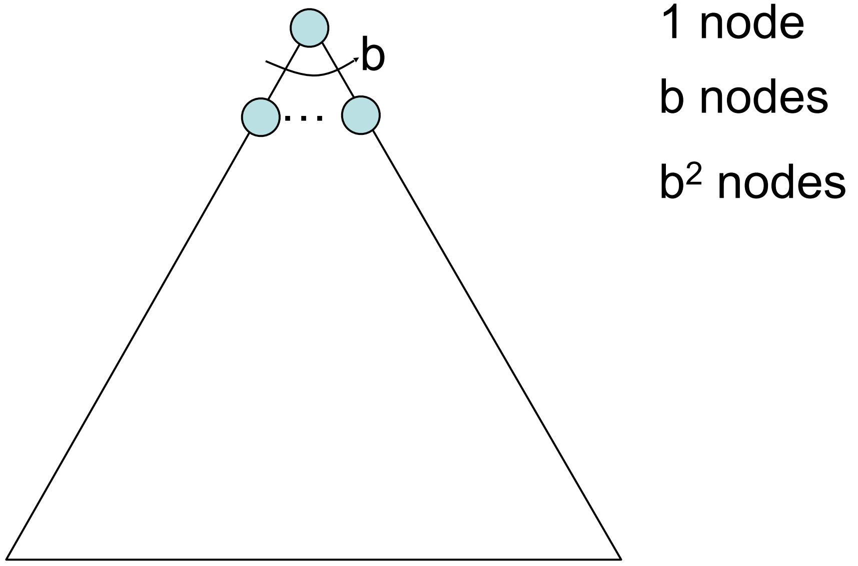

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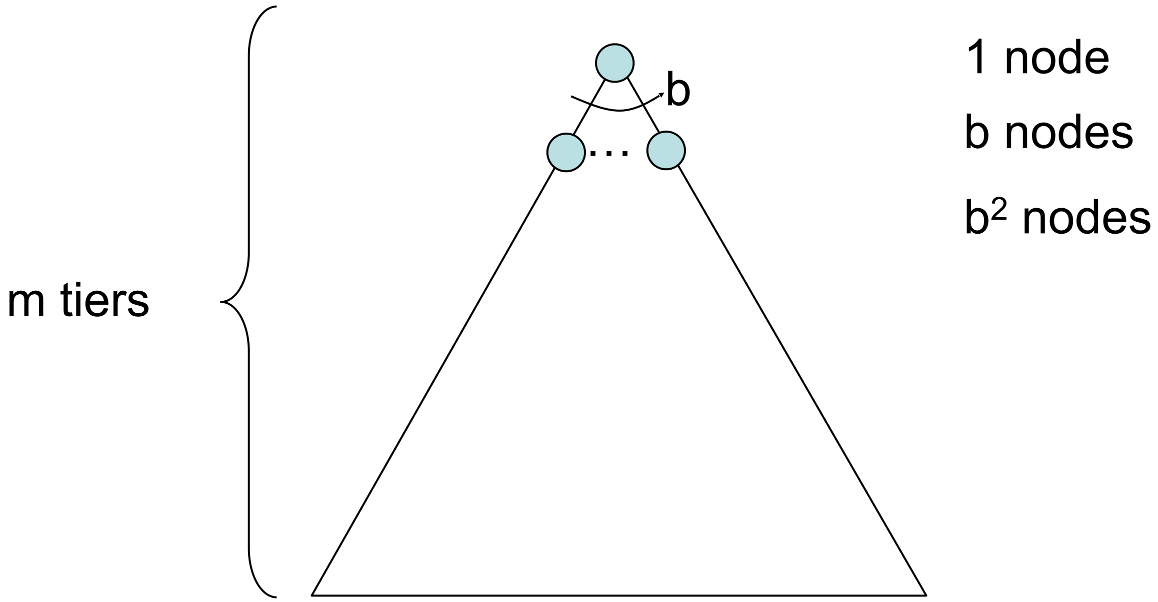

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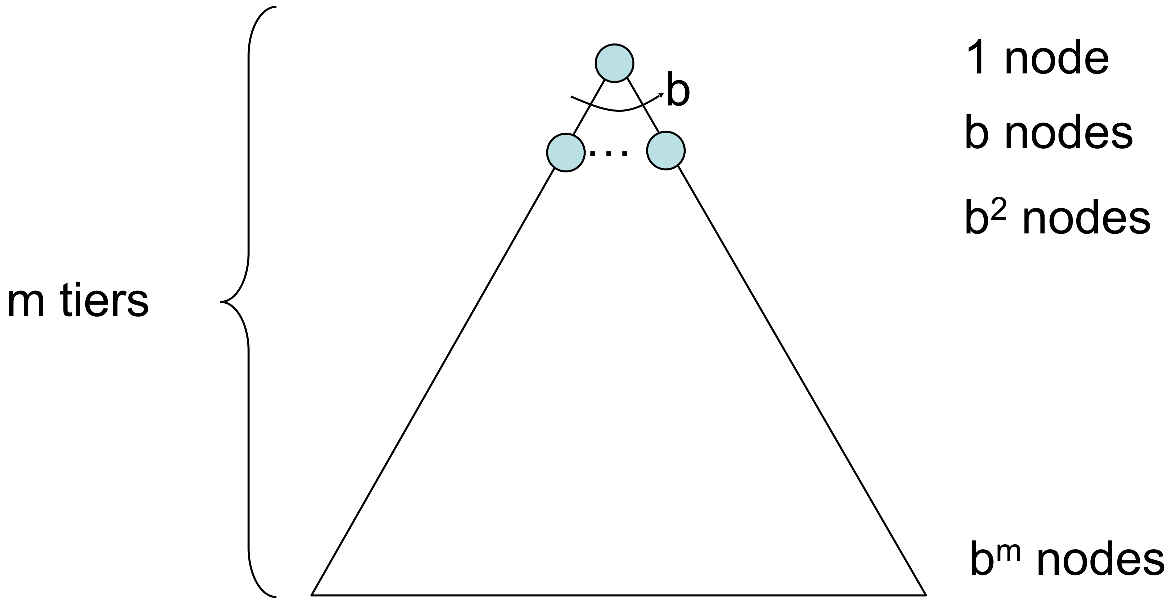

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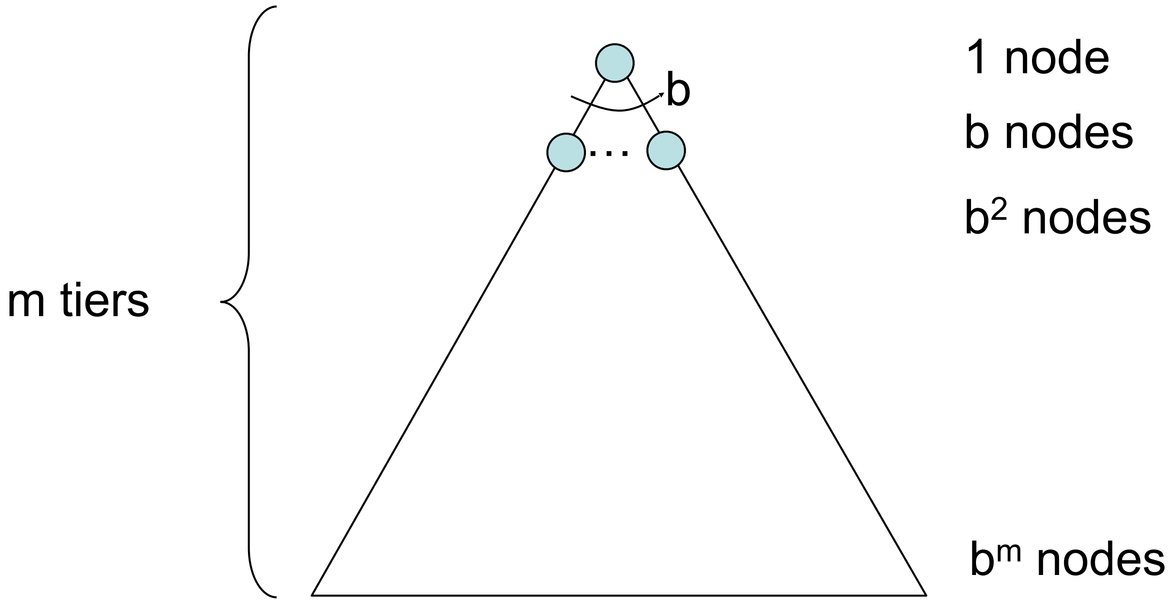

Search Algorithm Properties

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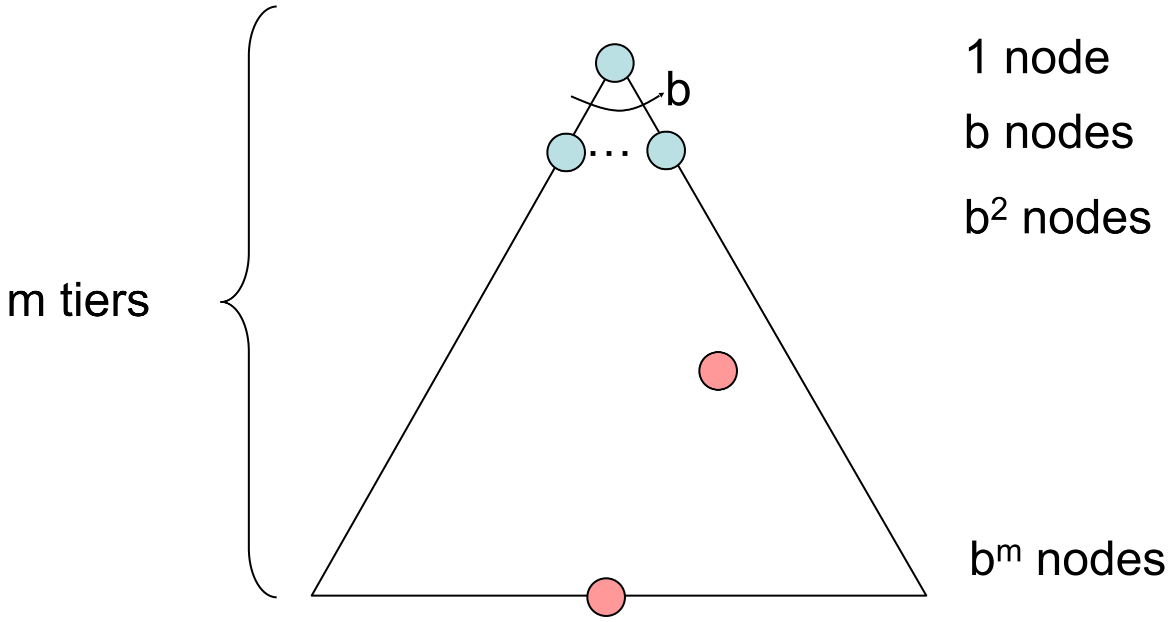

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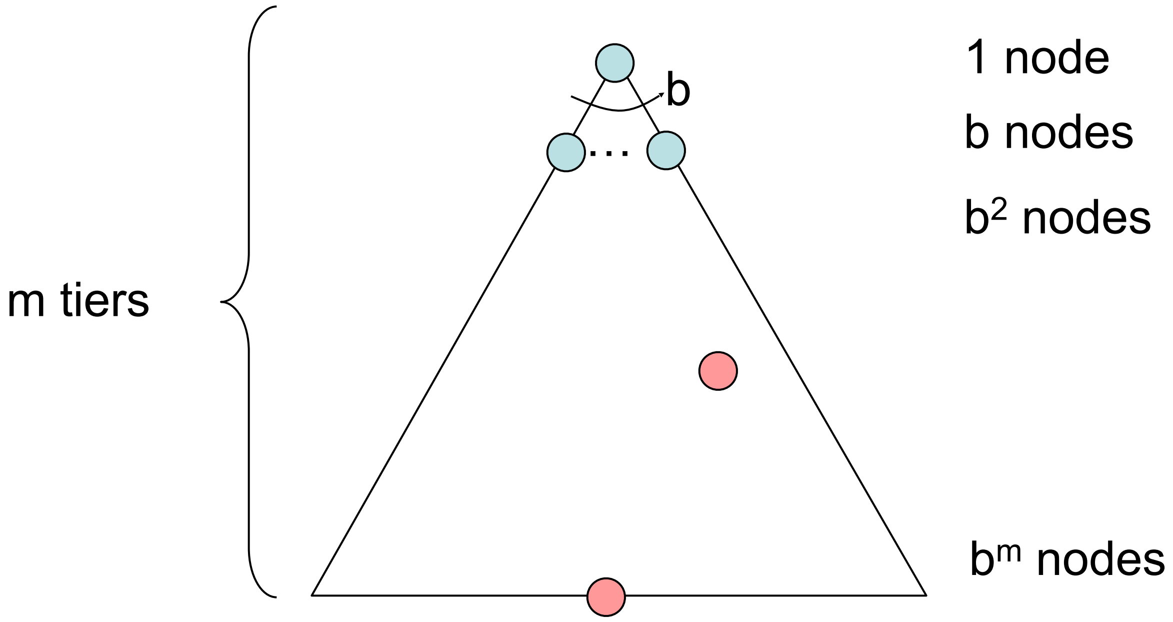

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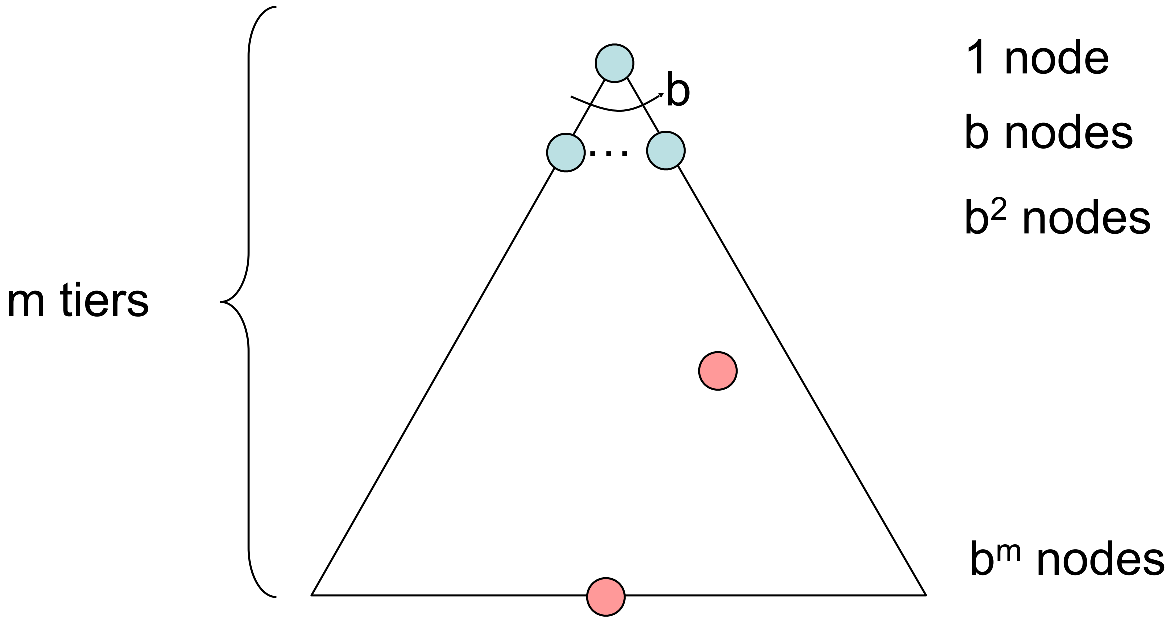
  - $1 + b + b^2 + ... b^m = O(b^m)$



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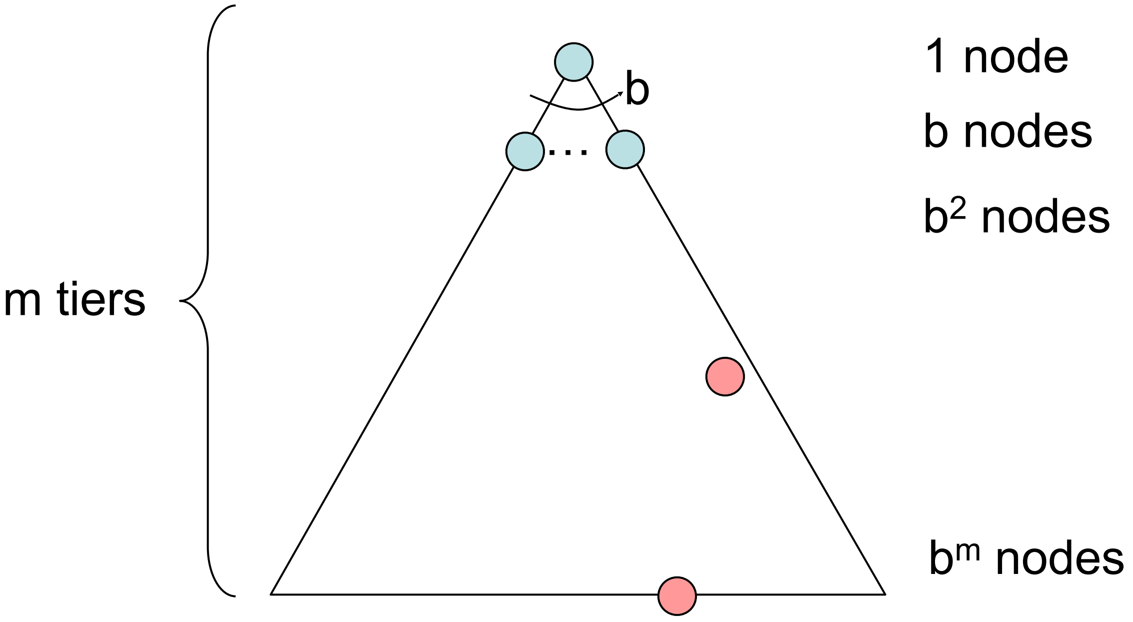

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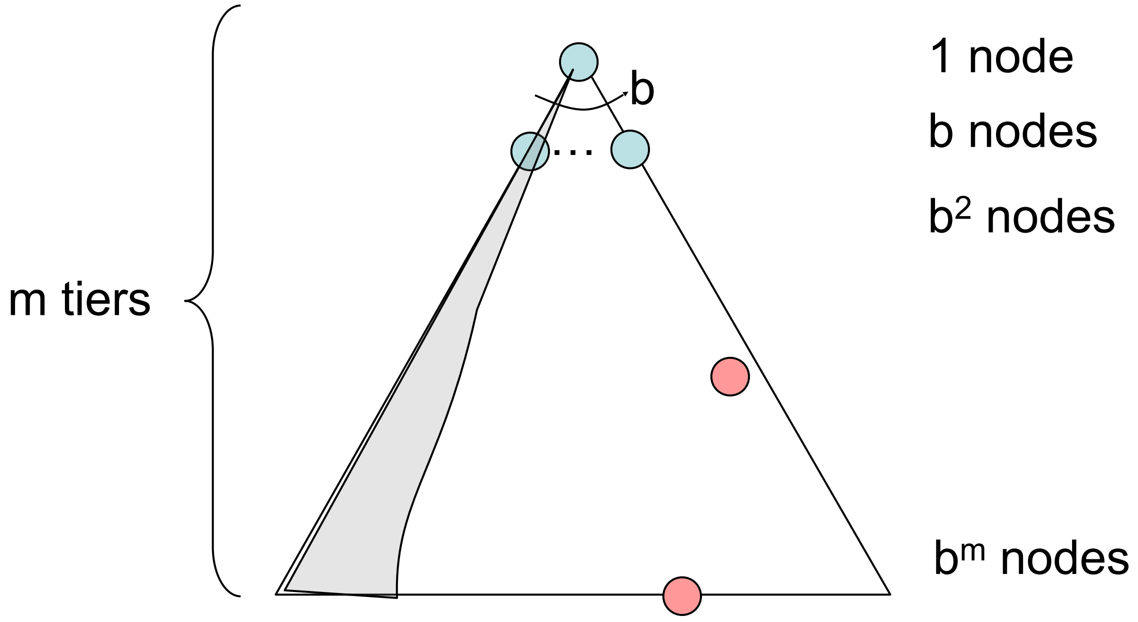

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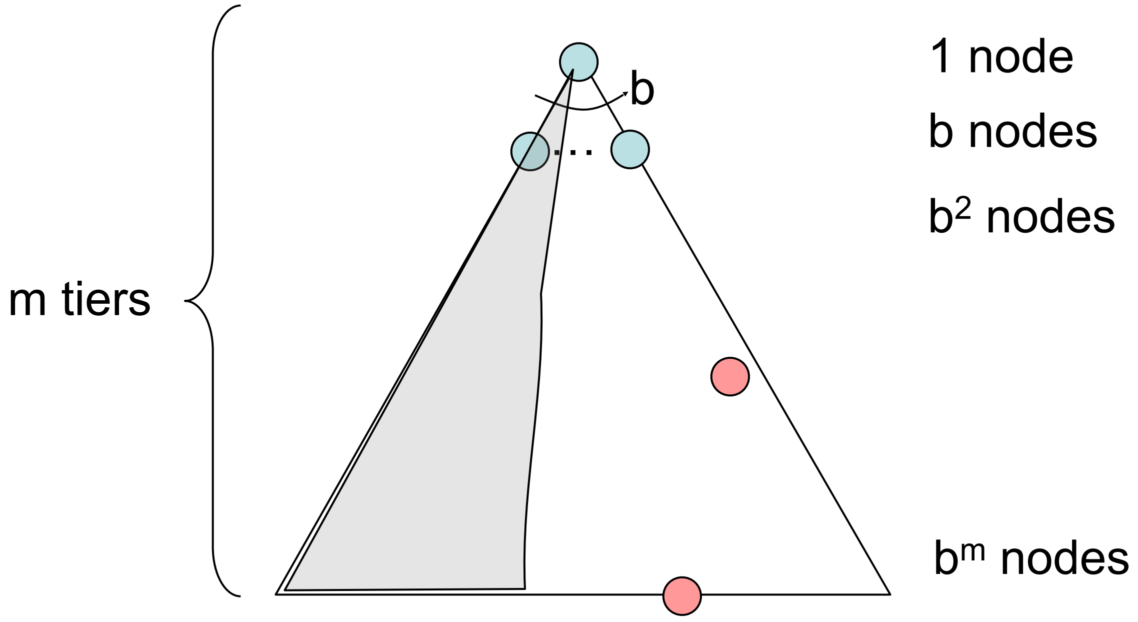

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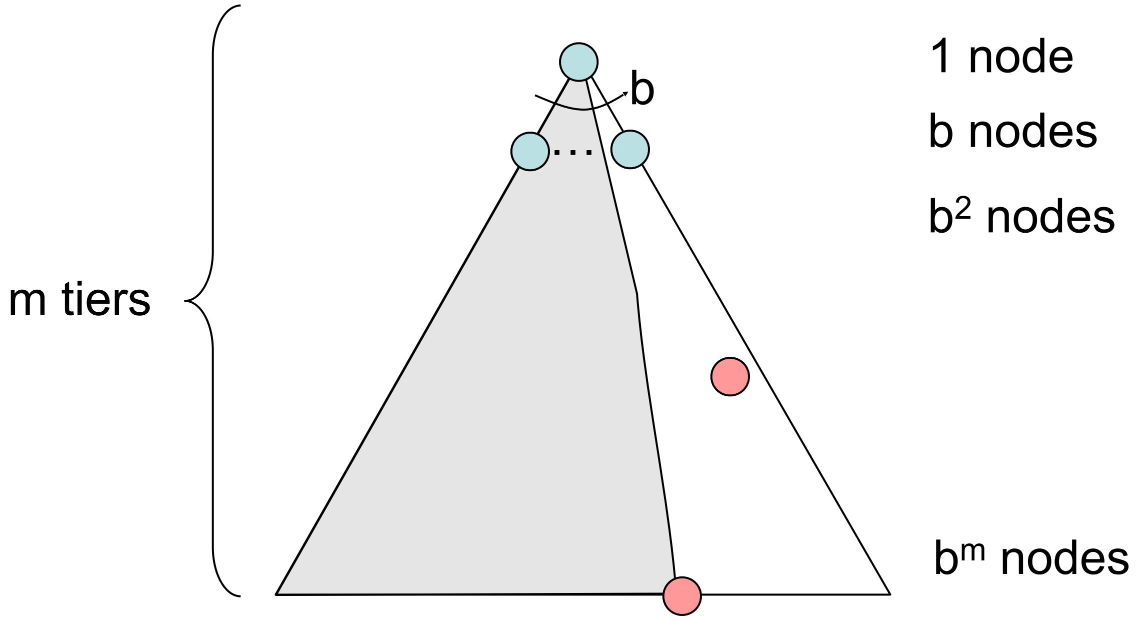

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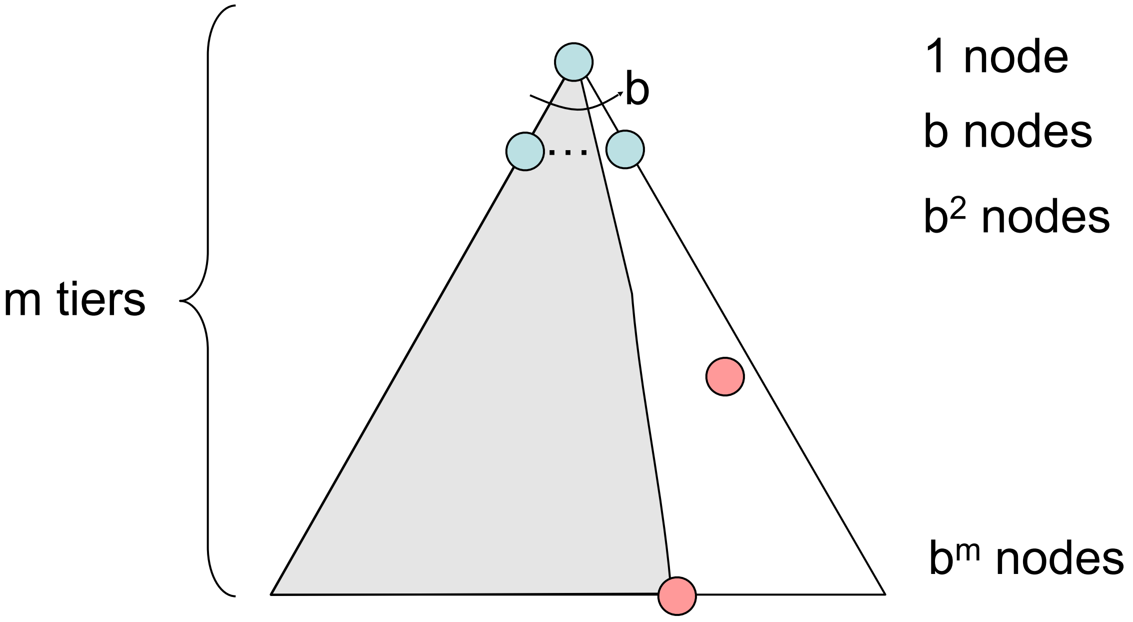

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- What nodes DFS expand?
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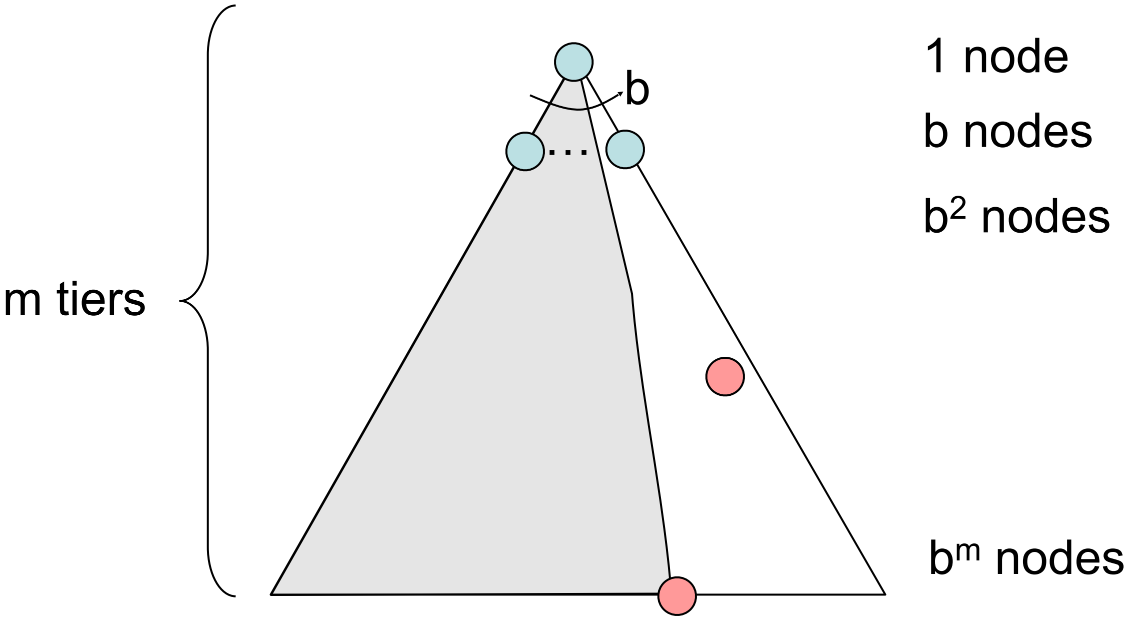

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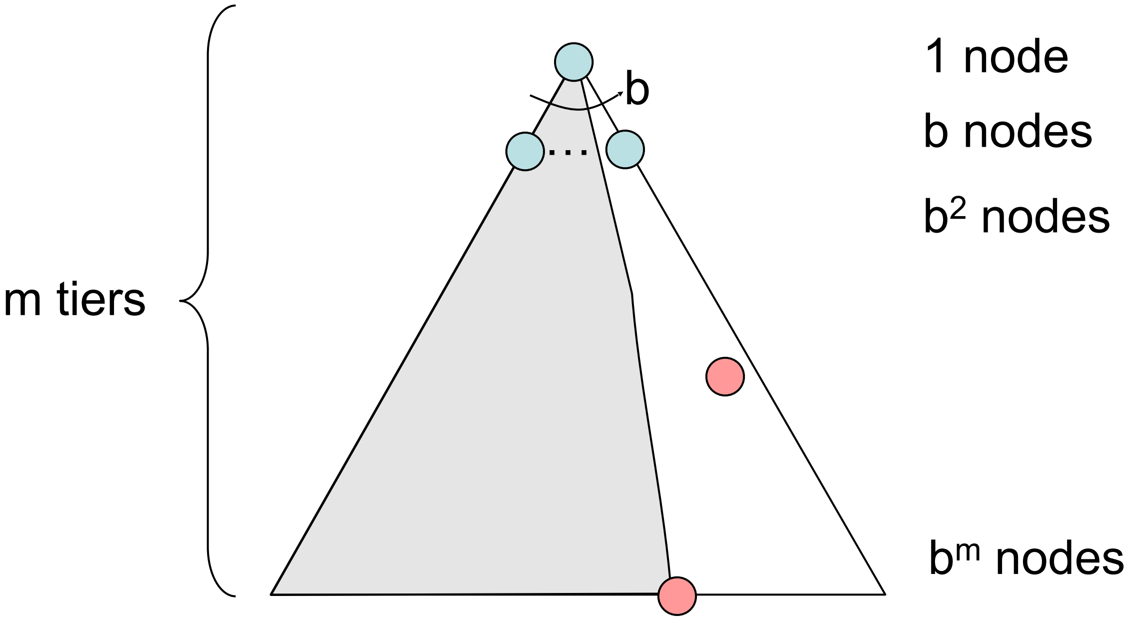

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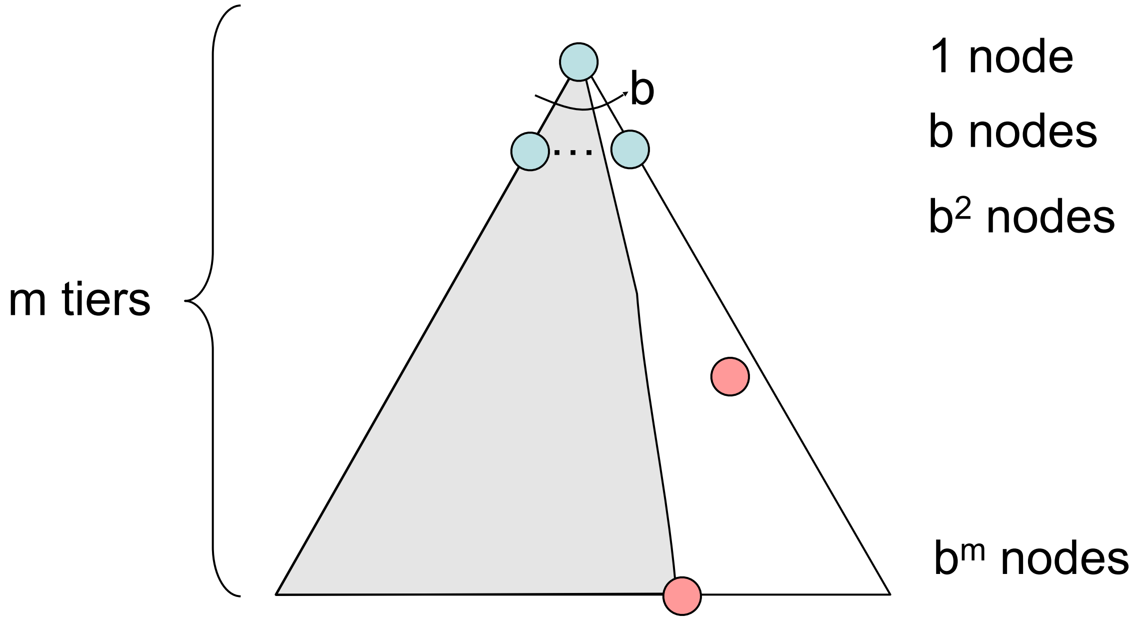

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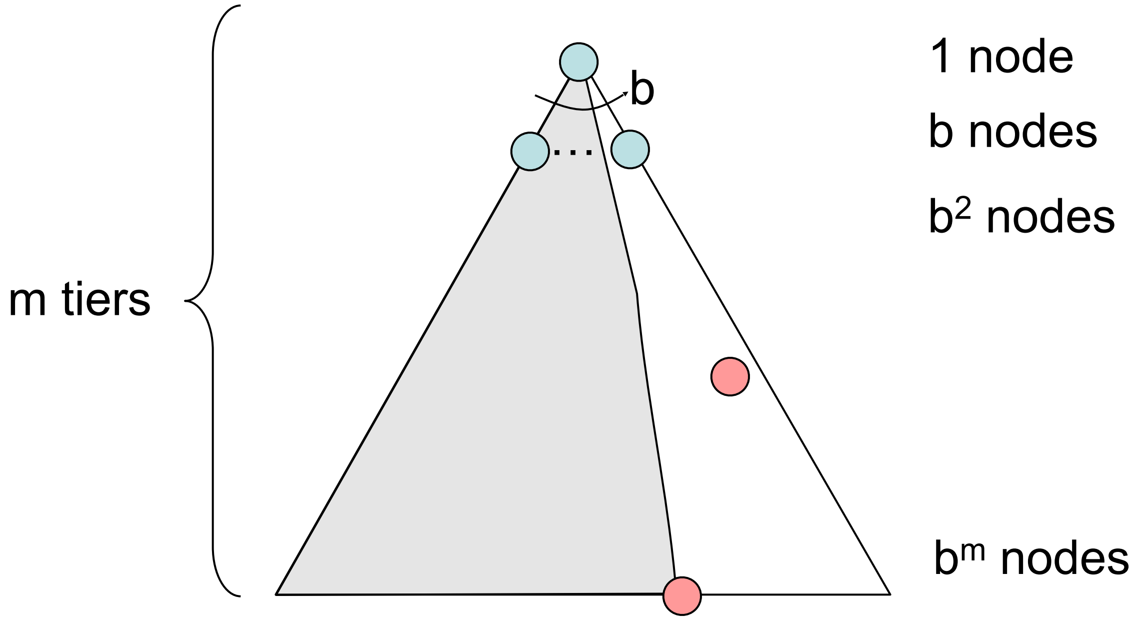

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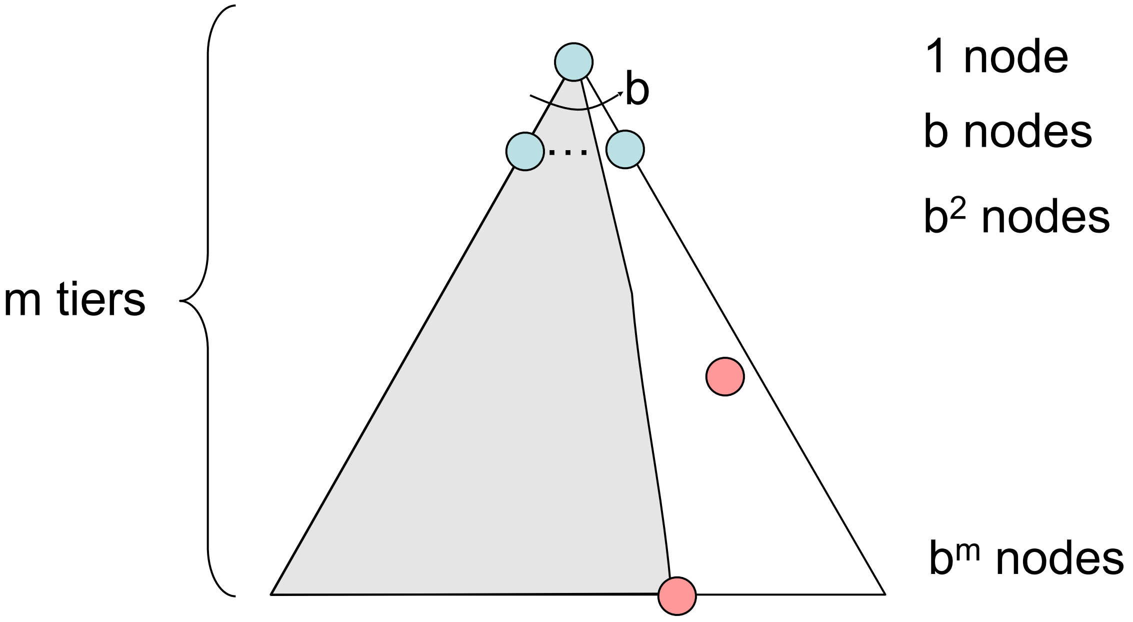

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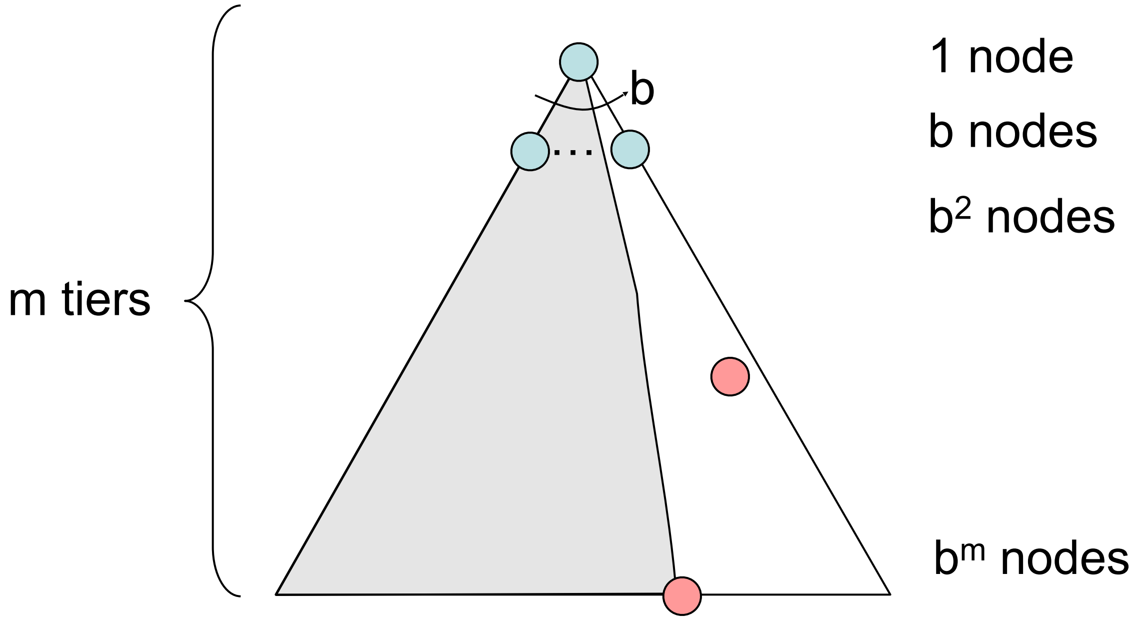

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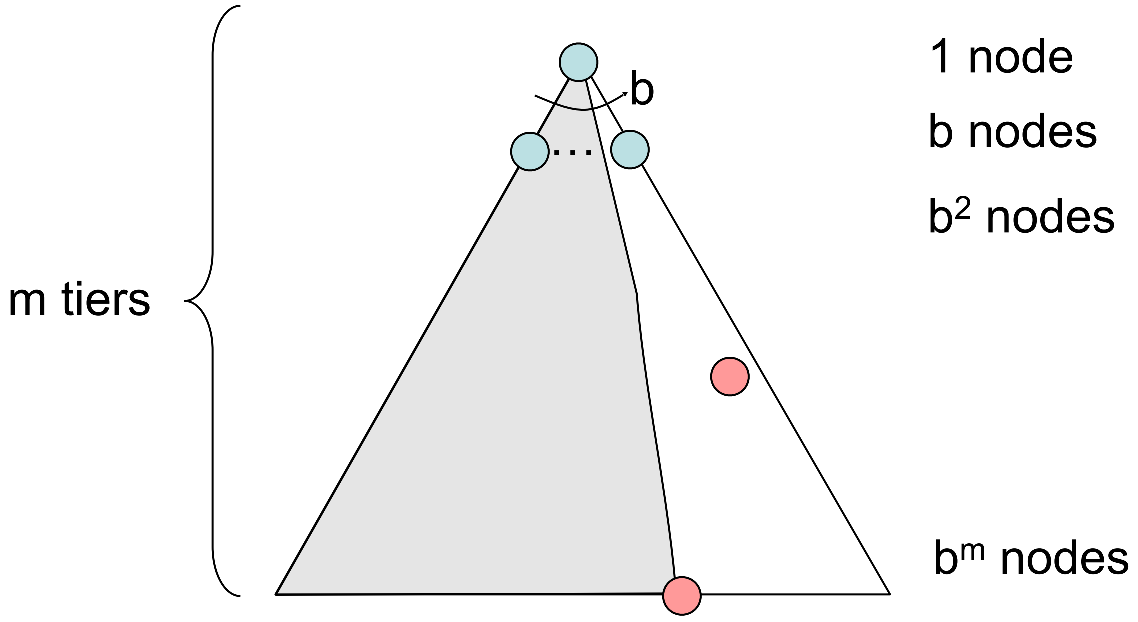

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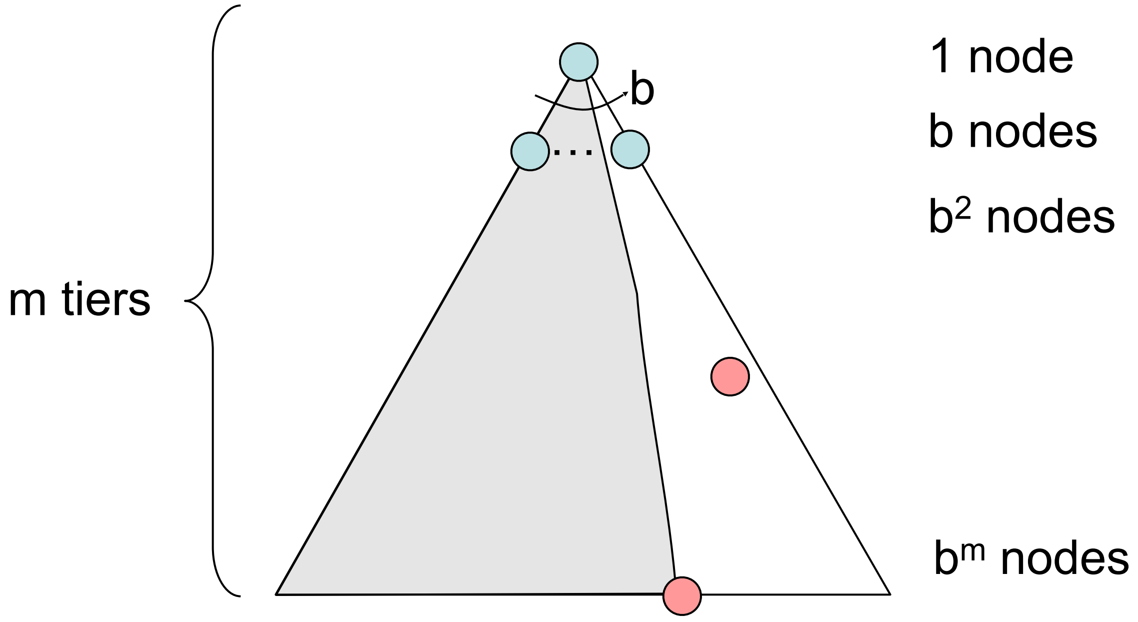
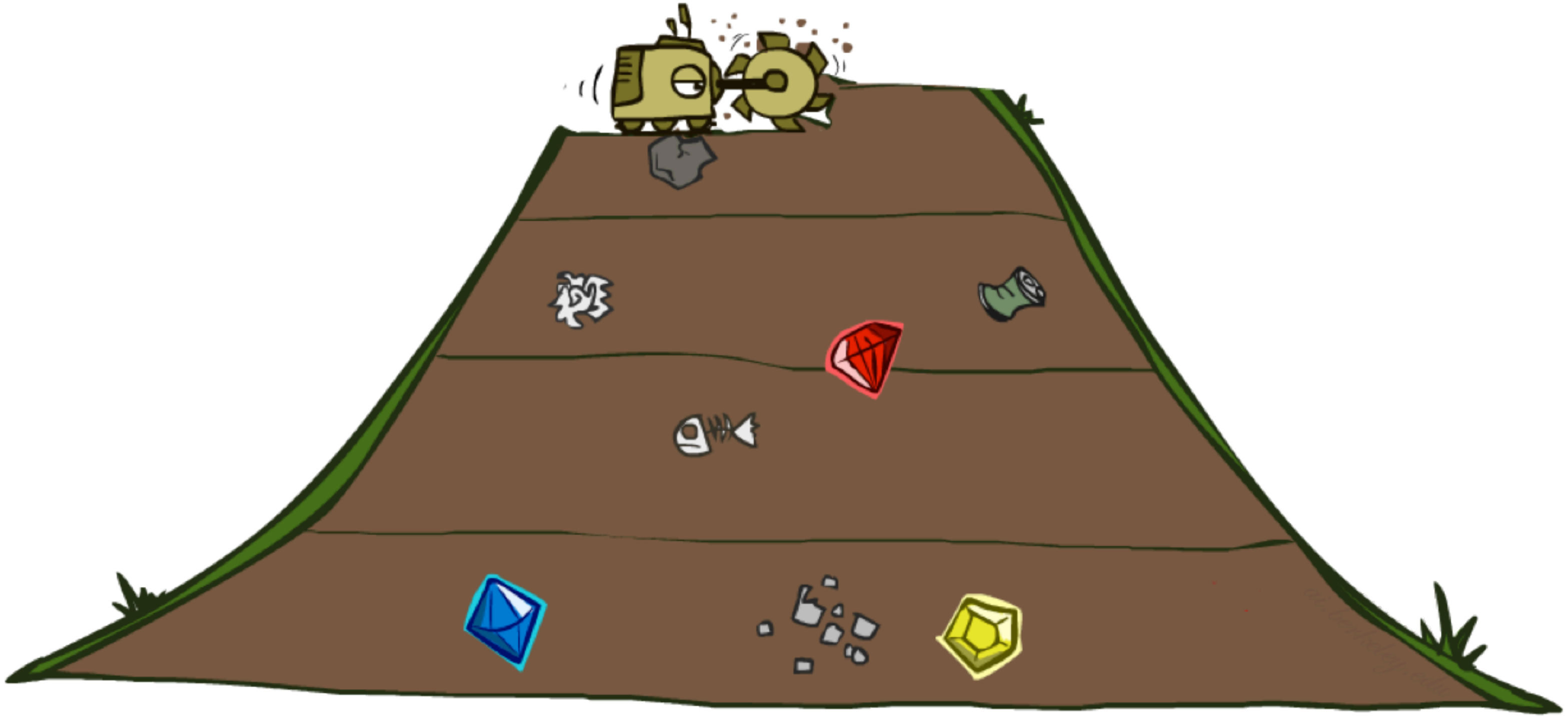
- Is it optimal?
  - No, it finds the "leftmost" solution, regardless of depth or cost



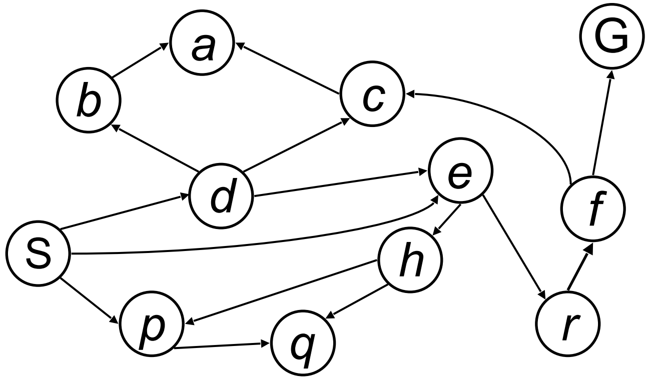
Breadth-First Search

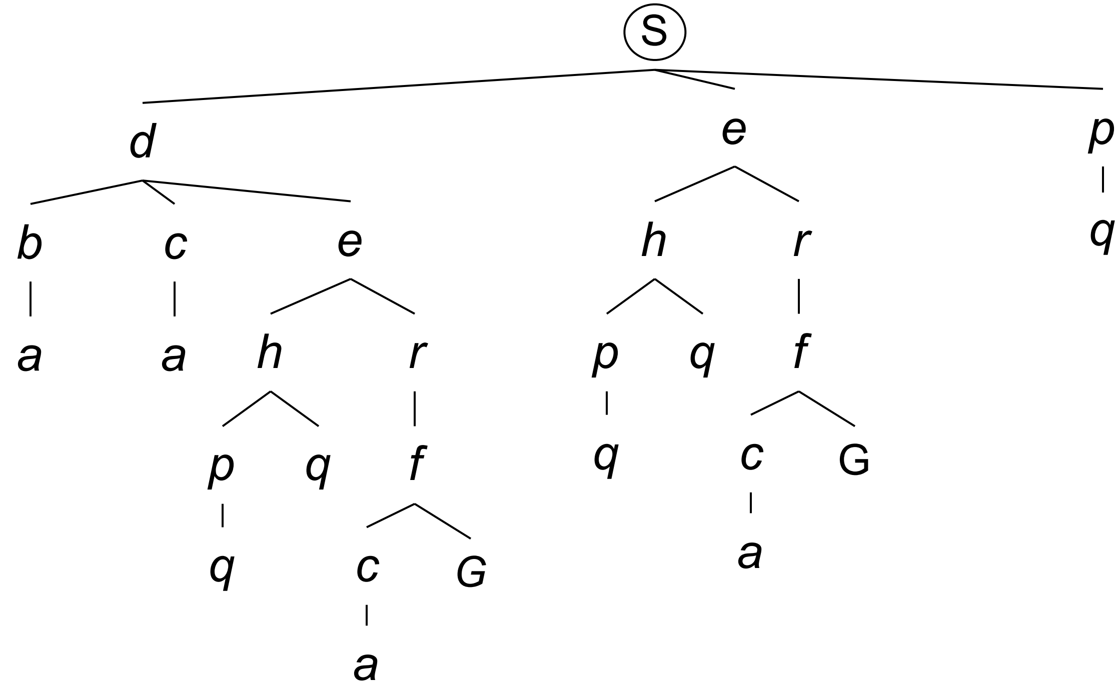


Breadth-First Search

Strategy: expand a shallowest node first

Implementation: Fringe is a FIFO queue





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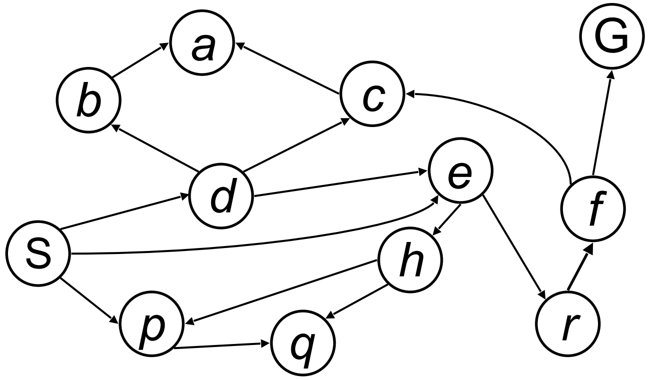

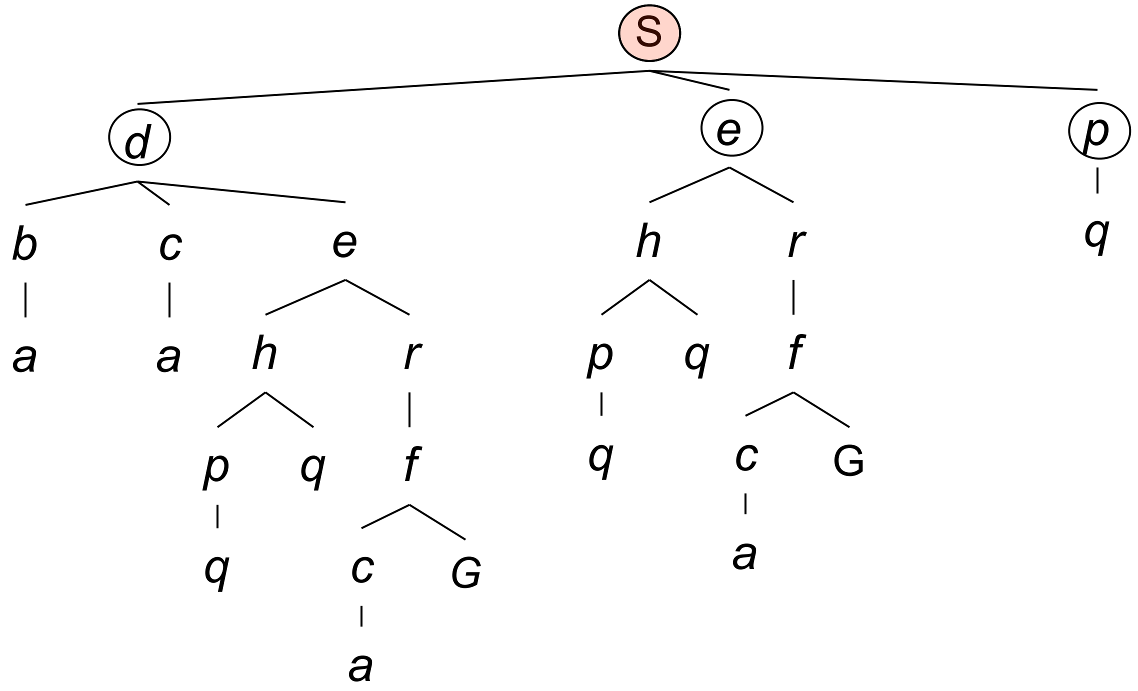

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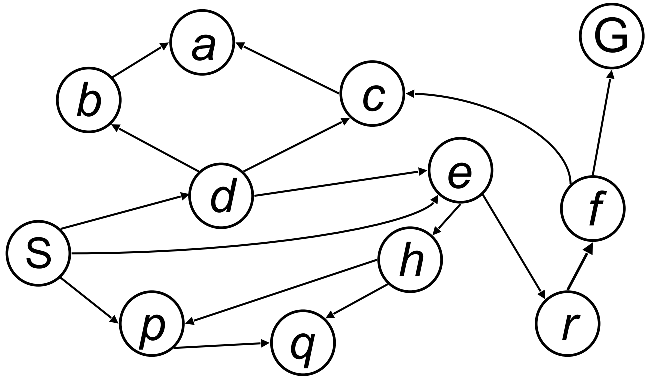

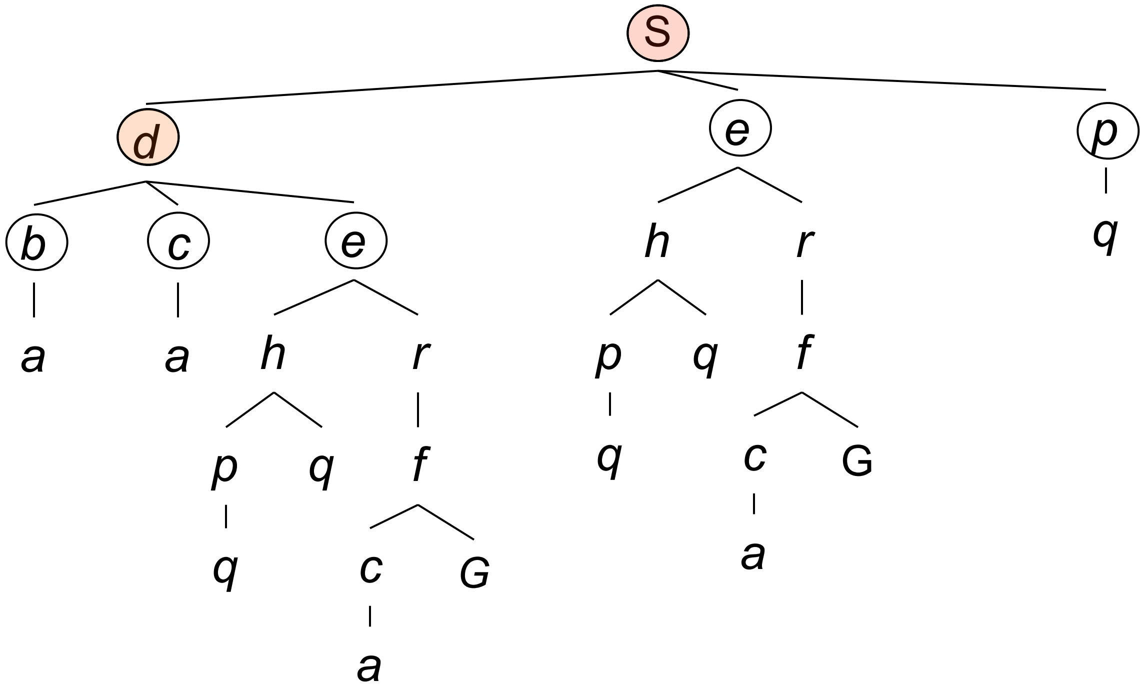

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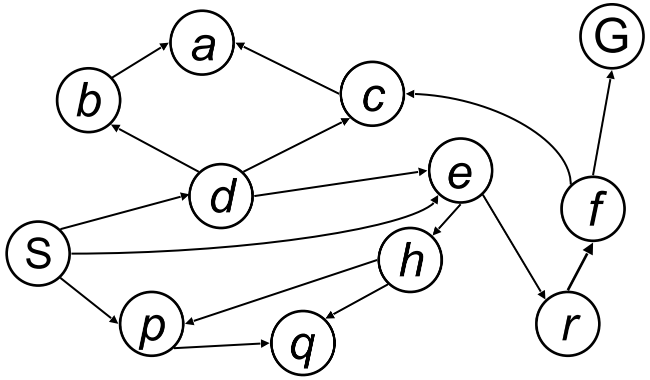

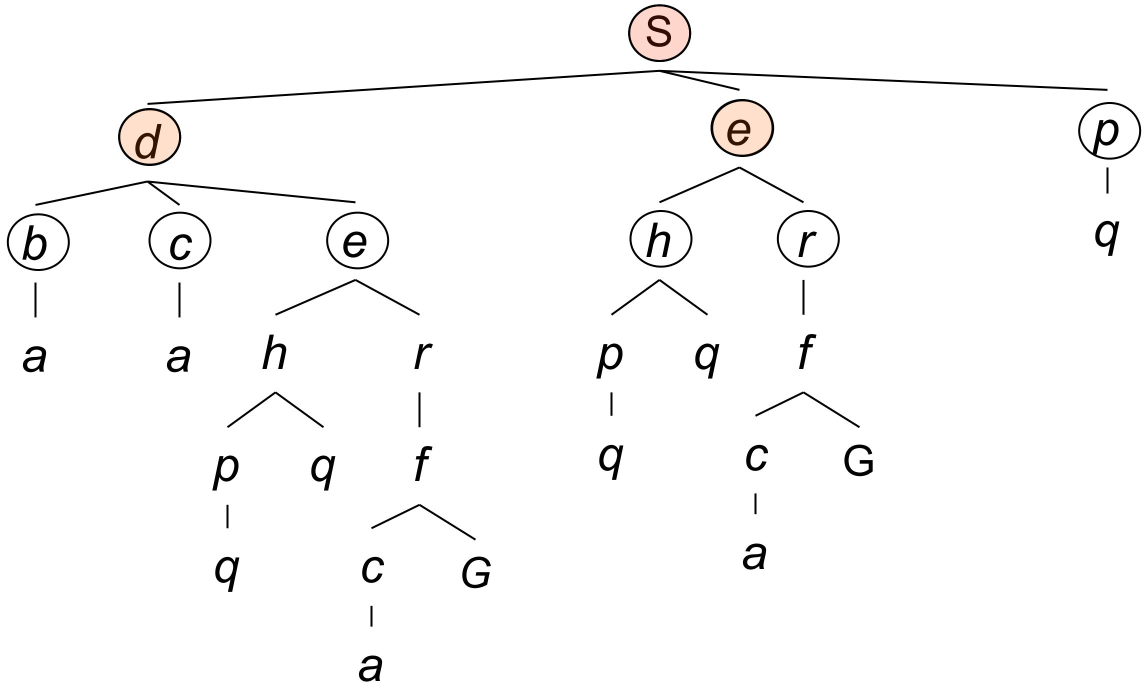

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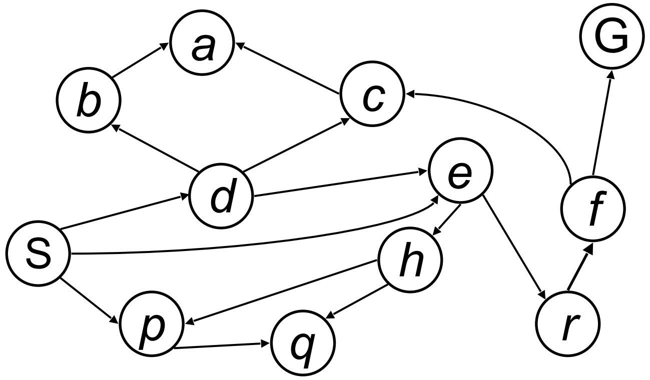

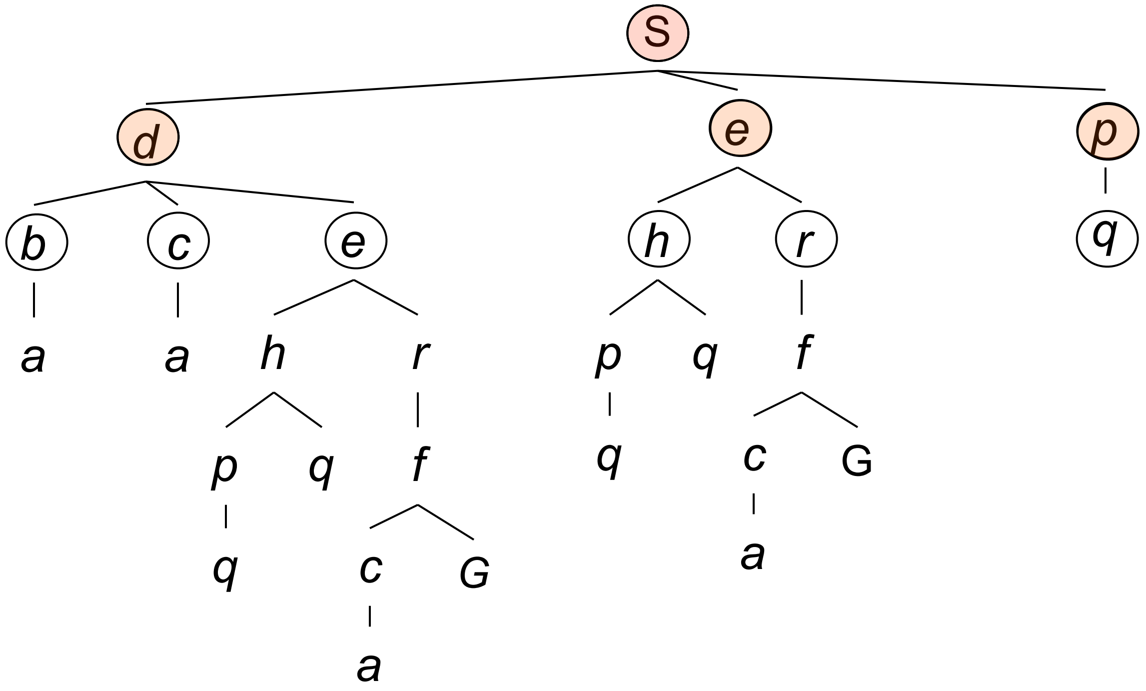

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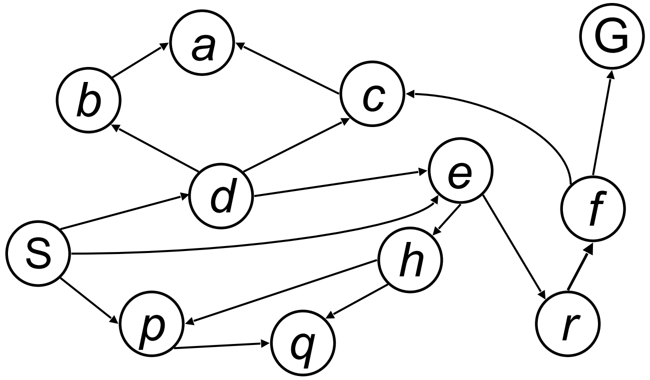

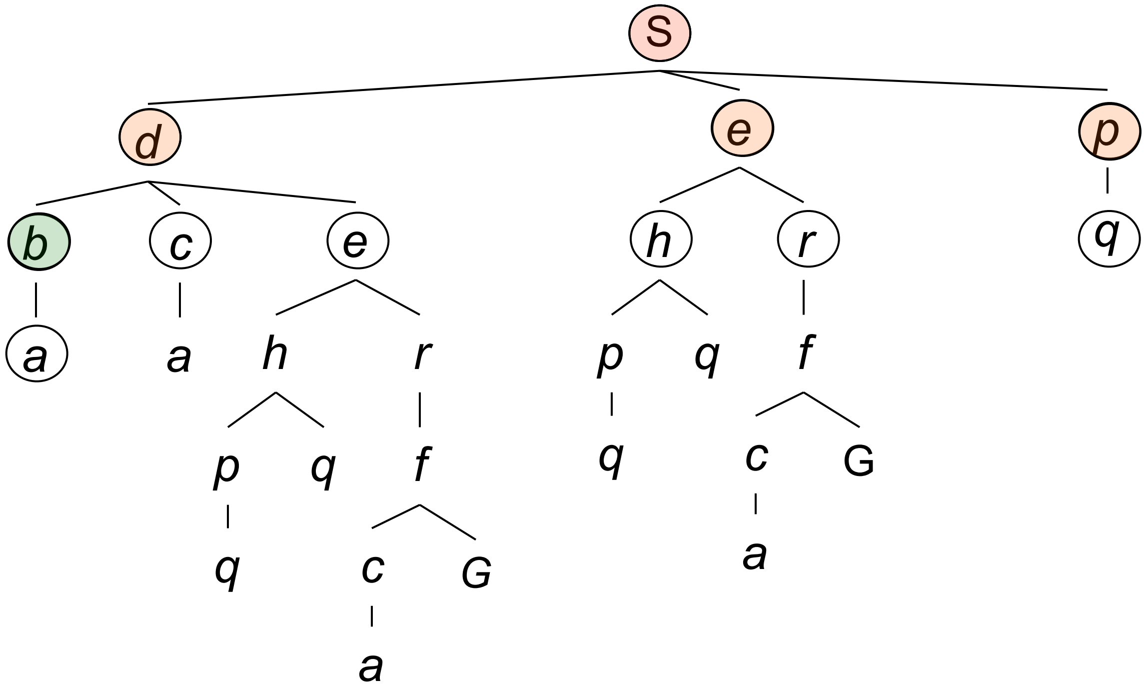

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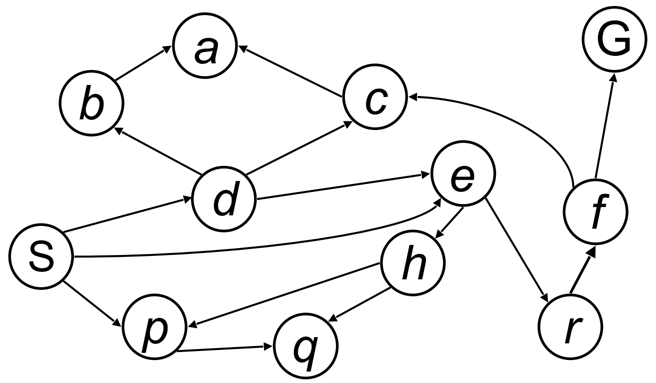
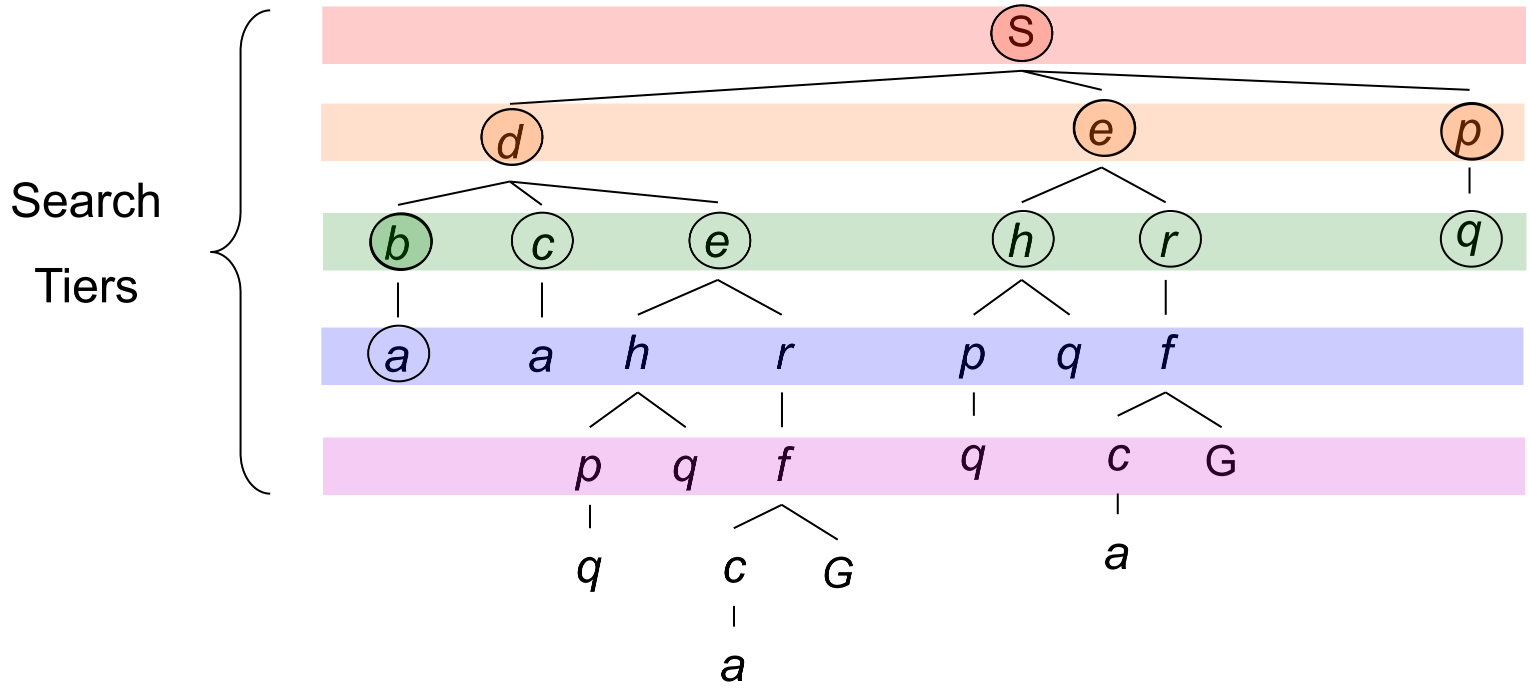
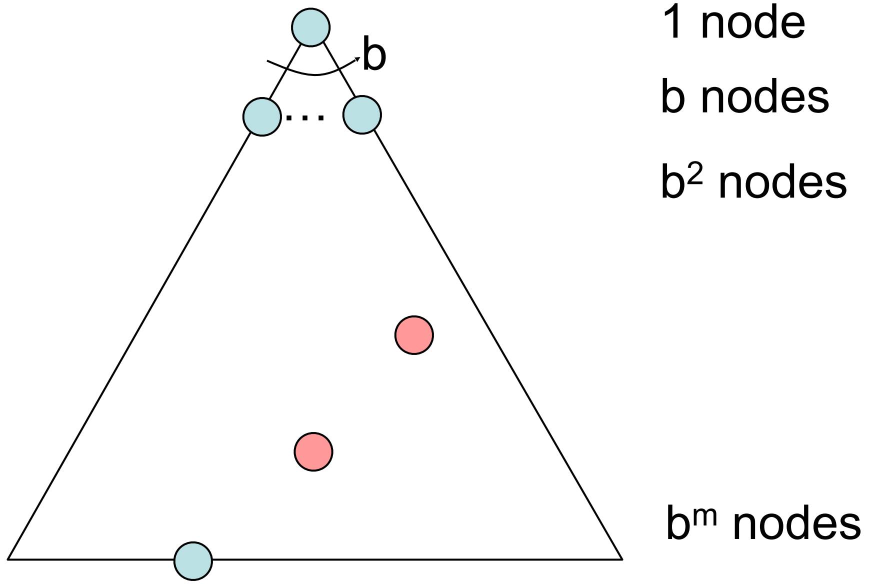




Breadth-First Search (BFS) Properties

- What nodes does BFS expand?



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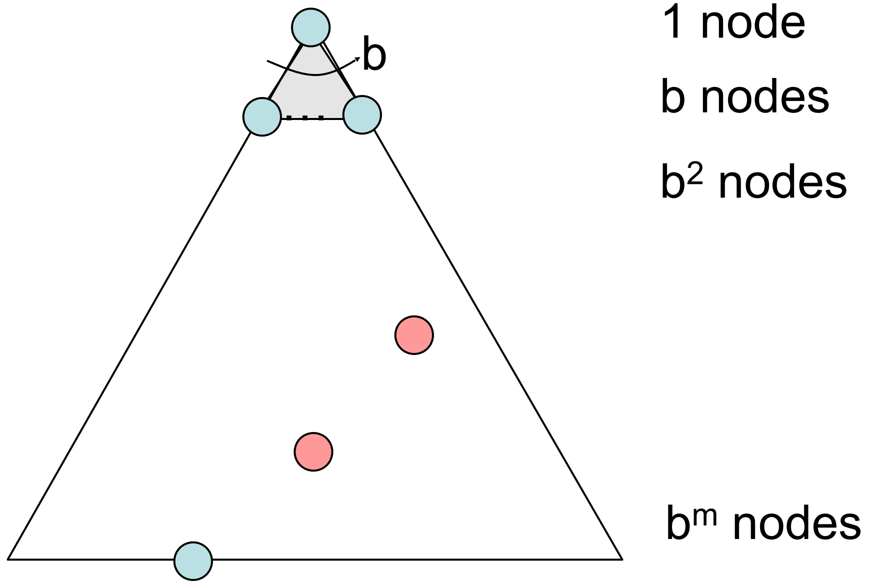

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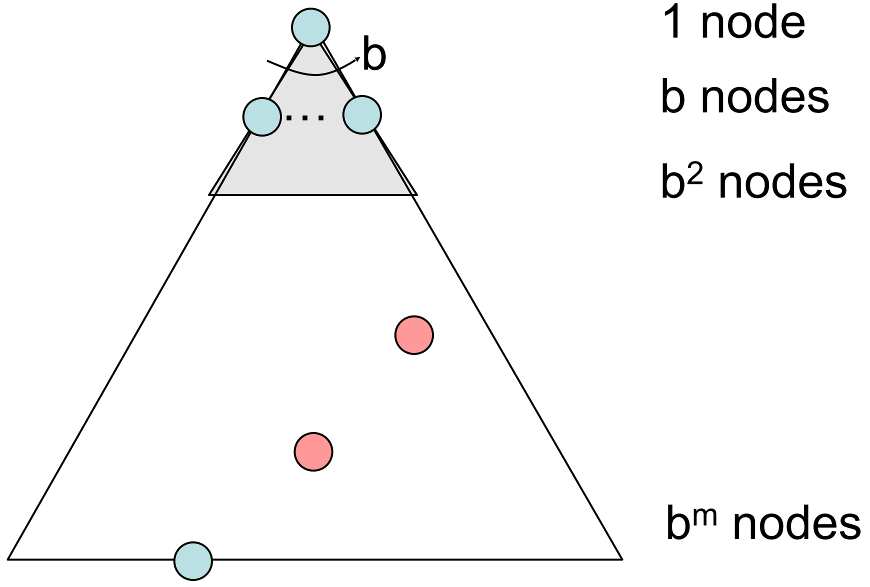

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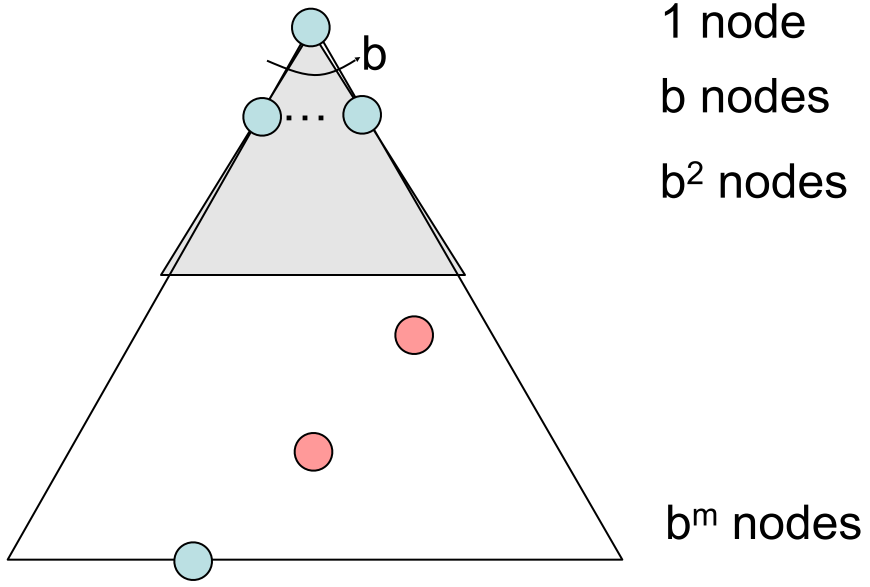

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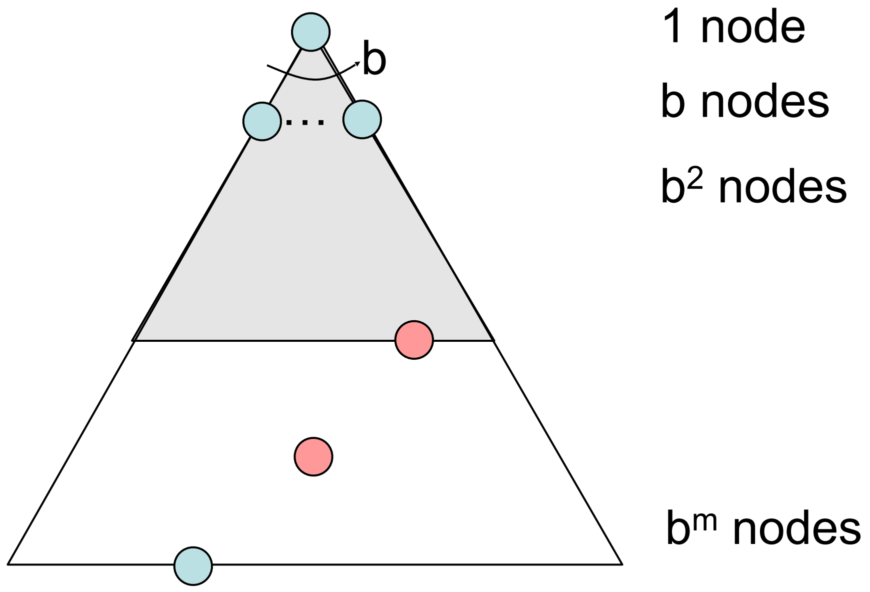

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- What nodes does BFS expand?
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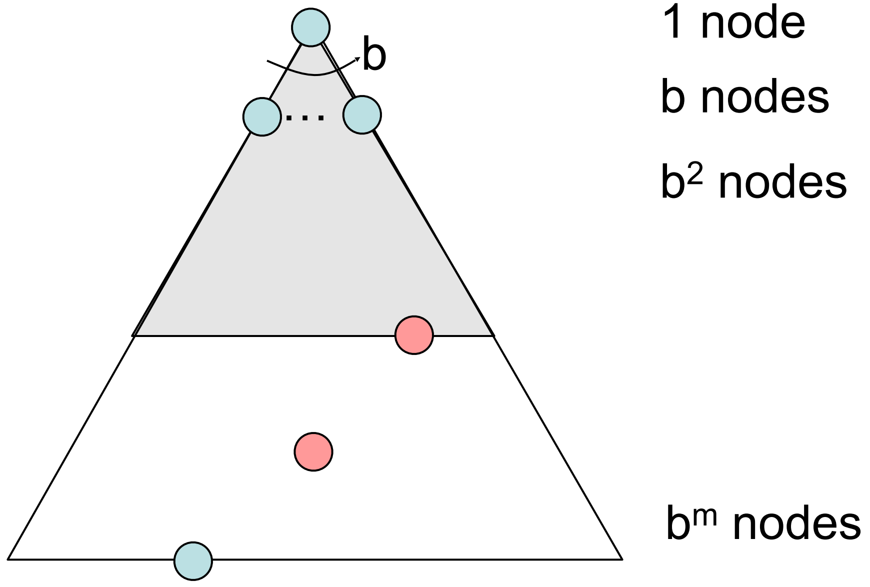

Breadth-First Search (BFS) Properties

- What nodes does BFS expand?
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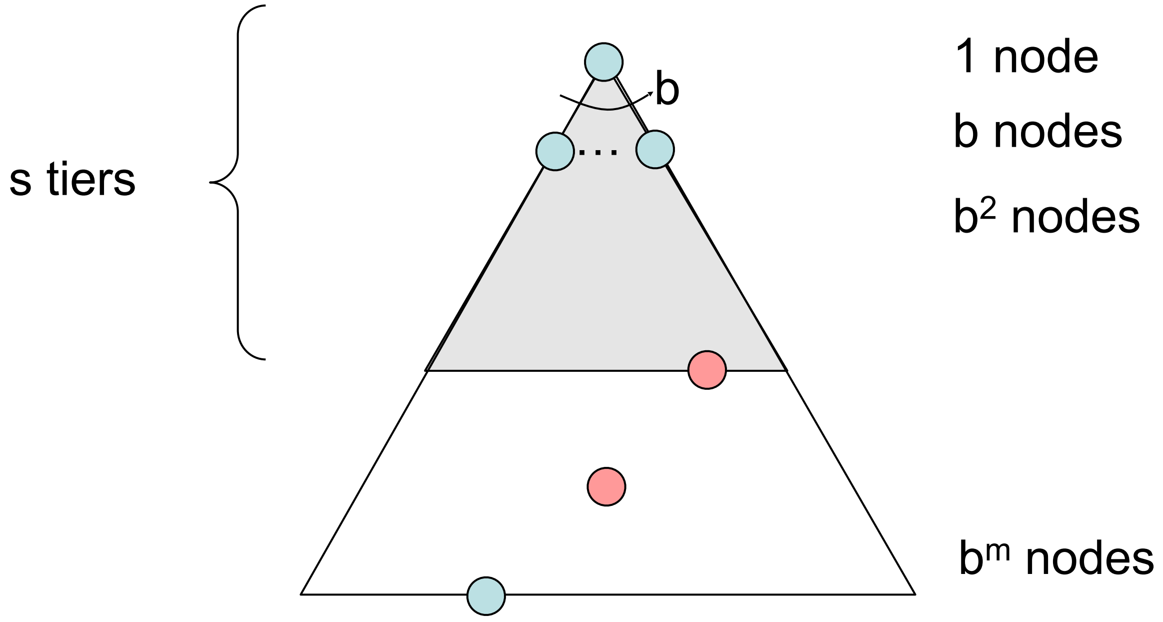
  - Let depth of shallowest solution be s



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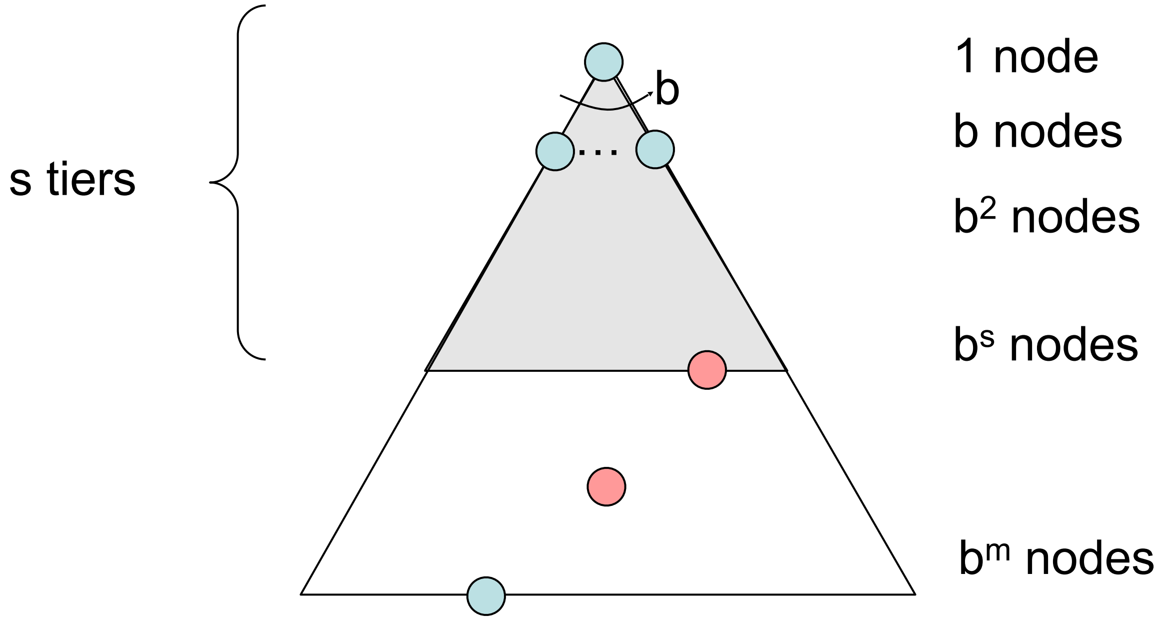

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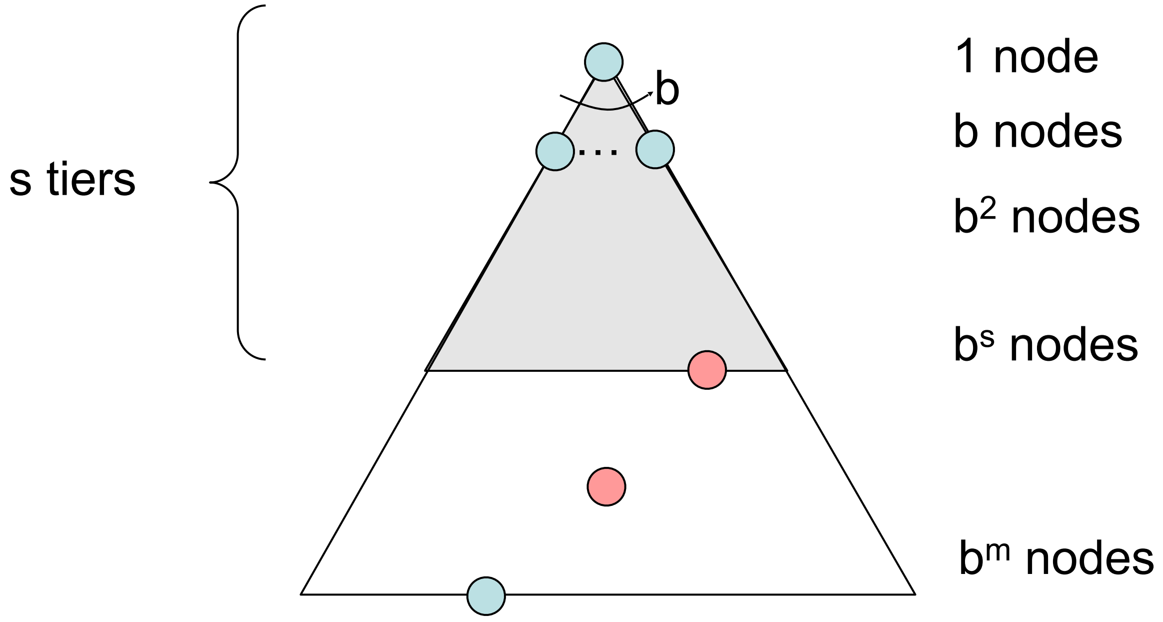

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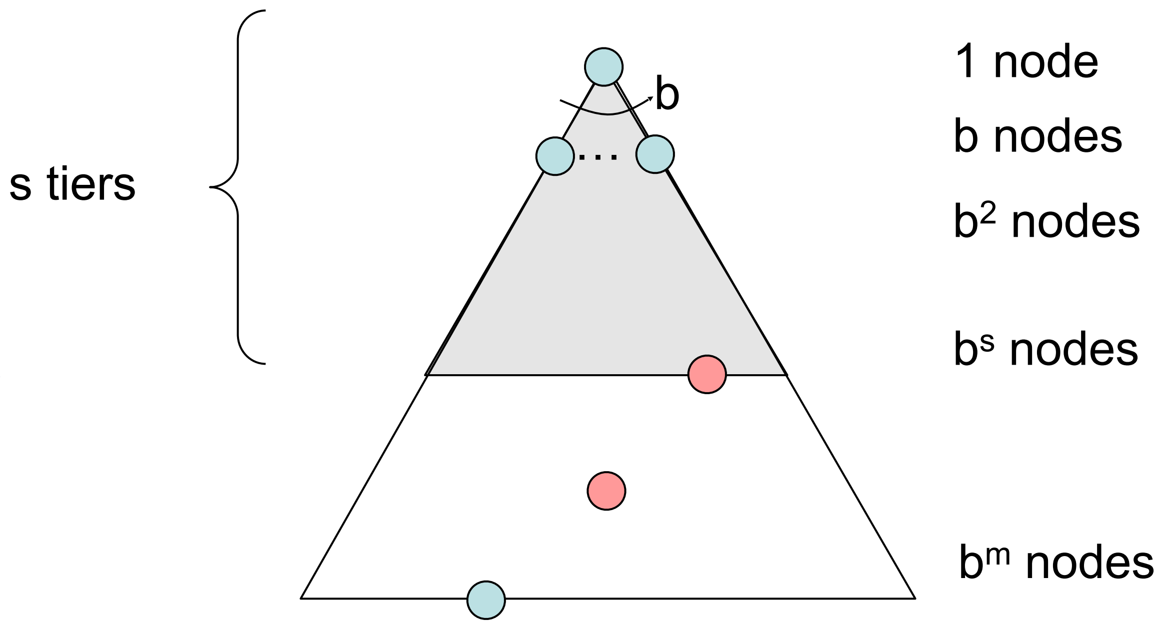

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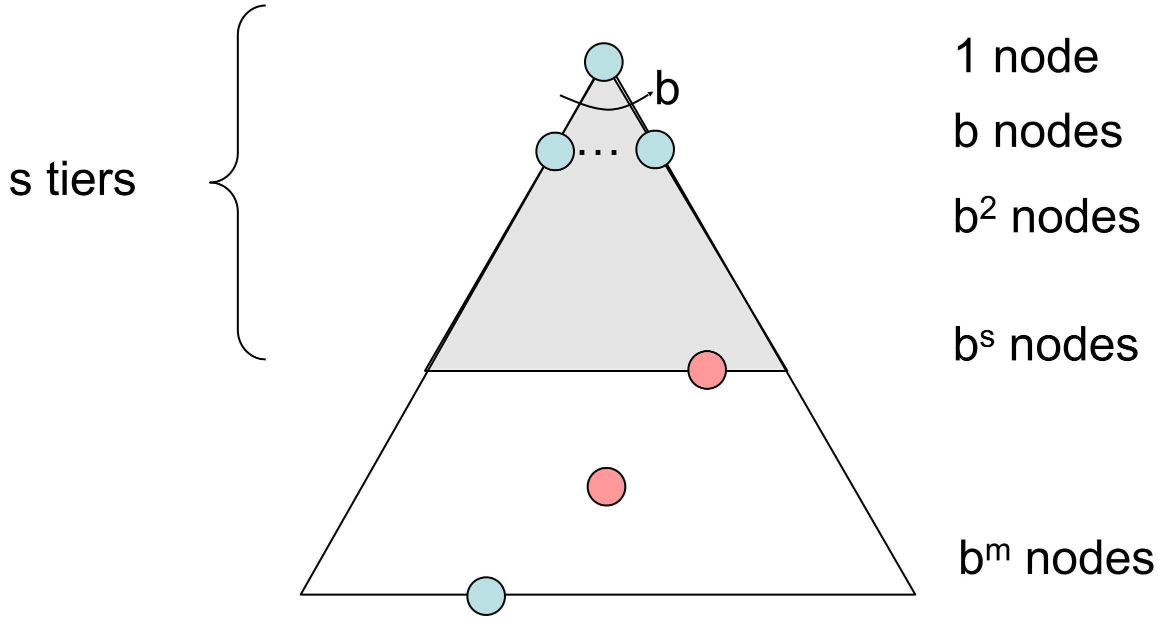

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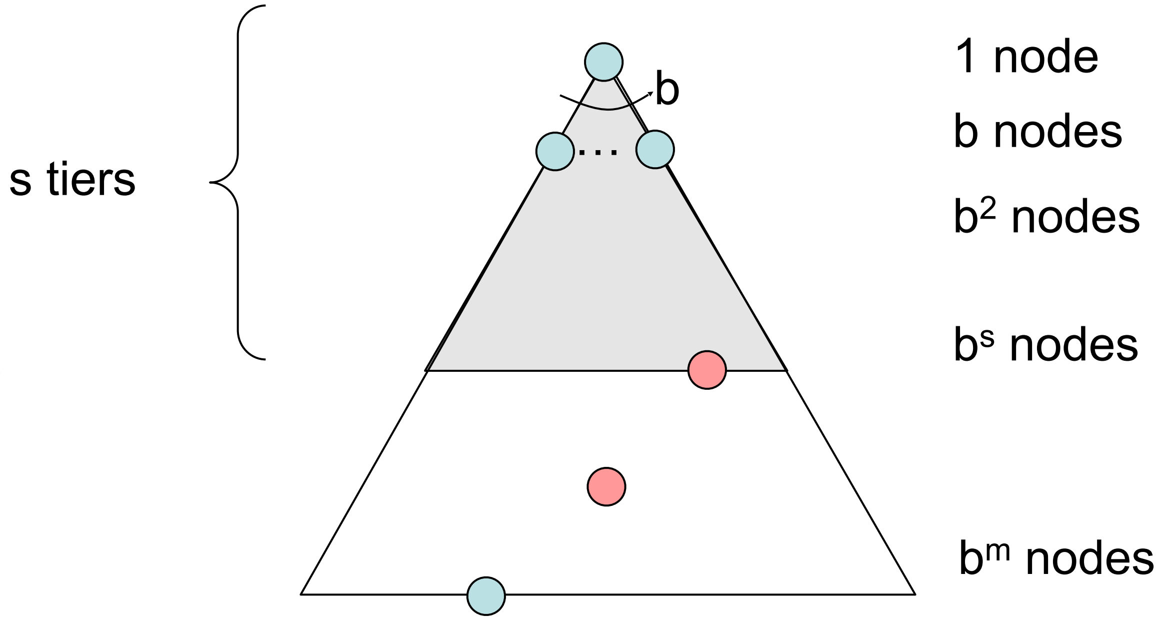

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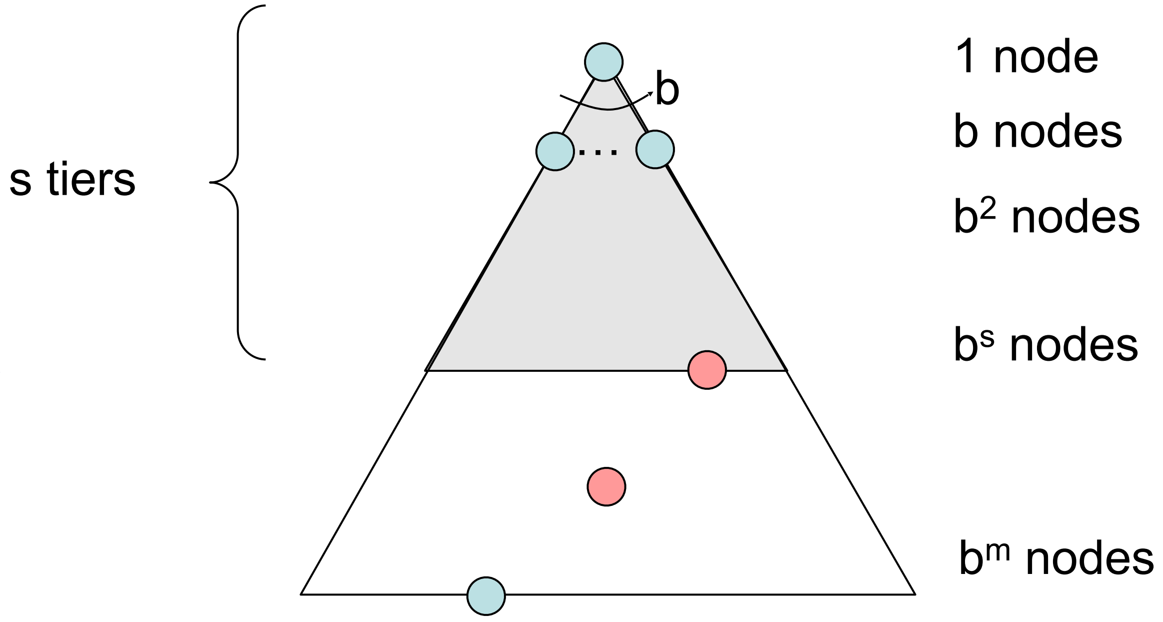

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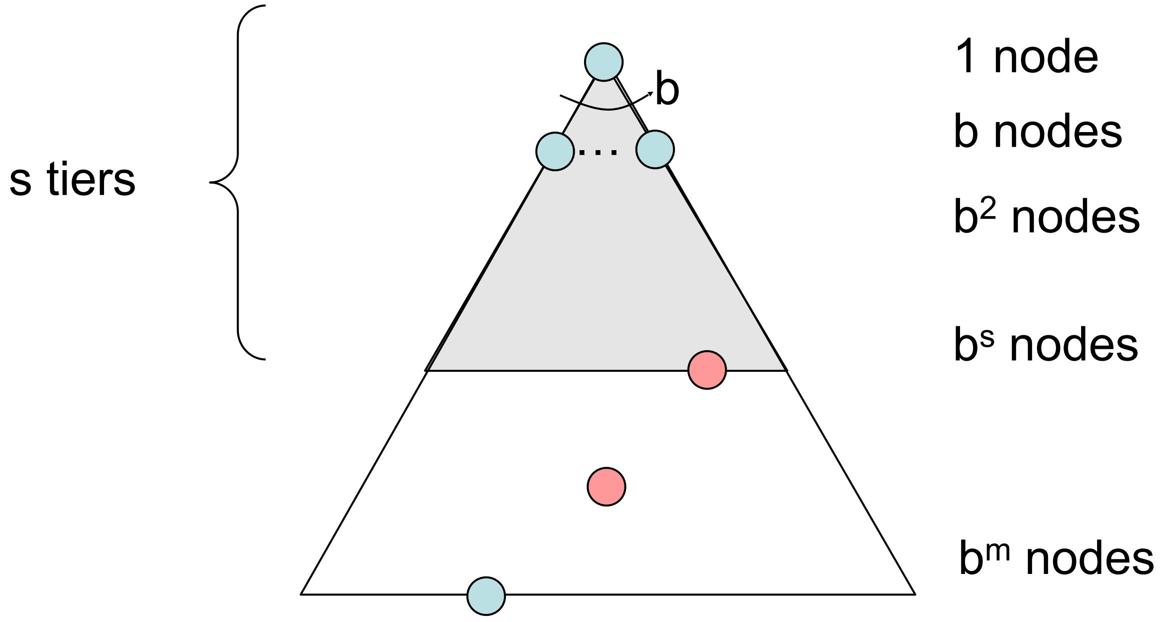

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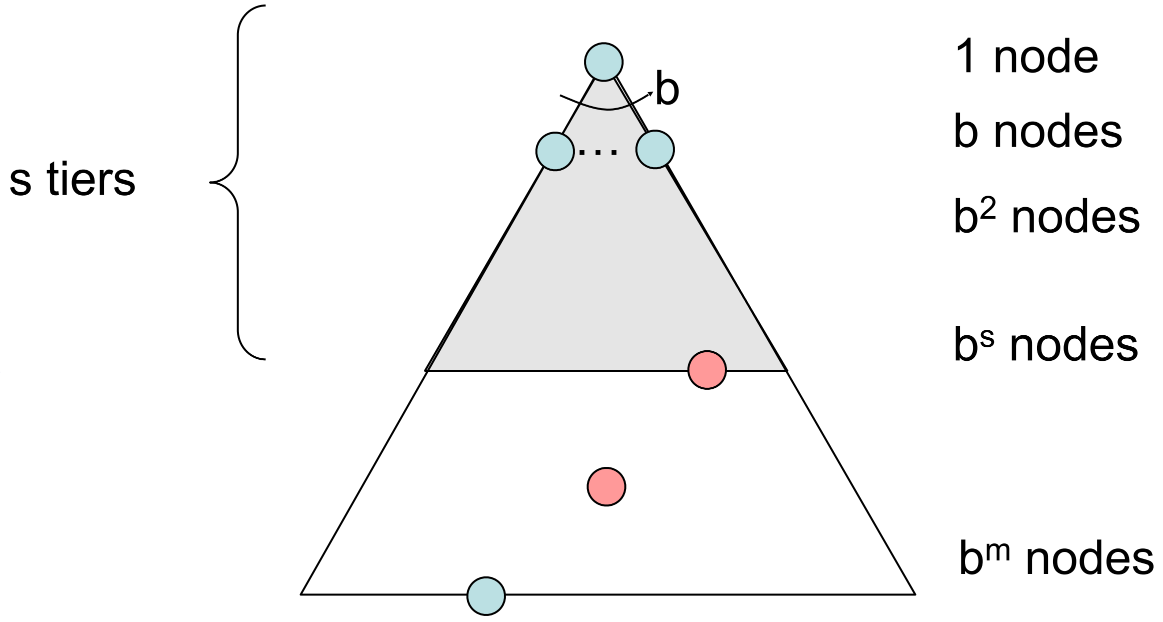
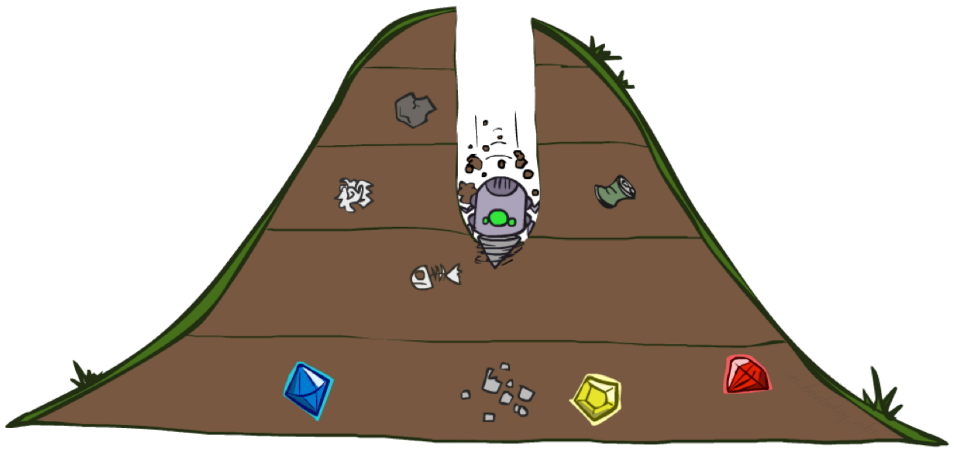
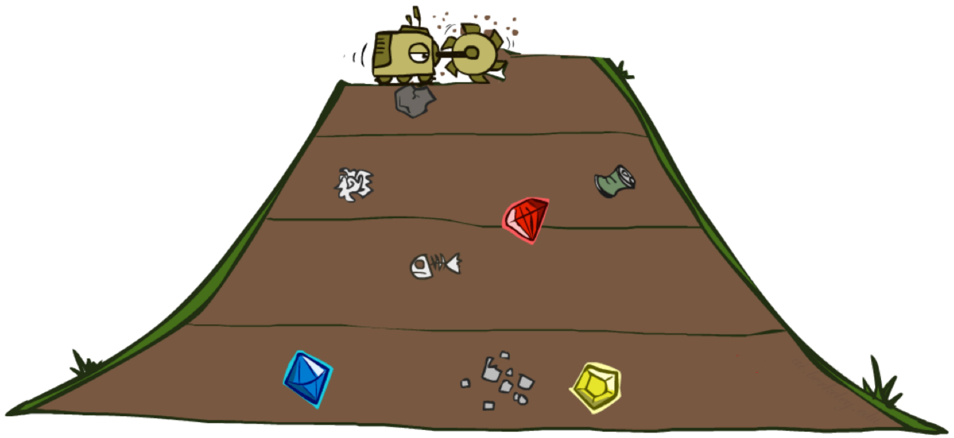
- Is it optimal?
  - Only if costs are all 1 (more on costs later)



Quiz: DFS vs BFS



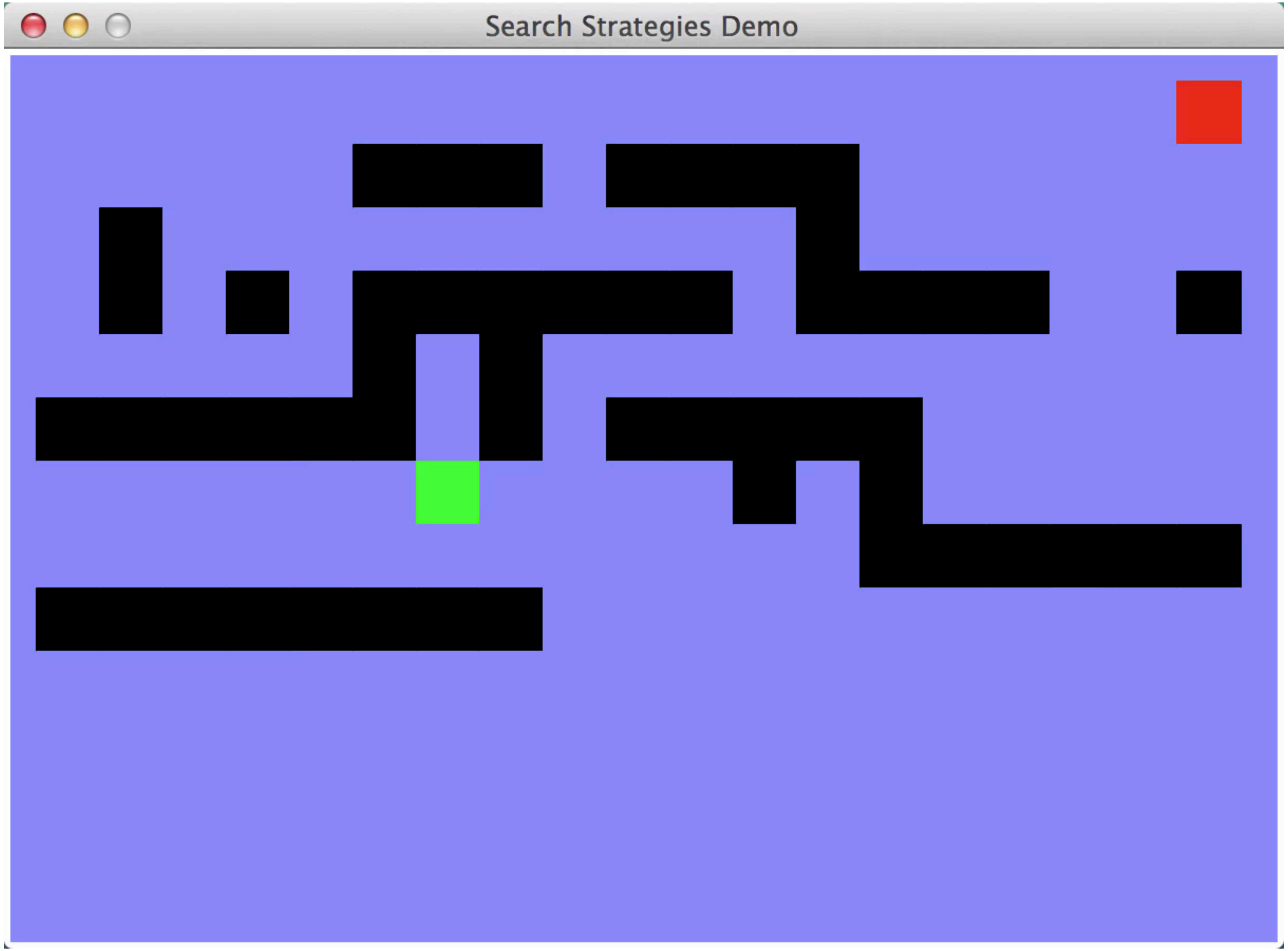


Quiz: DFS vs BFS

- 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)



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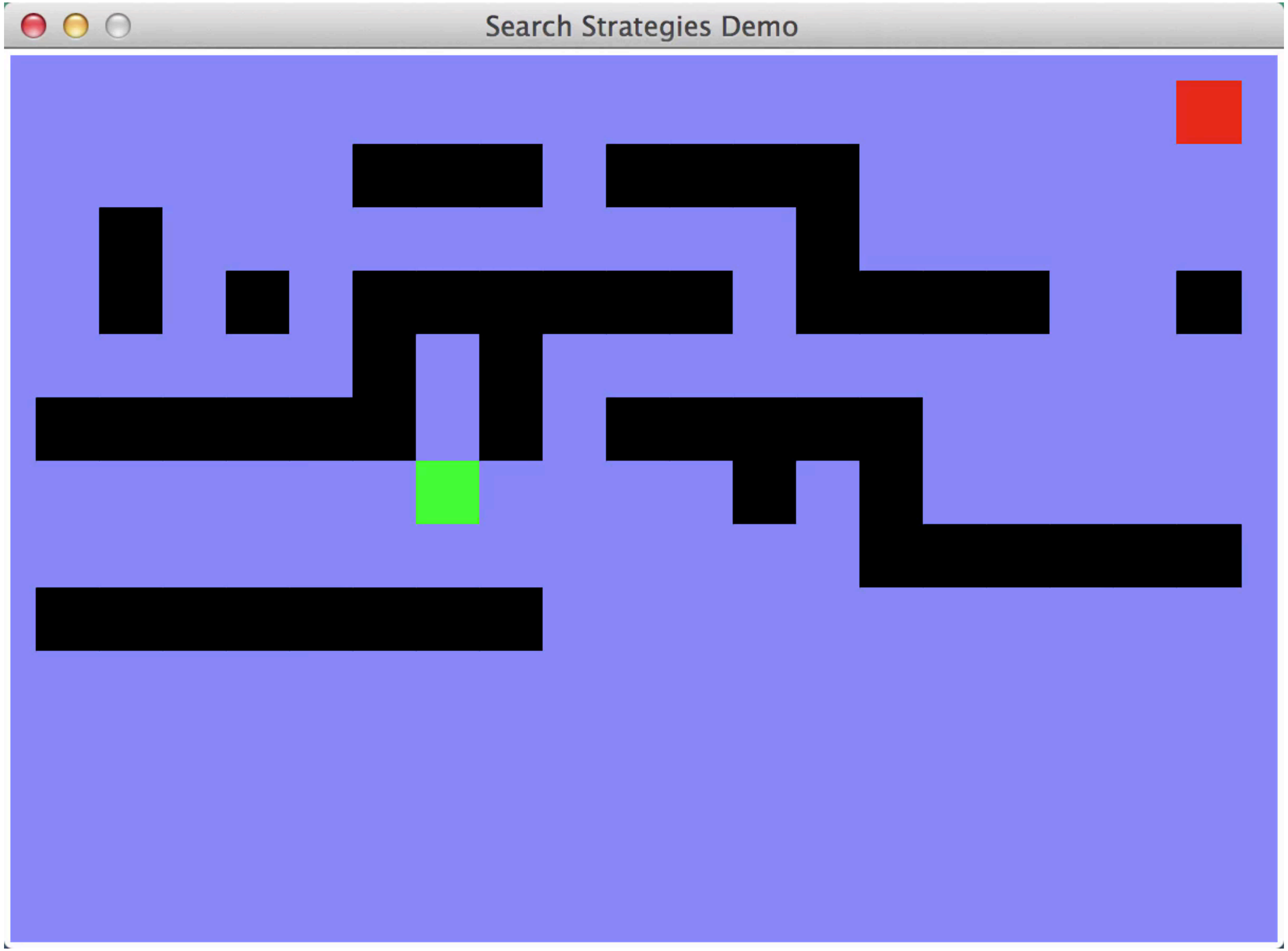

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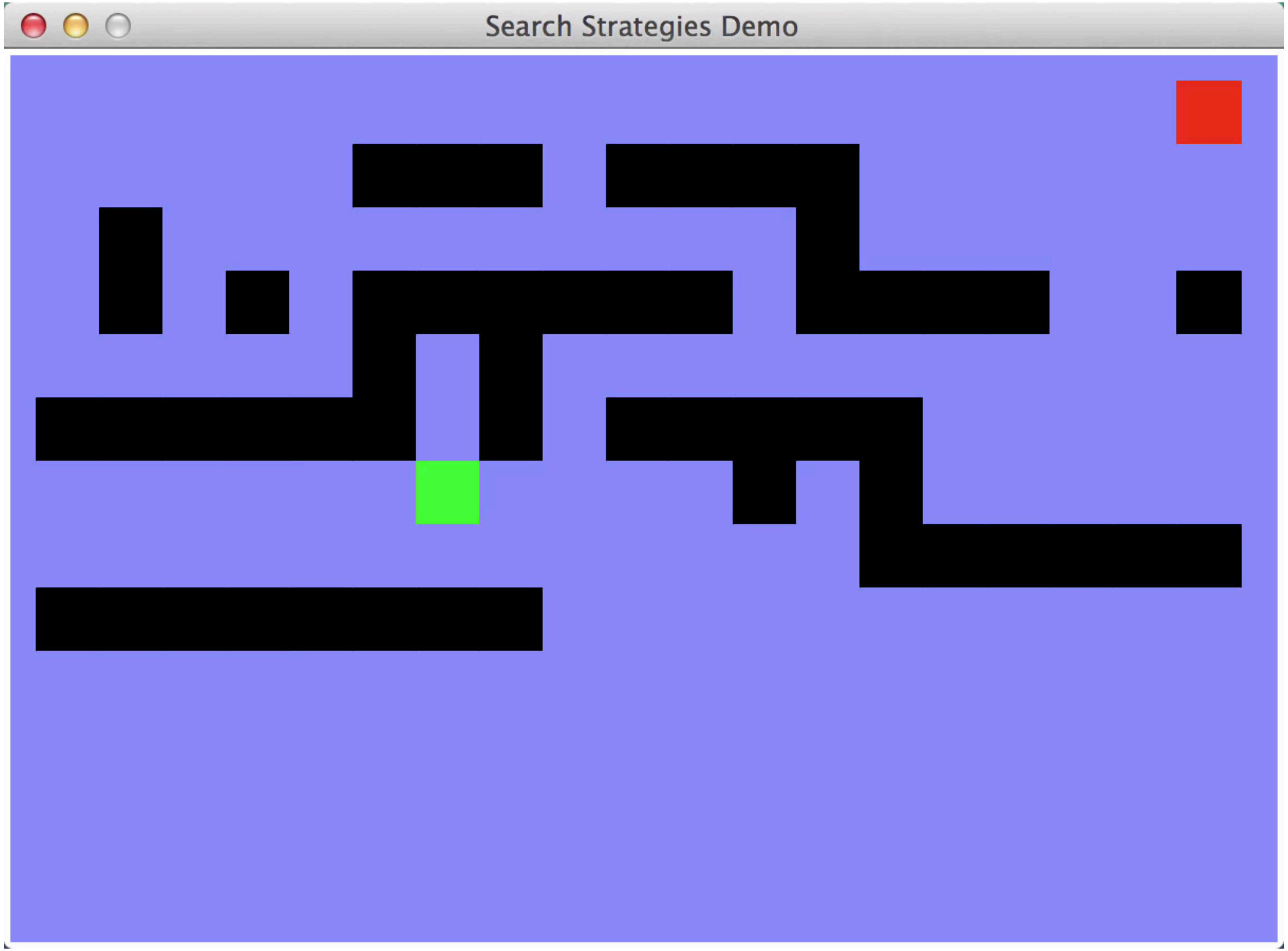
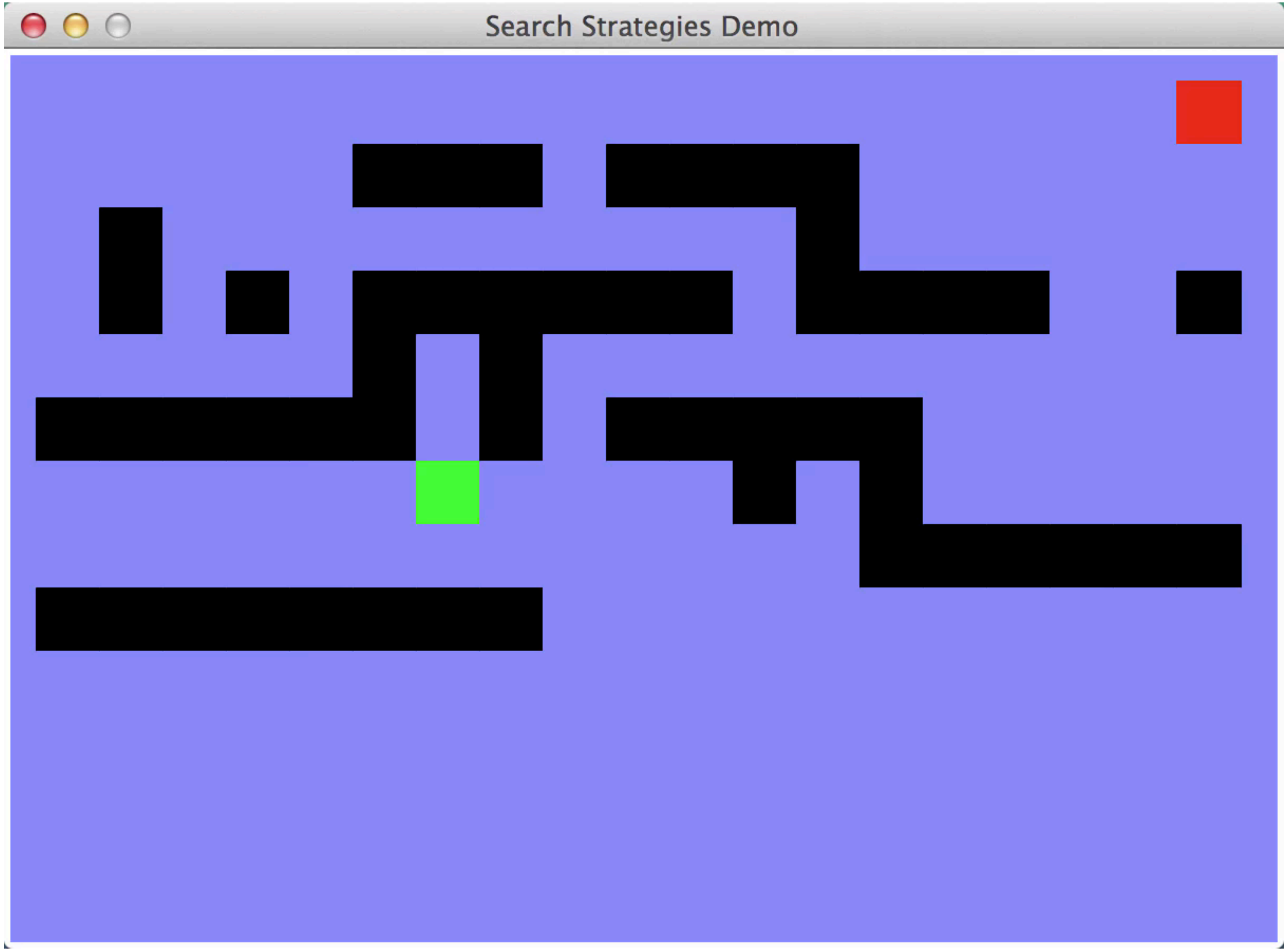


Video of Demo Maze Water DFS/BFS (part 2)



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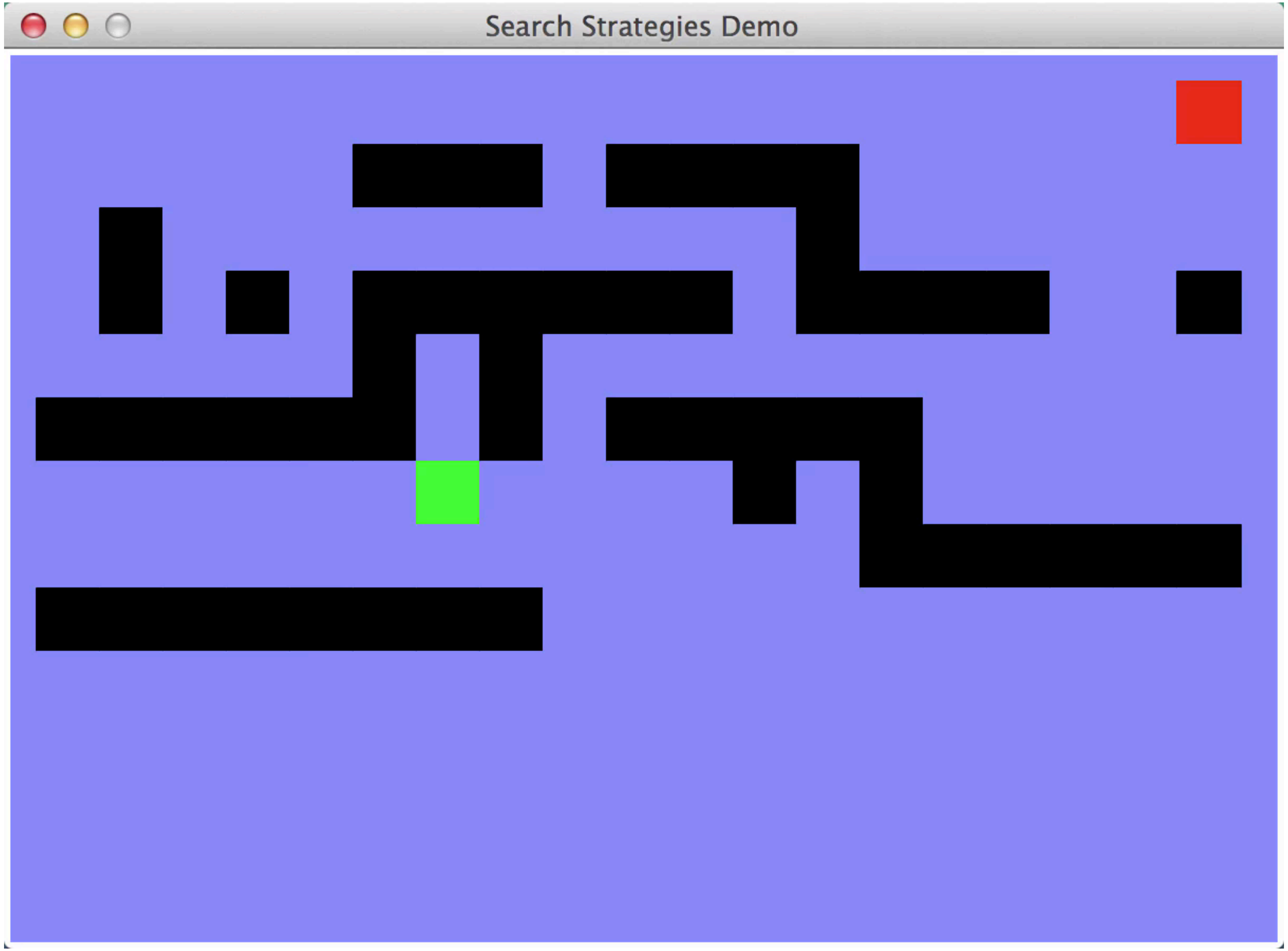
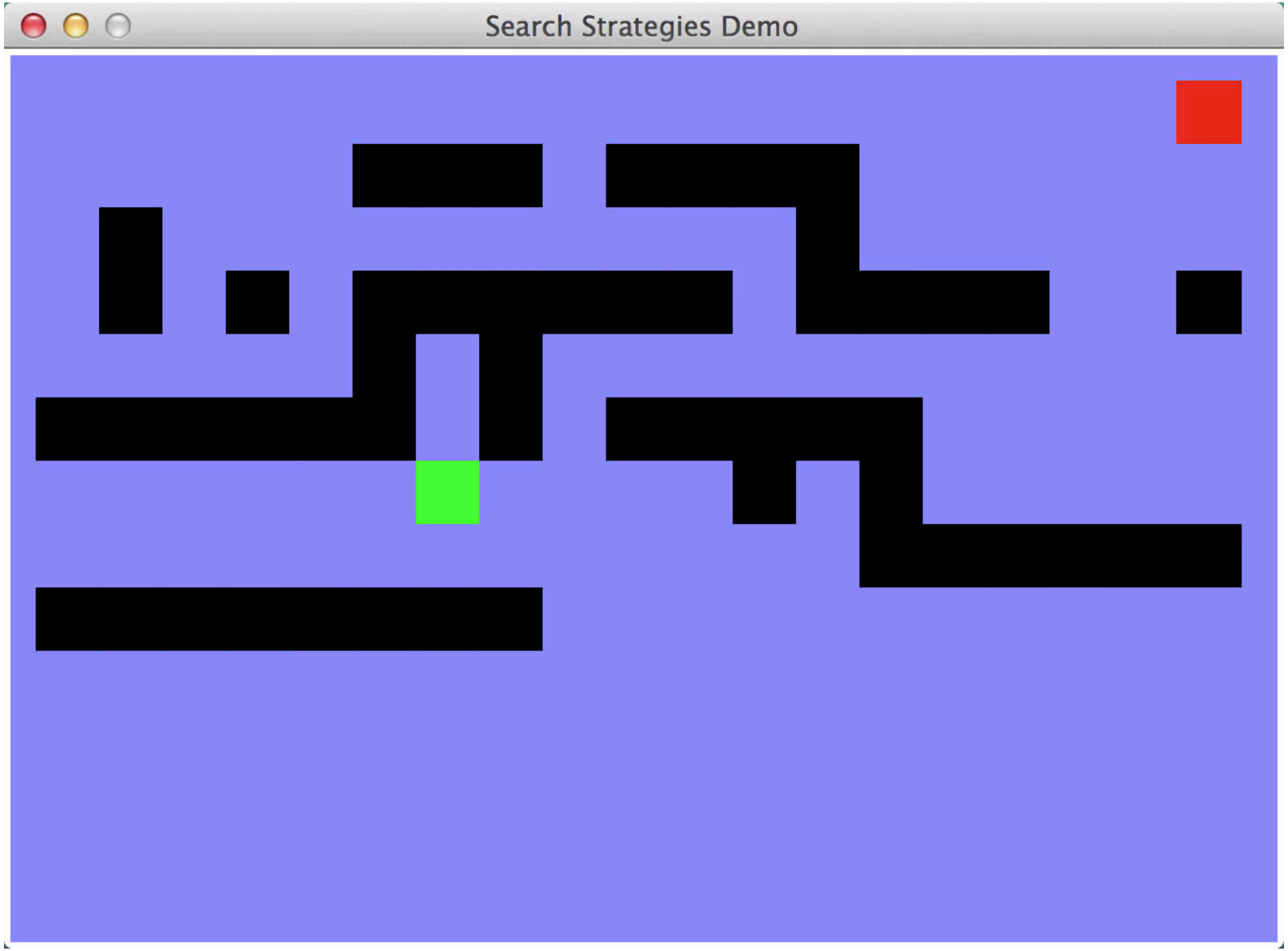
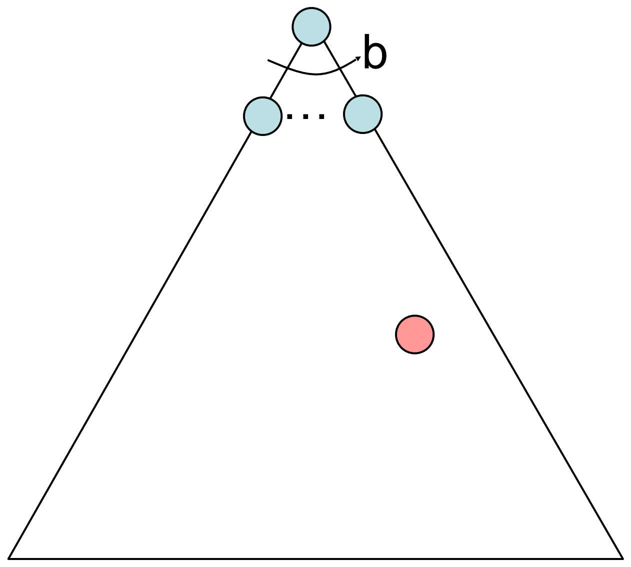


Video of Demo Maze Water DFS/BFS (part 2)



Iterative Deepening

- Idea: get DFS's space advantage with BFS's time / shallow-solution advantages



Iterative Deepening

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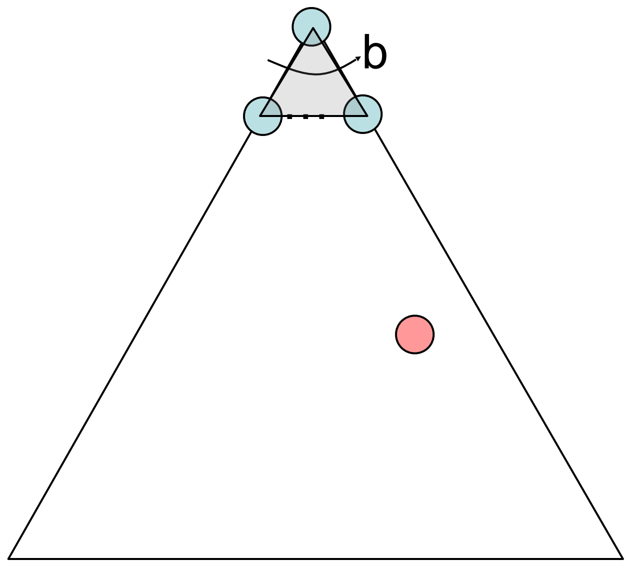
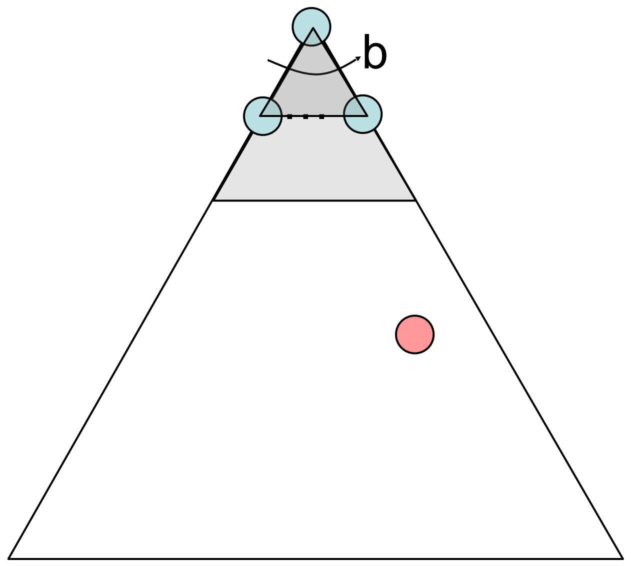
  - Run a DFS with depth limit 1. If no solution…



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…



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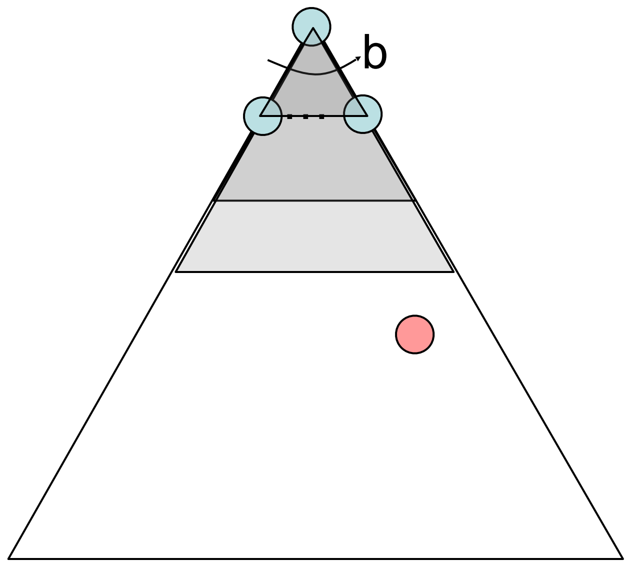

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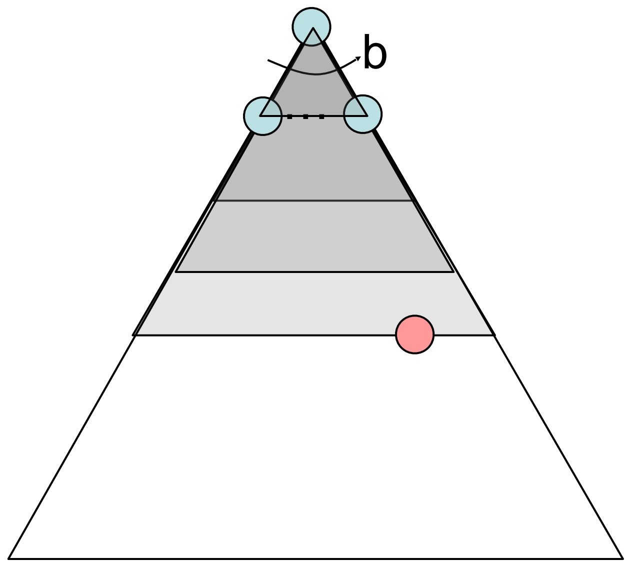

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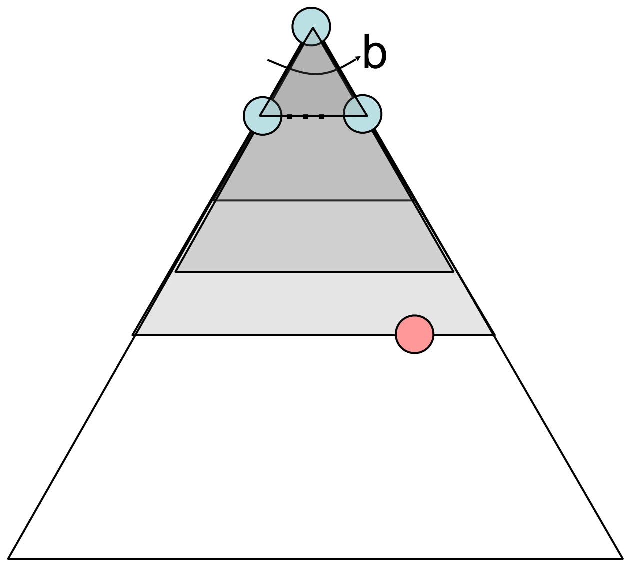
- Isn't that wastefully redundant?



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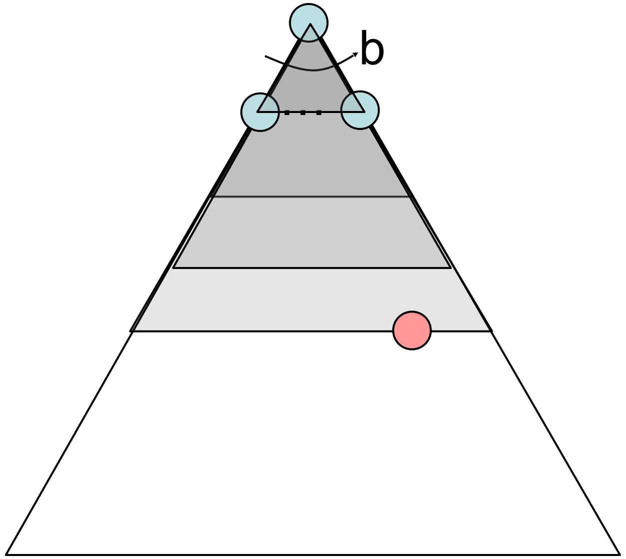
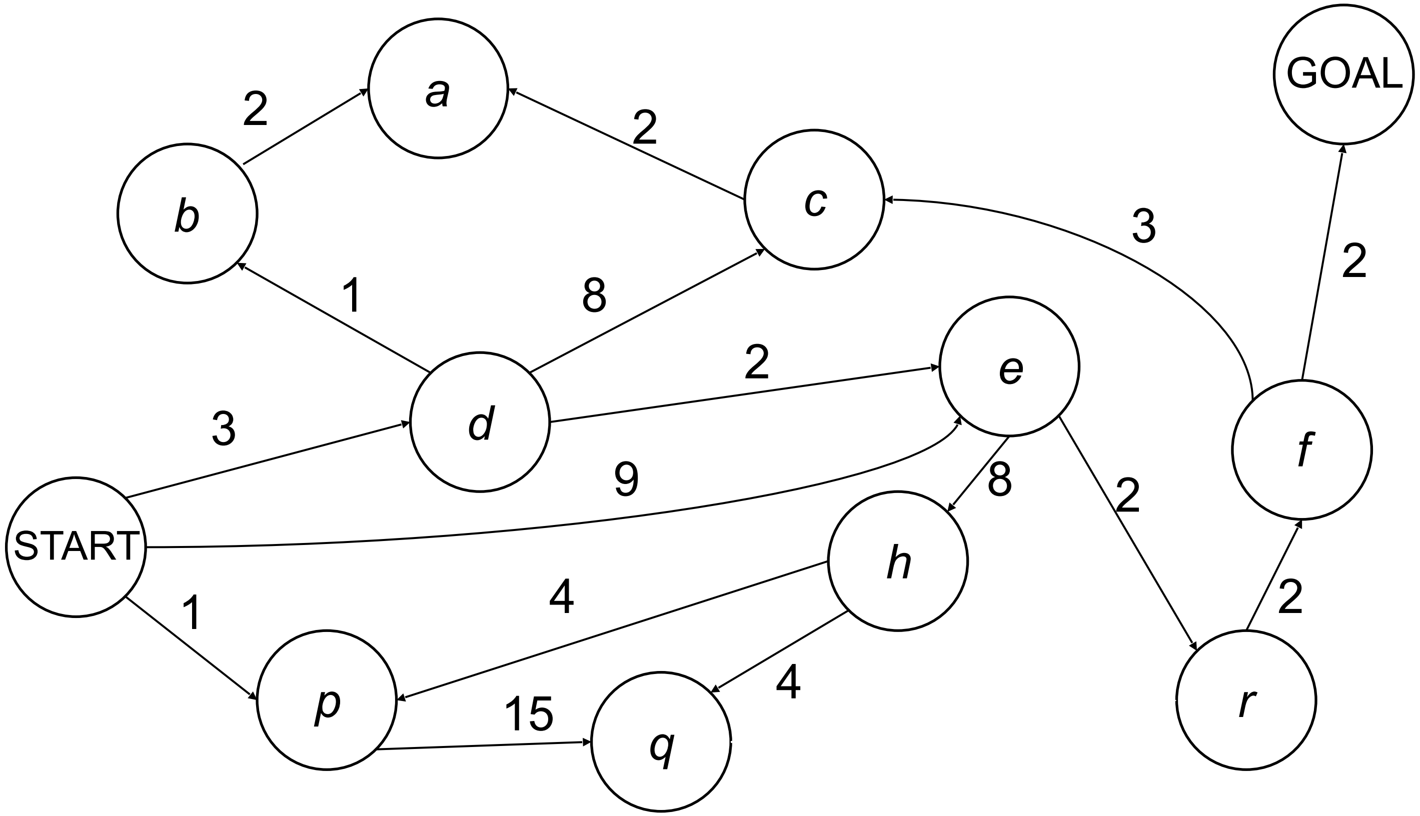


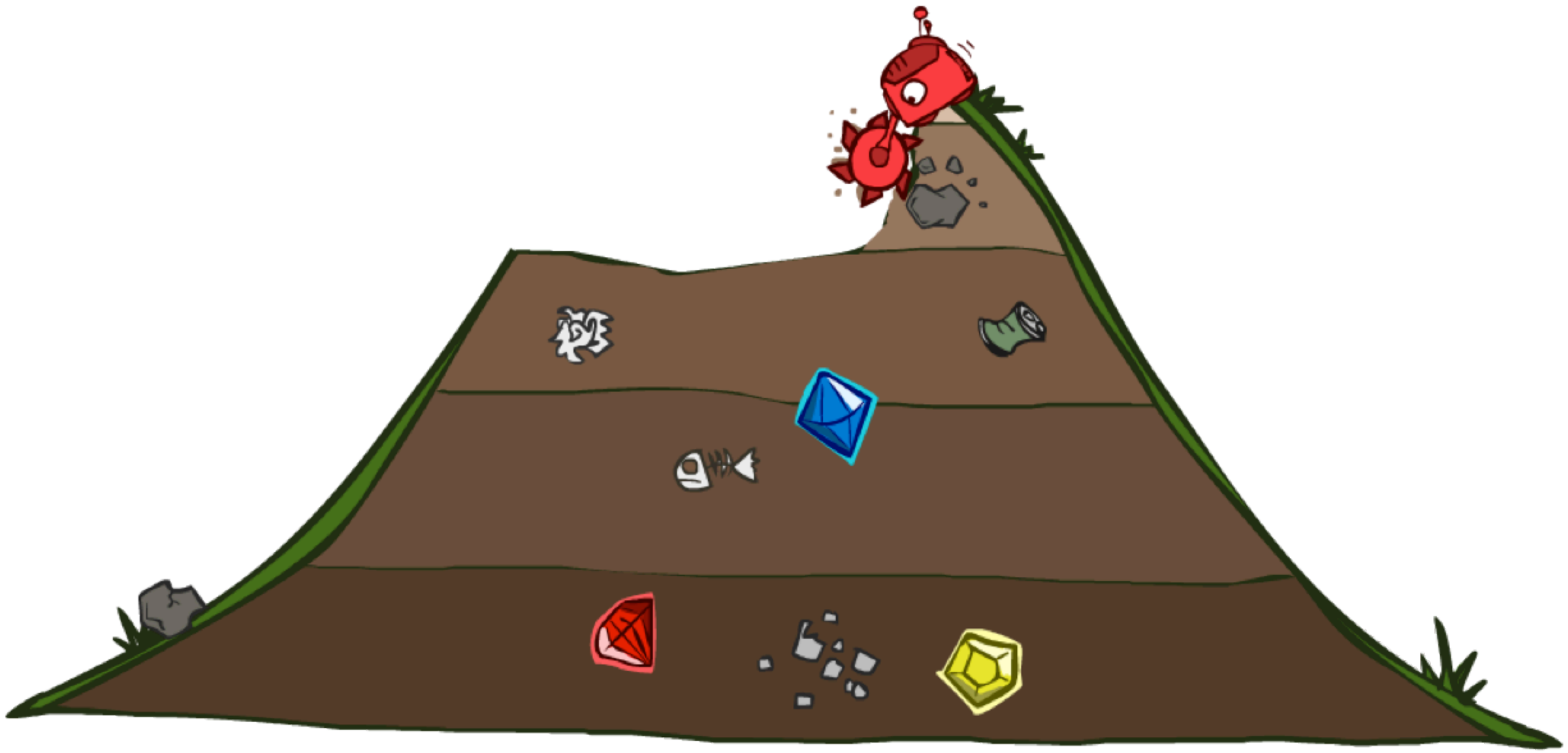
- Isn't that wastefully redundant?
  - Generally most work happens in the lowest level searched, so not so bad!

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.

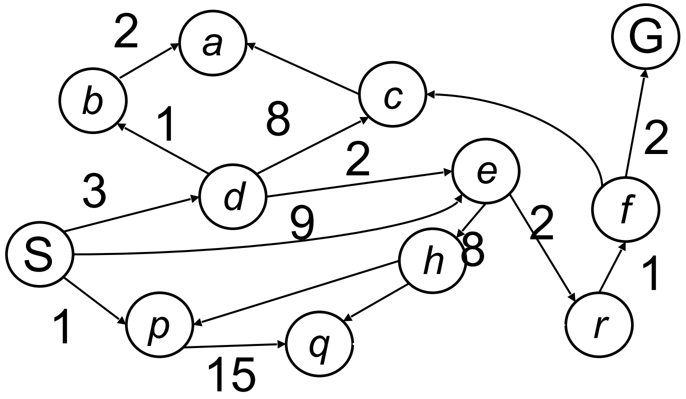
Uniform Cost Search

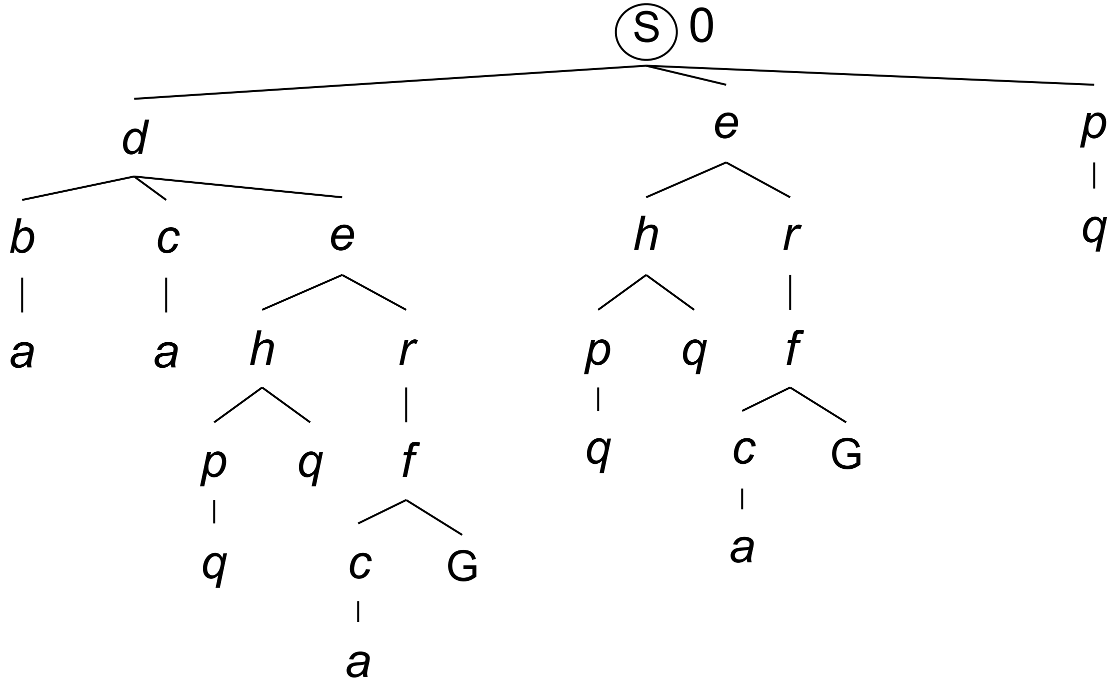


Uniform Cost Search

Strategy: expand a cheapest node first:

Fringe is a priority queue (priority: cumulative cost)





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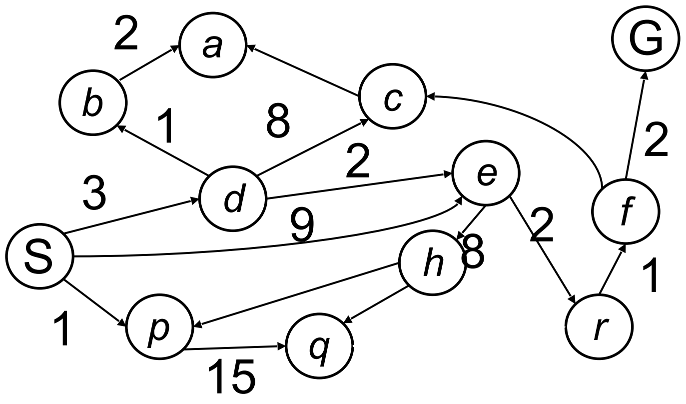

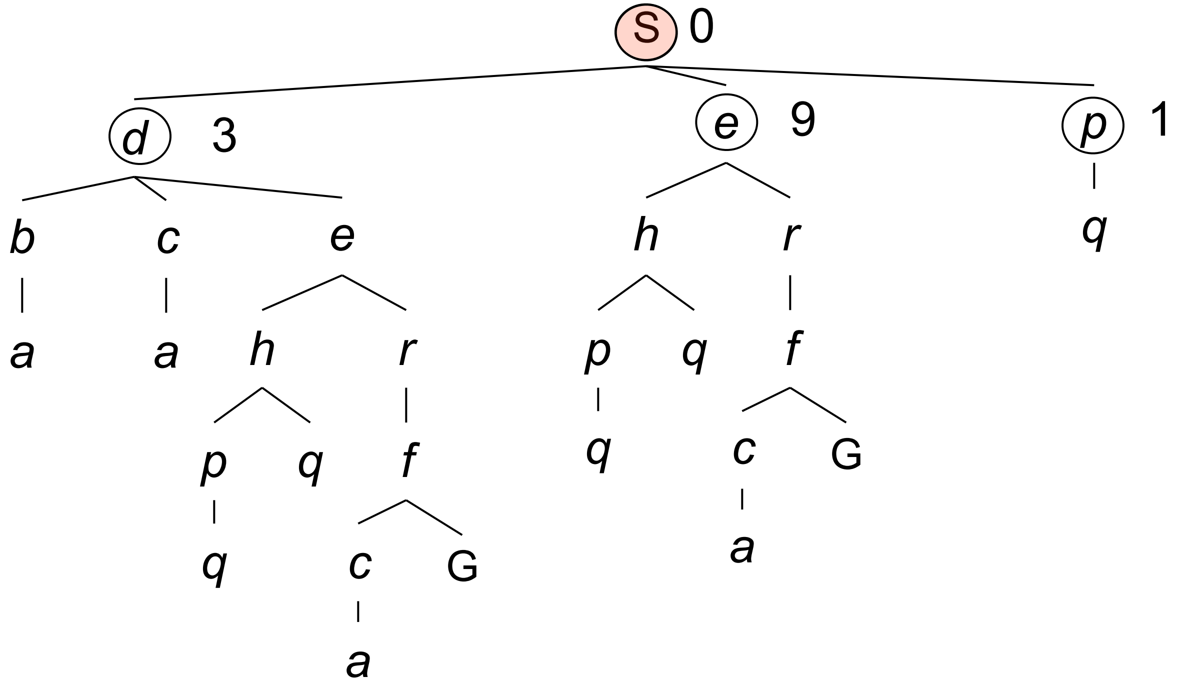

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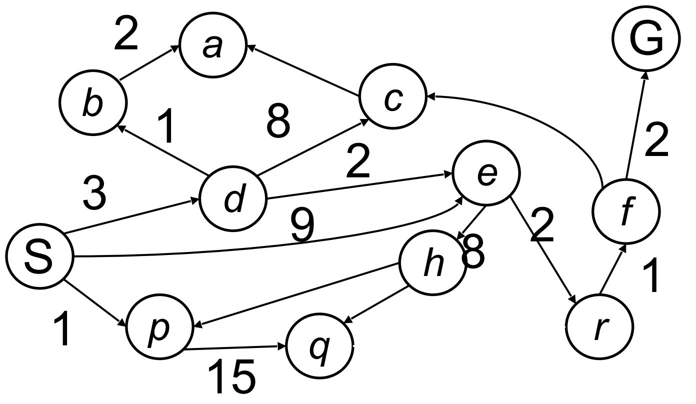

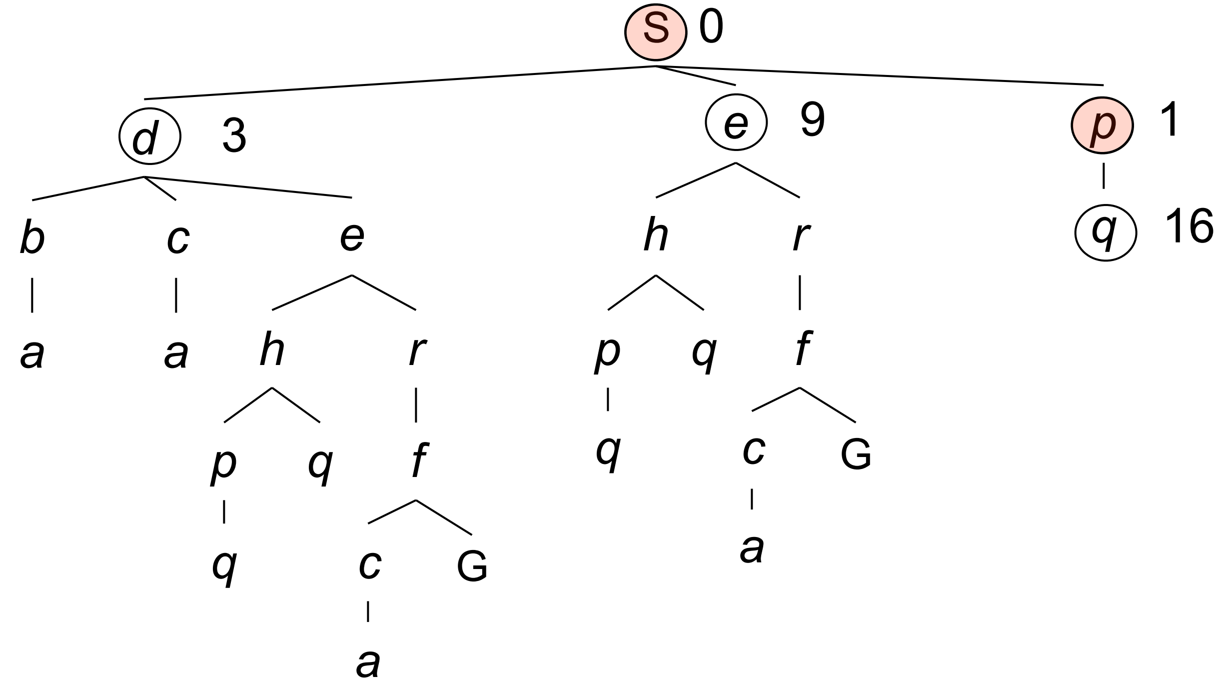

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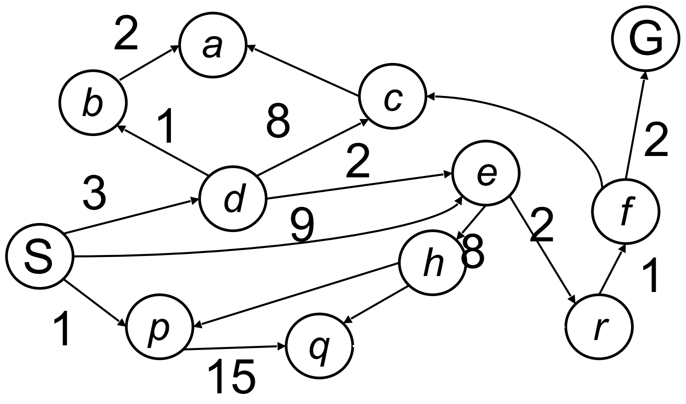

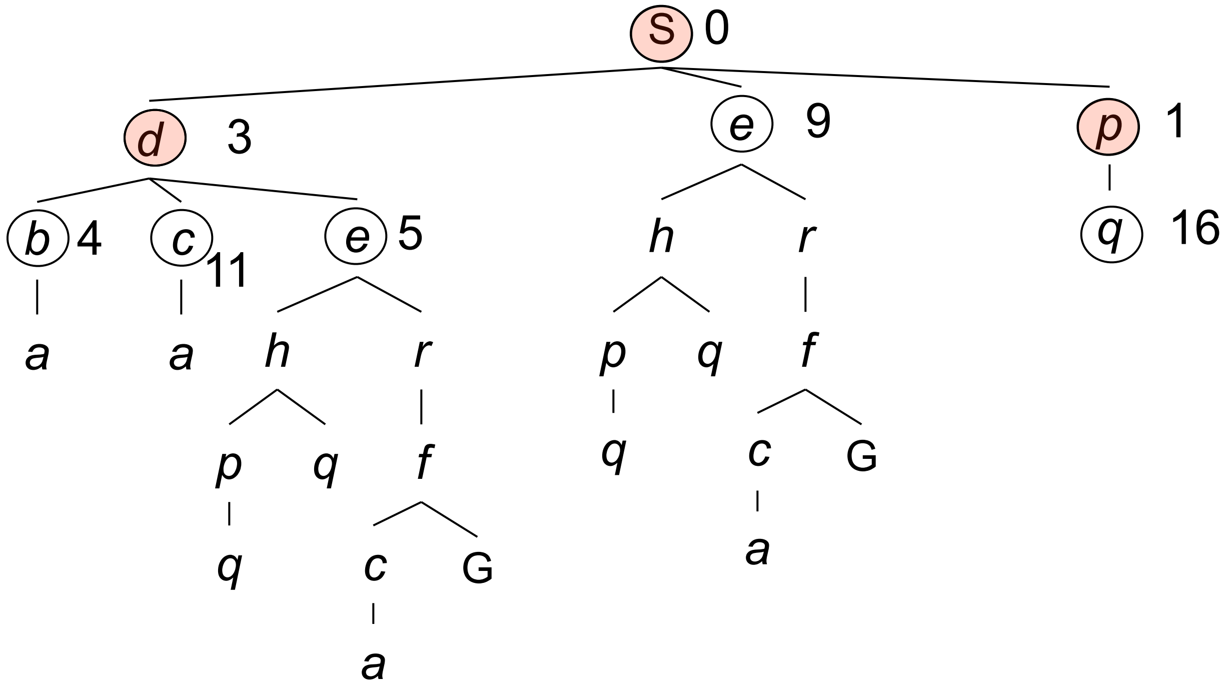

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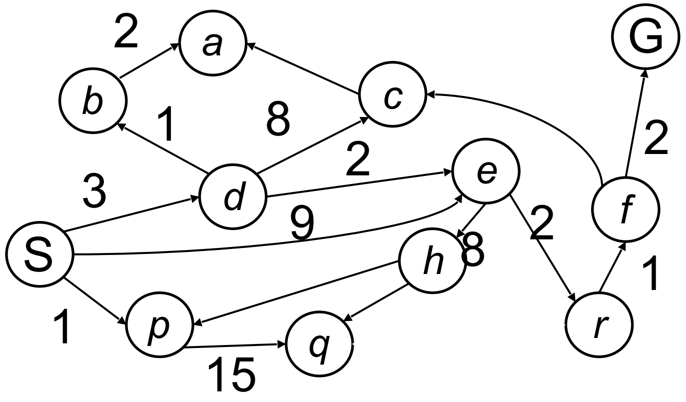

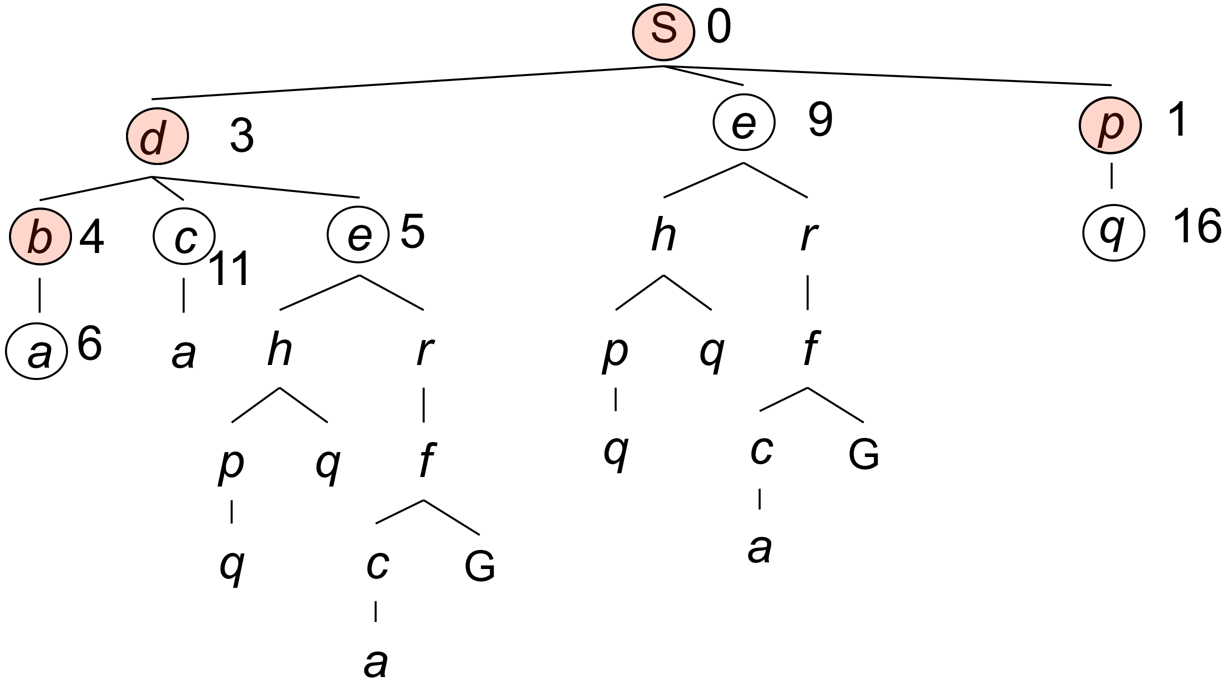

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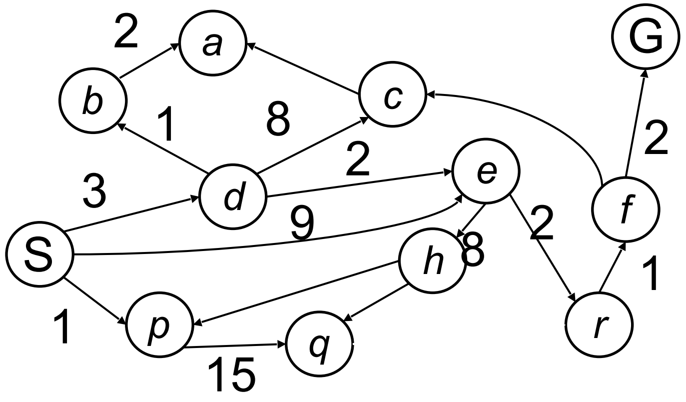

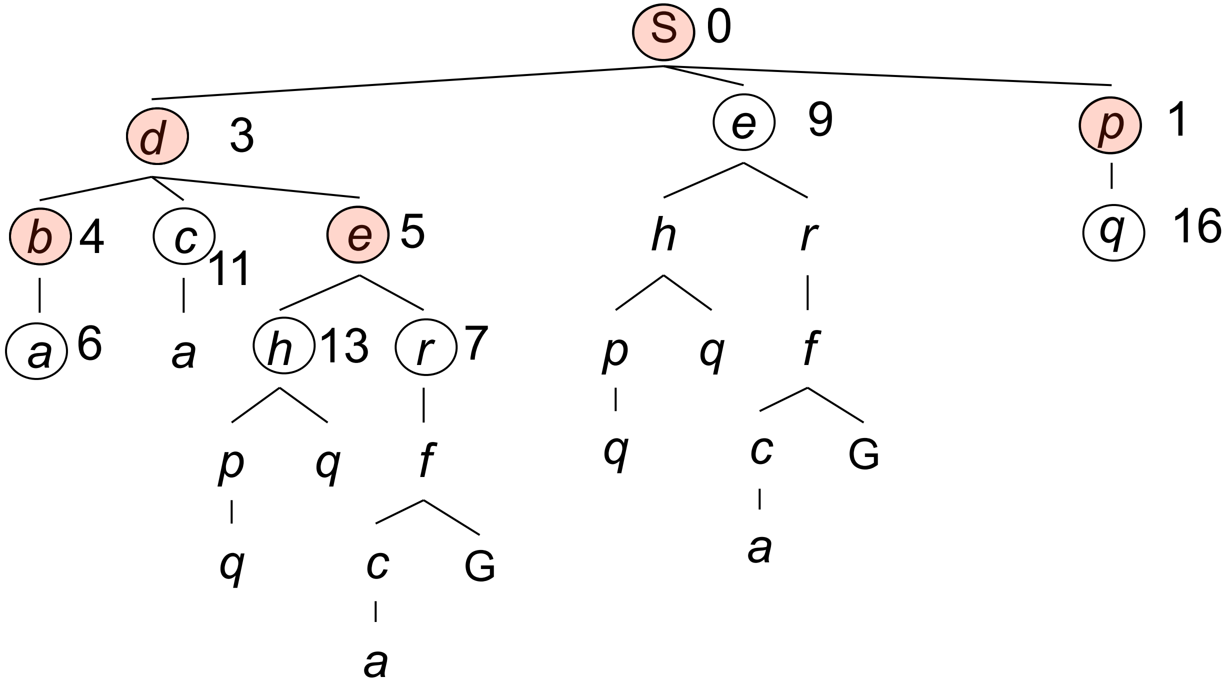

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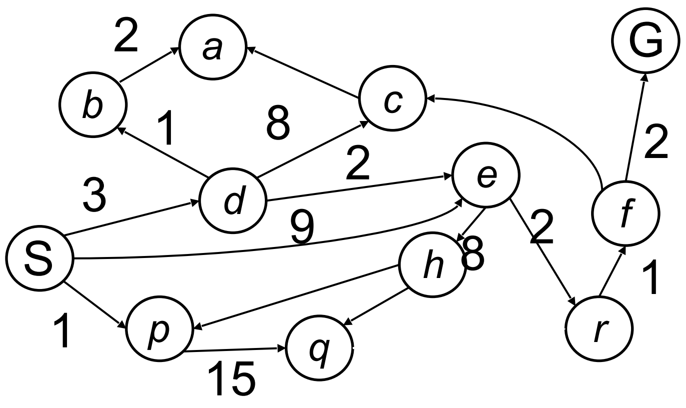

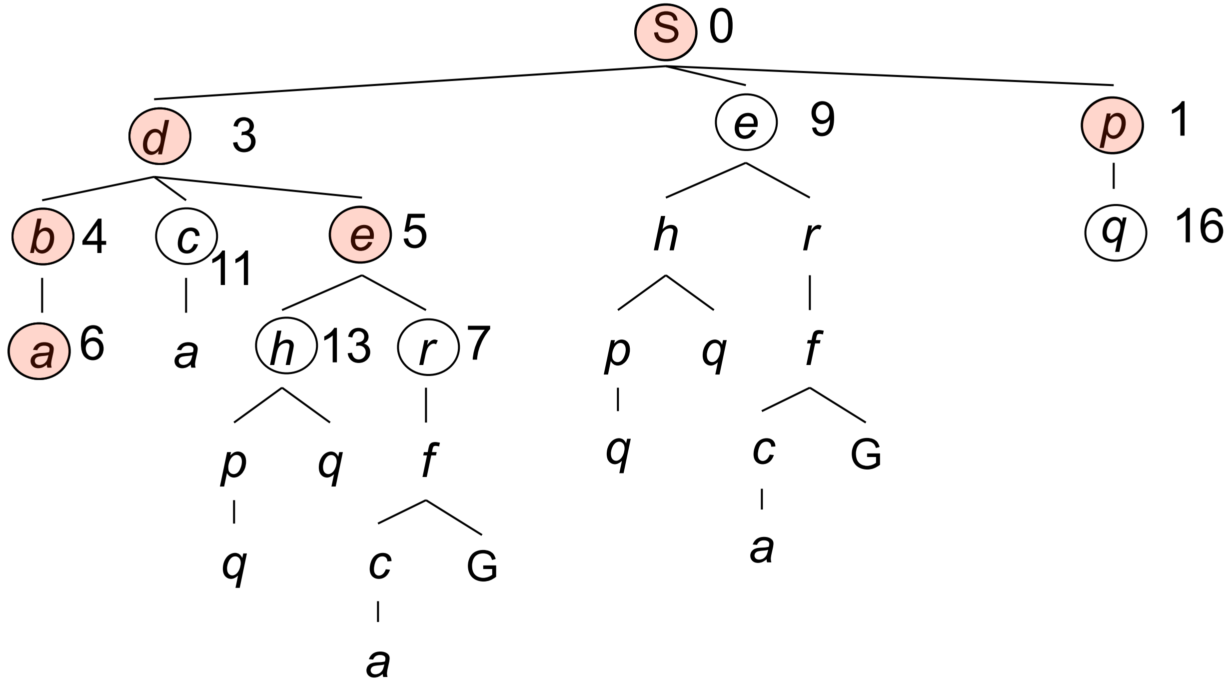

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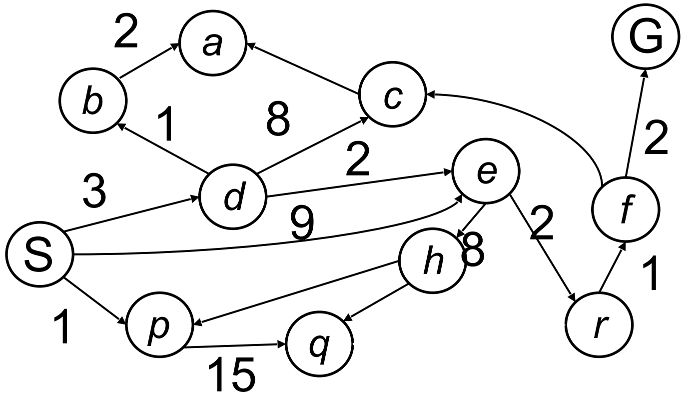

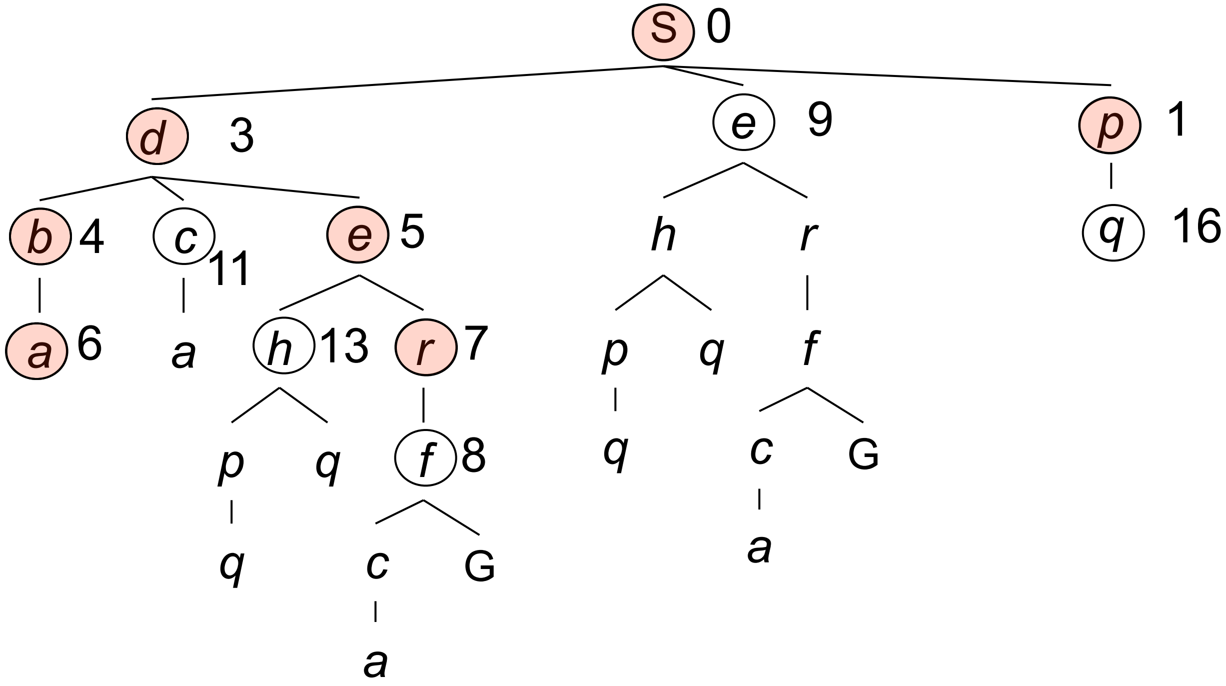

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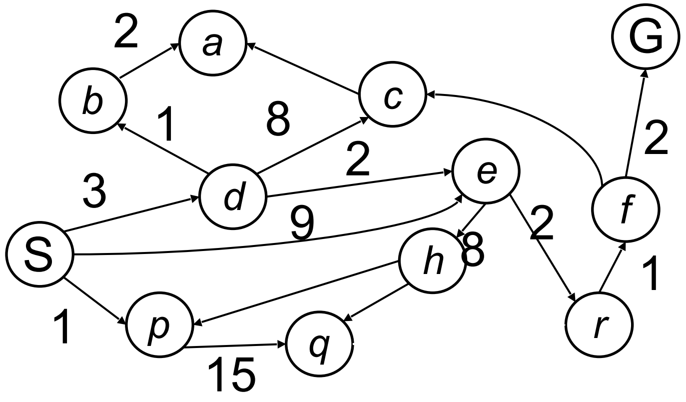

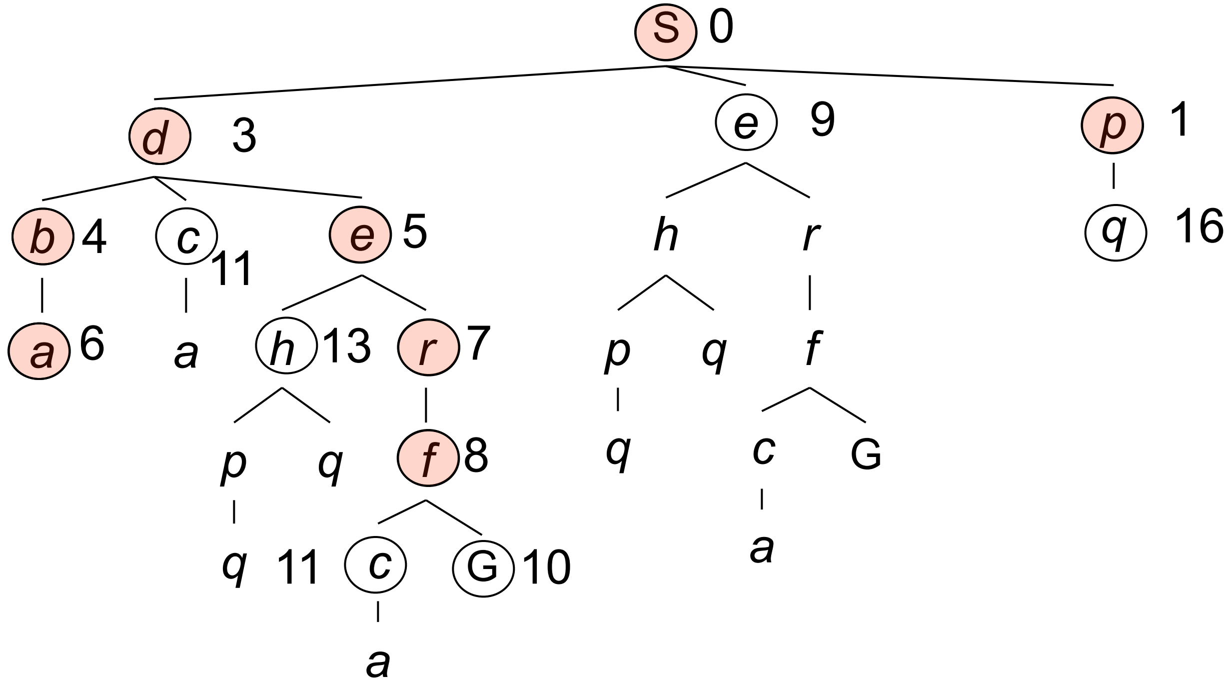

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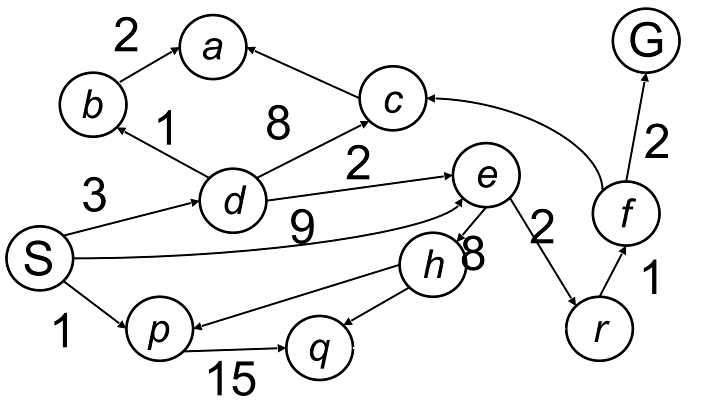

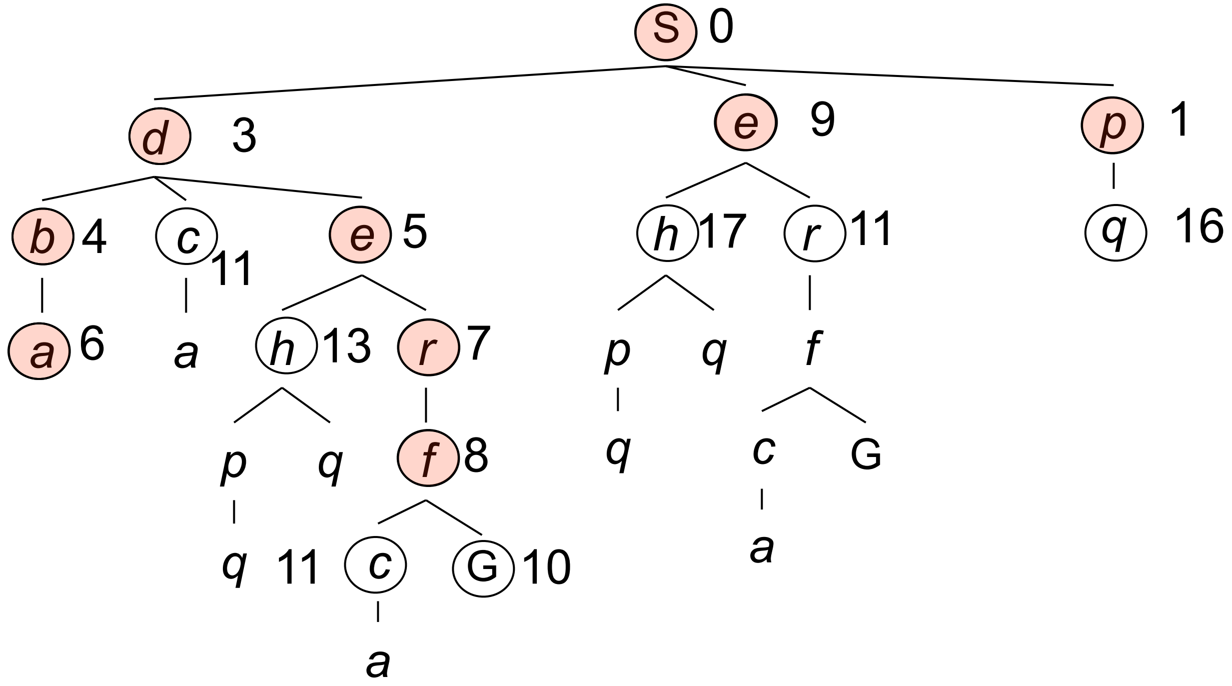

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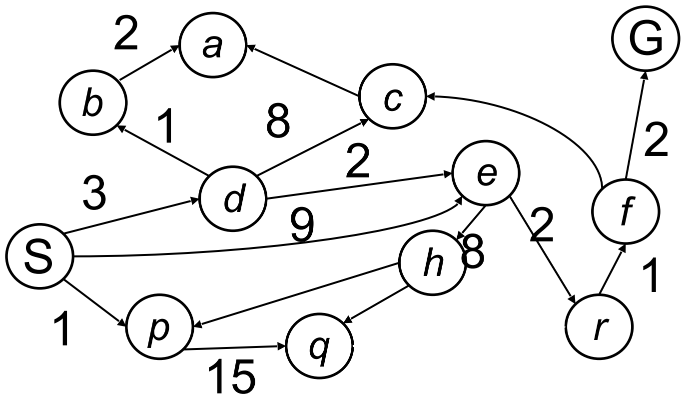

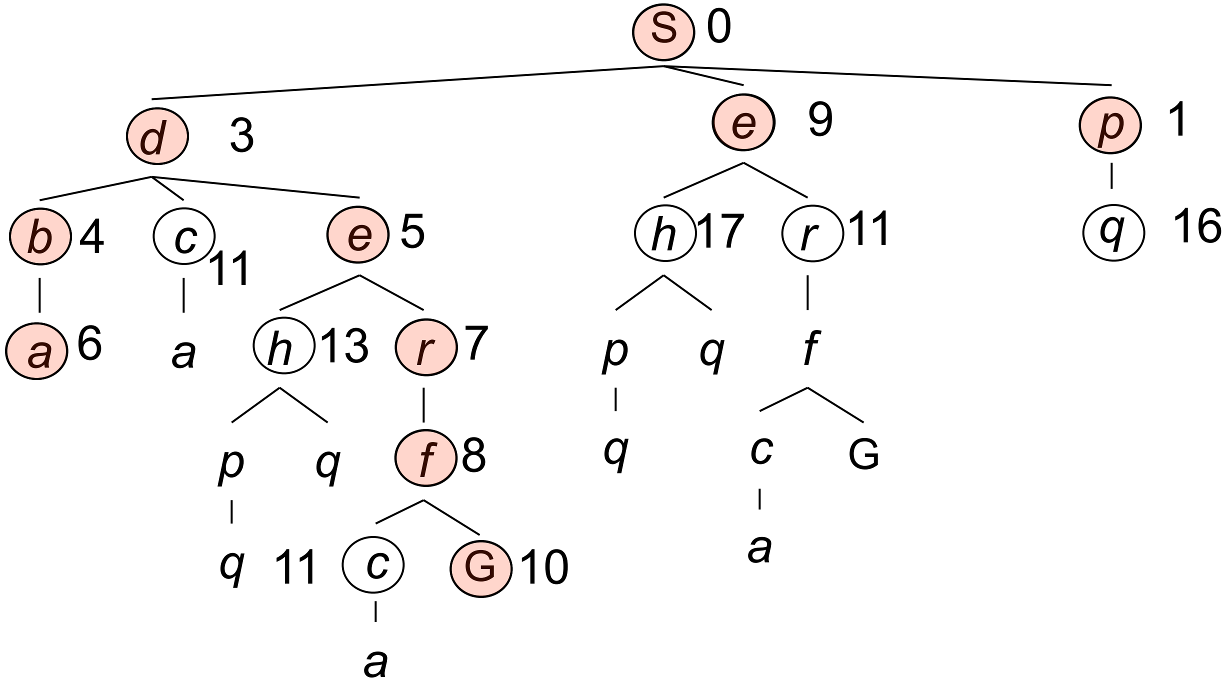

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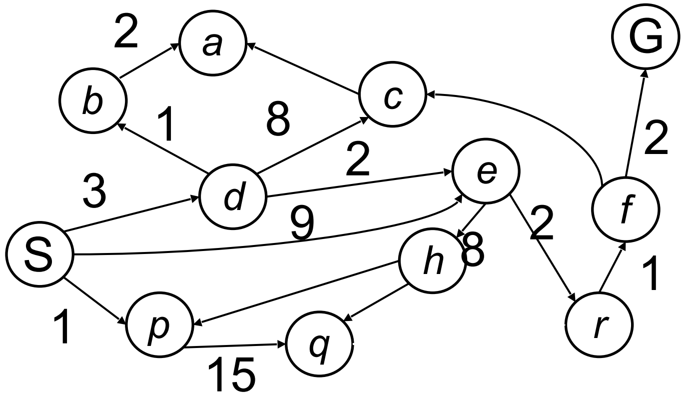
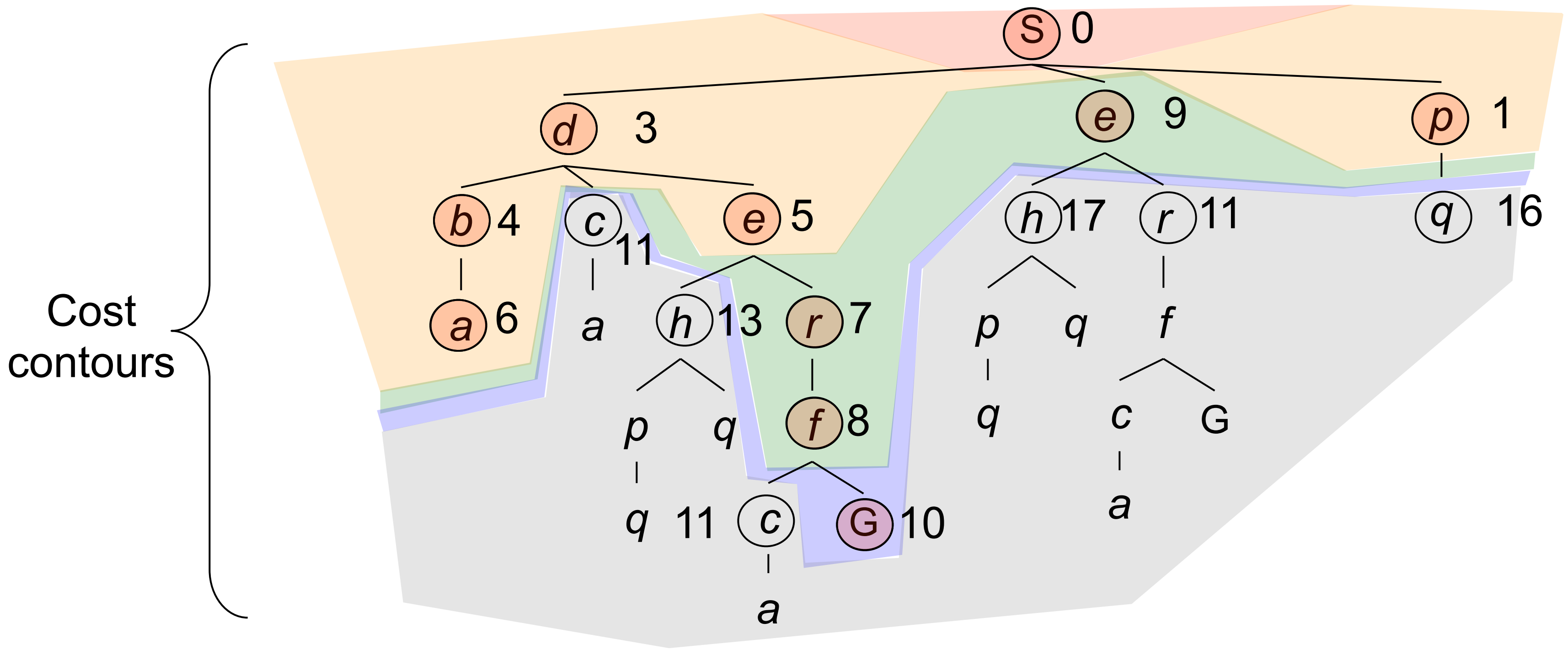
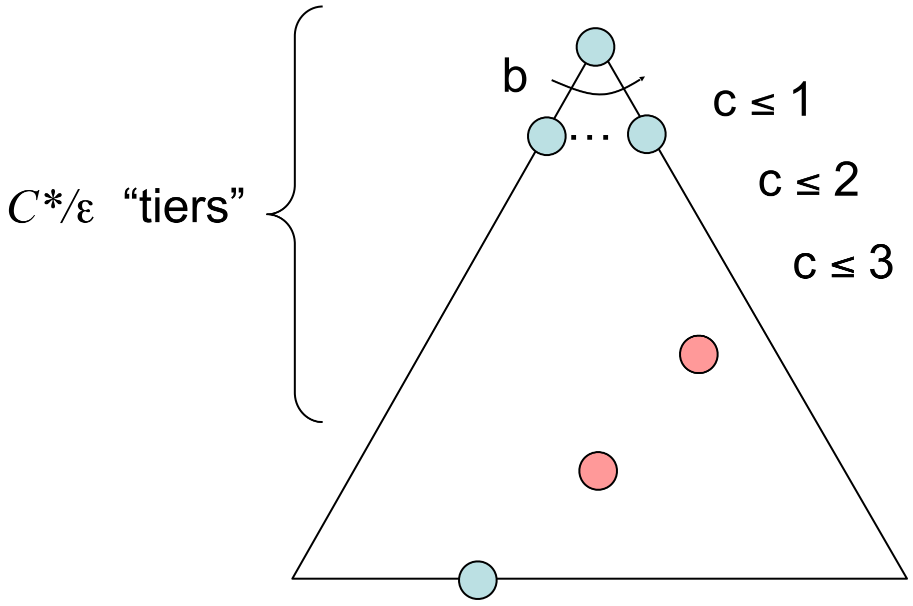




Uniform Cost Search (UCS) Properties

- What nodes does UCS expand?



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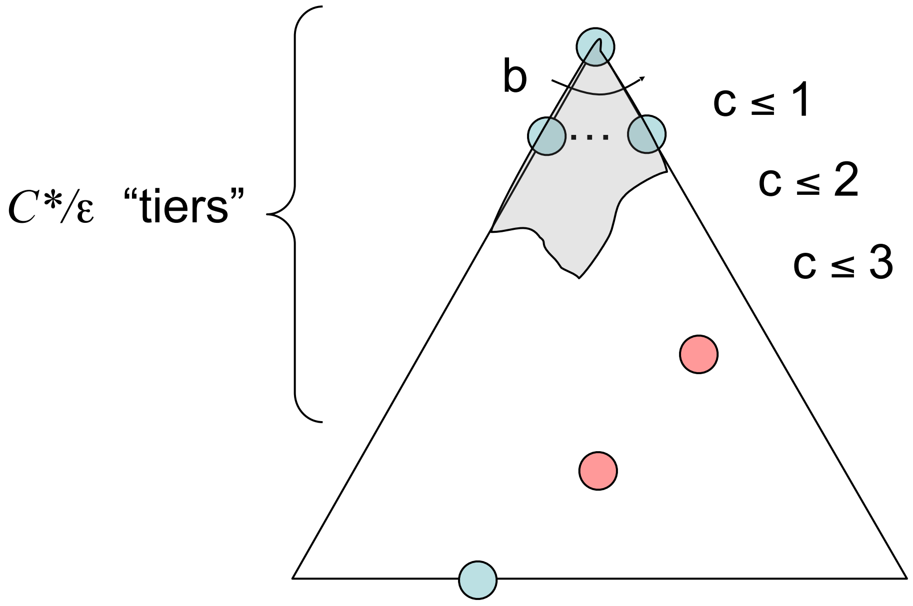

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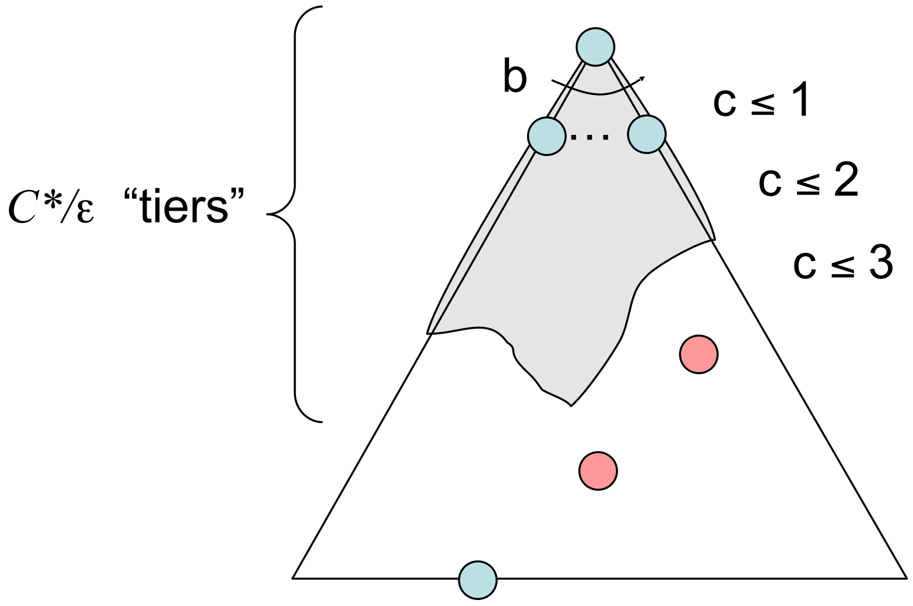

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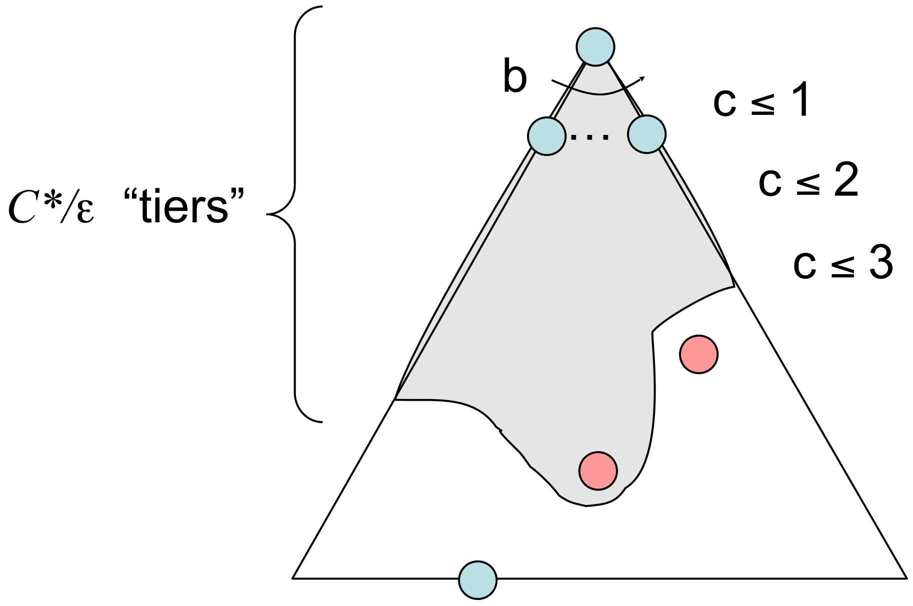

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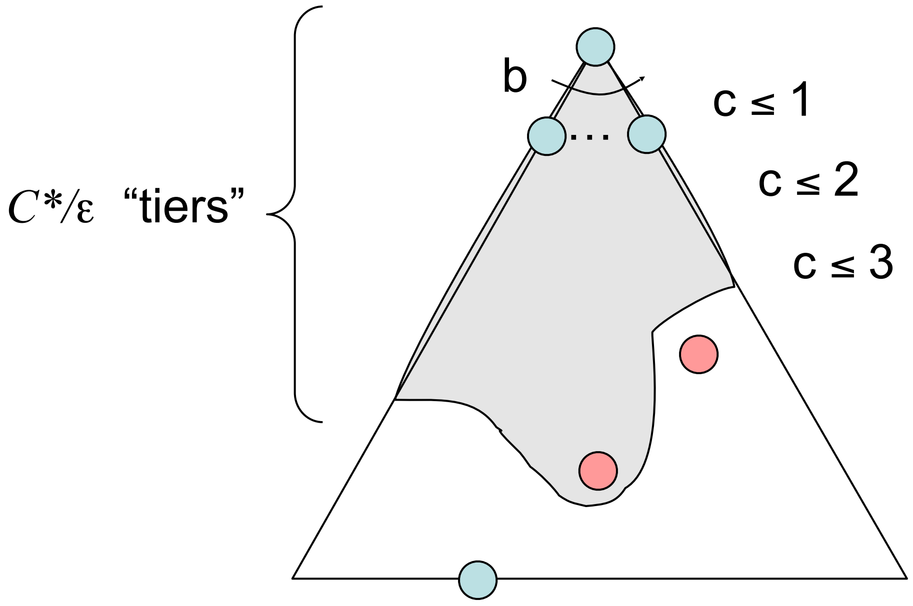

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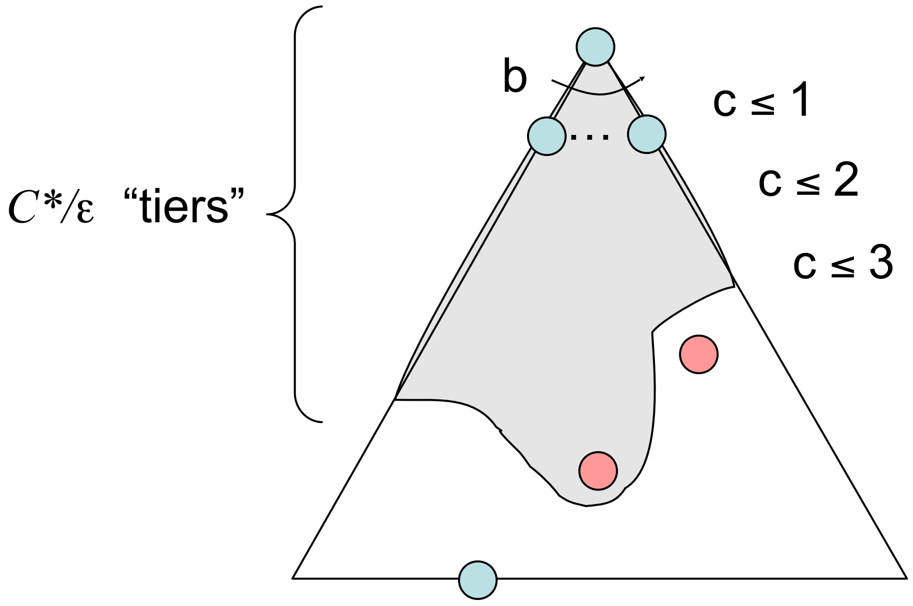

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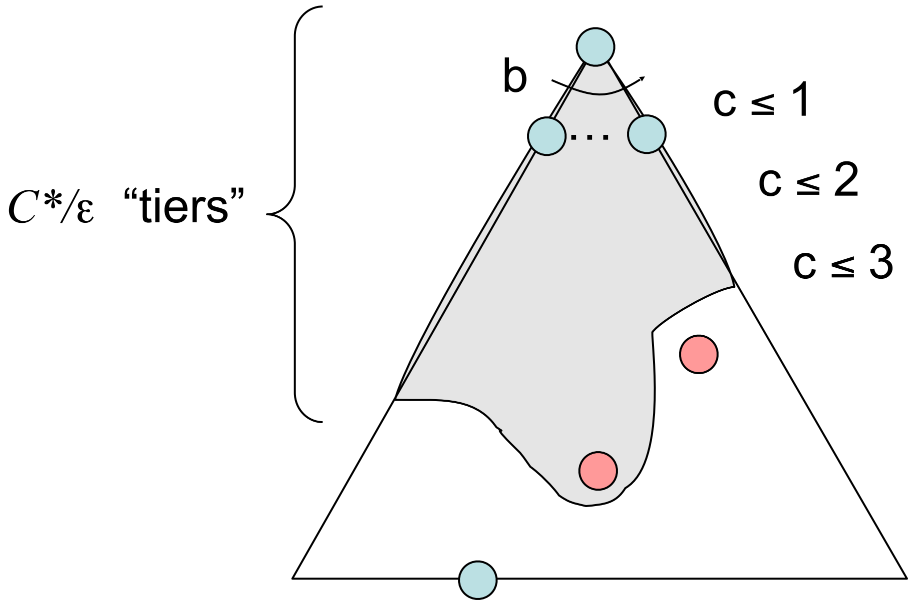

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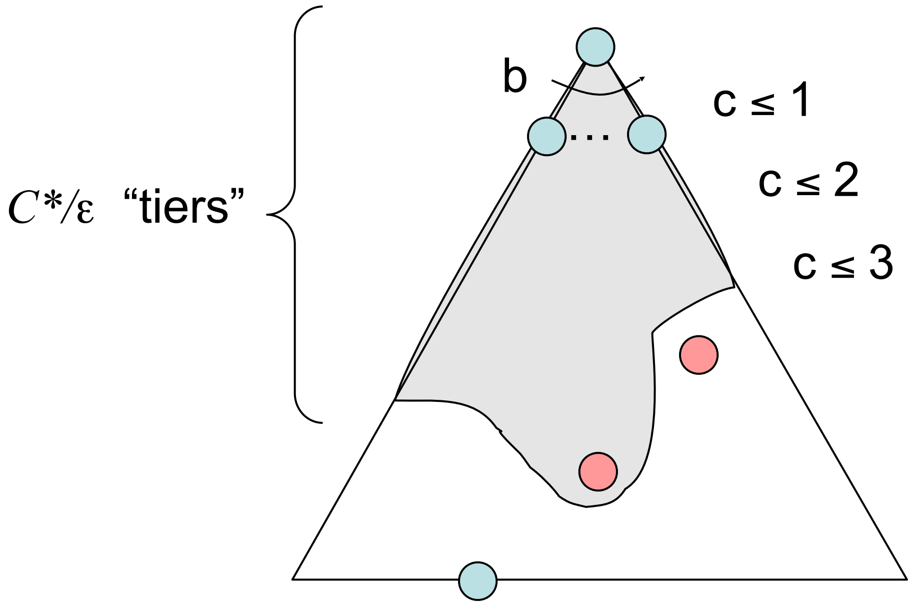

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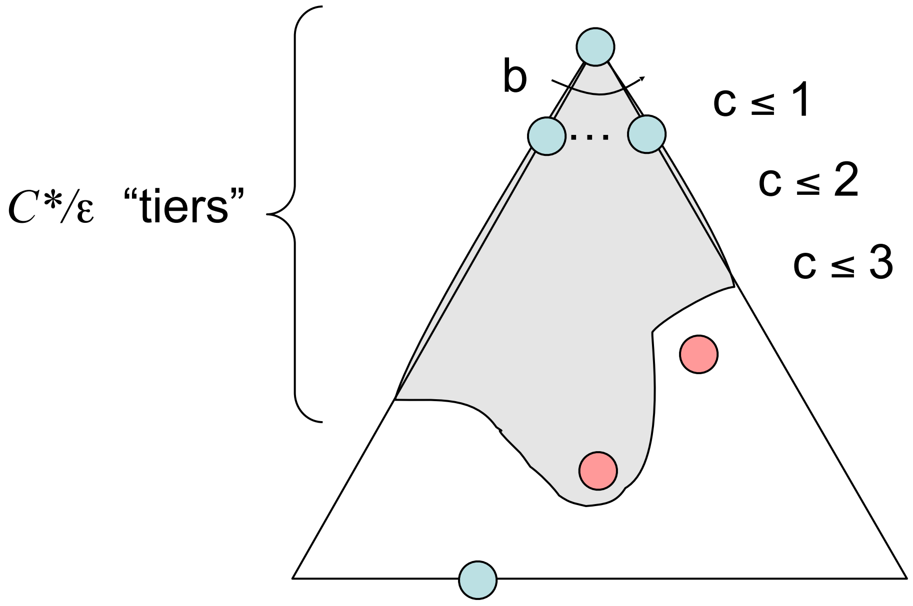
- How much space does the fringe take?
  - Has roughly the last tier, so O($b^{C*/\varepsilon}$)



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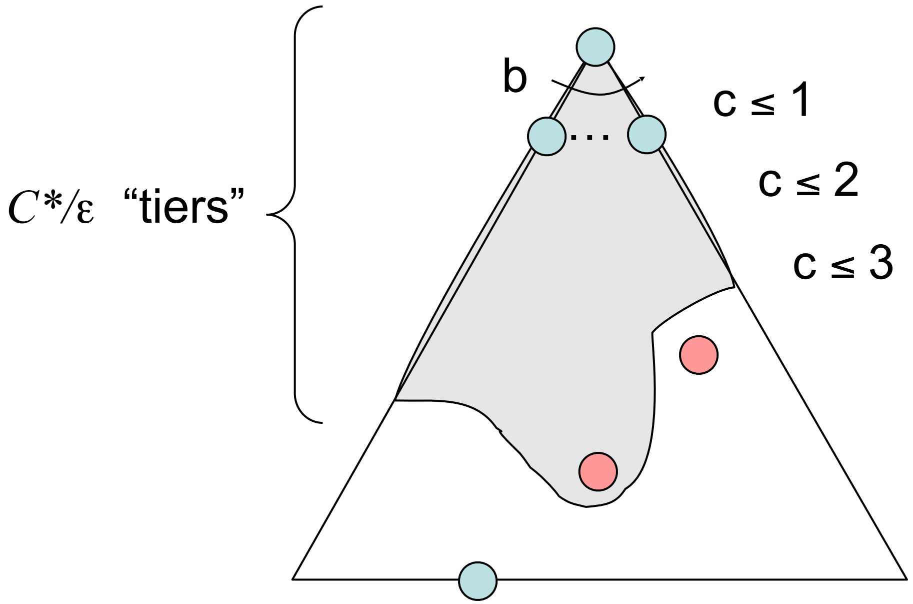
- How much space does the fringe take?
  - Has roughly the last tier, so $O(b^{C^*/\varepsilon})$
- Is it complete?



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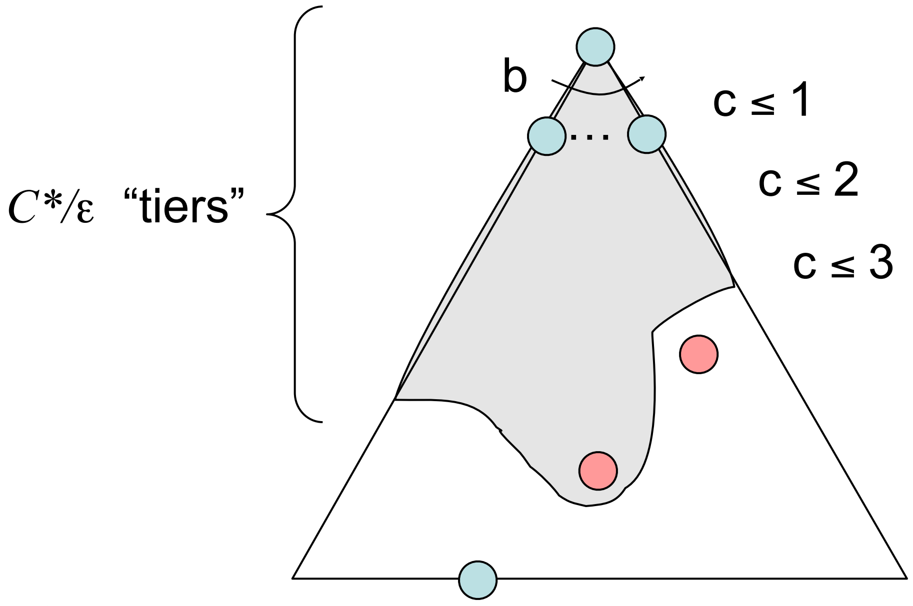

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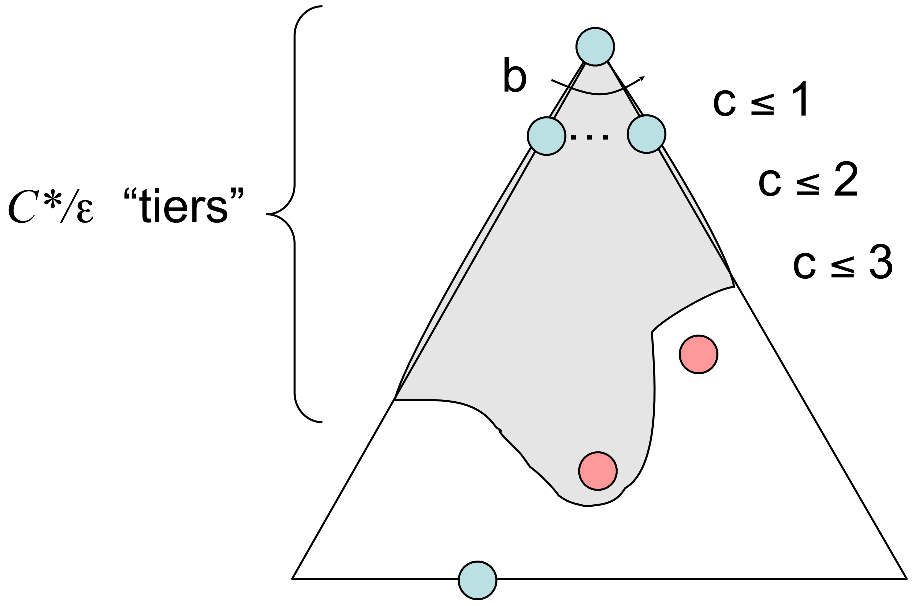
- Is it optimal?



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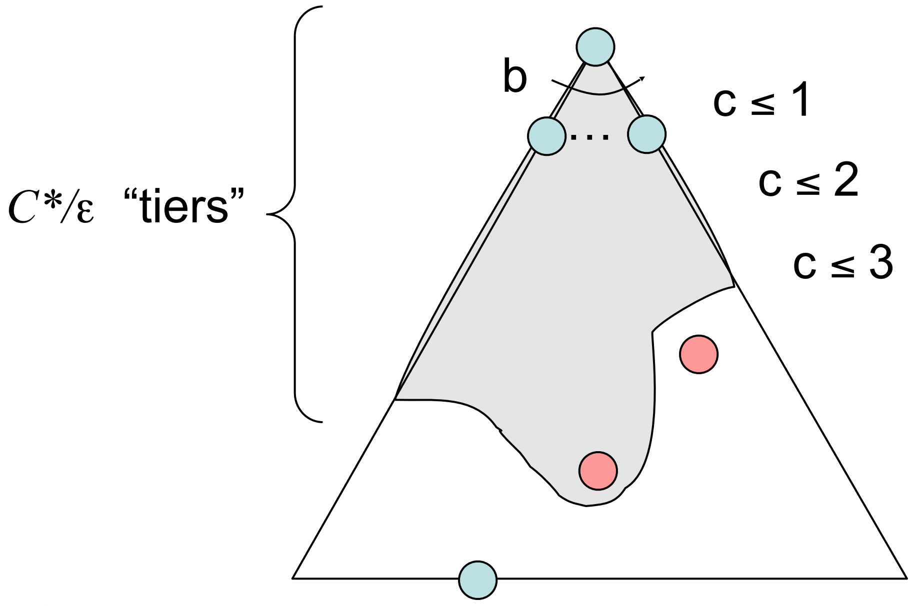
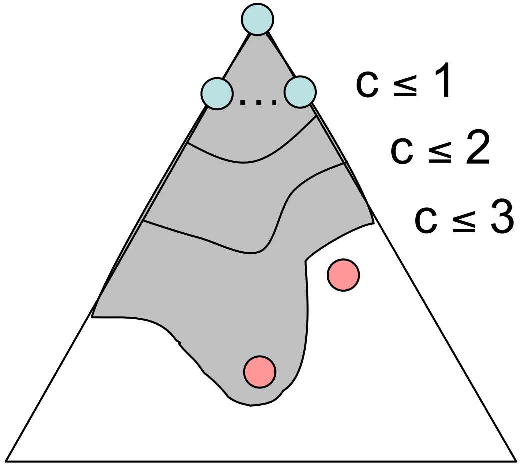
- Is it optimal?
  - Yes! (Proof next lecture via A*)



Uniform Cost Issues

- Remember: UCS explores increasing cost contours

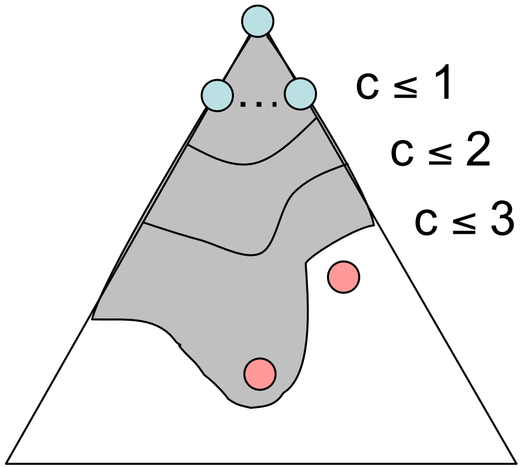
- The good: UCS is complete and optimal!



[Demo: empty grid UCS (L2D5)]
[Demo: maze with deep/shallow water DFS/BFS/UCS (L2D7)]

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



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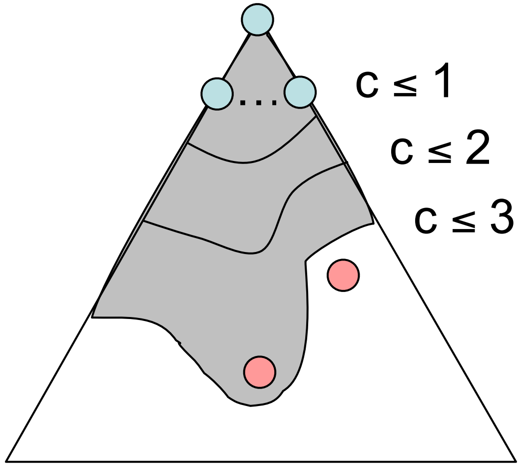

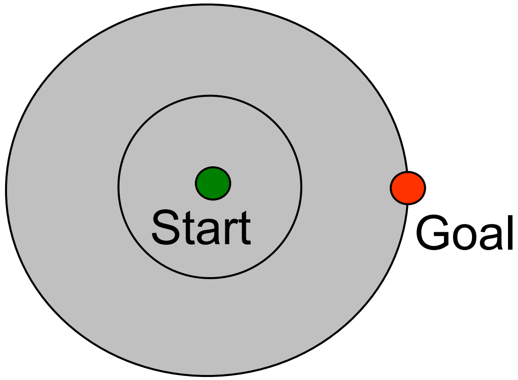

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Uniform Cost Issues

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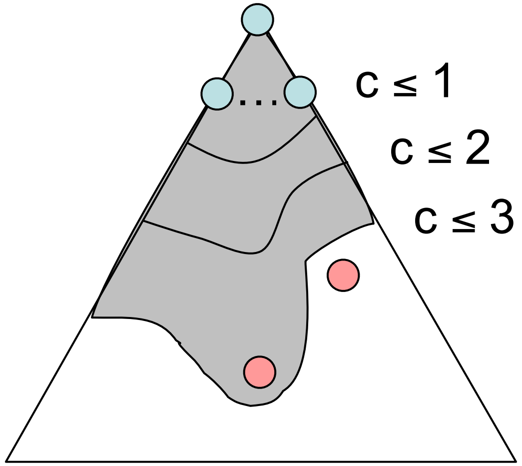
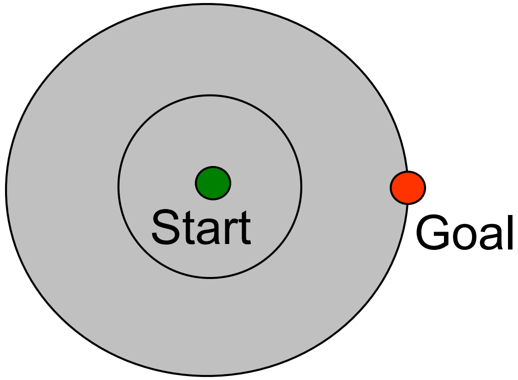
- We'll fix that soon!





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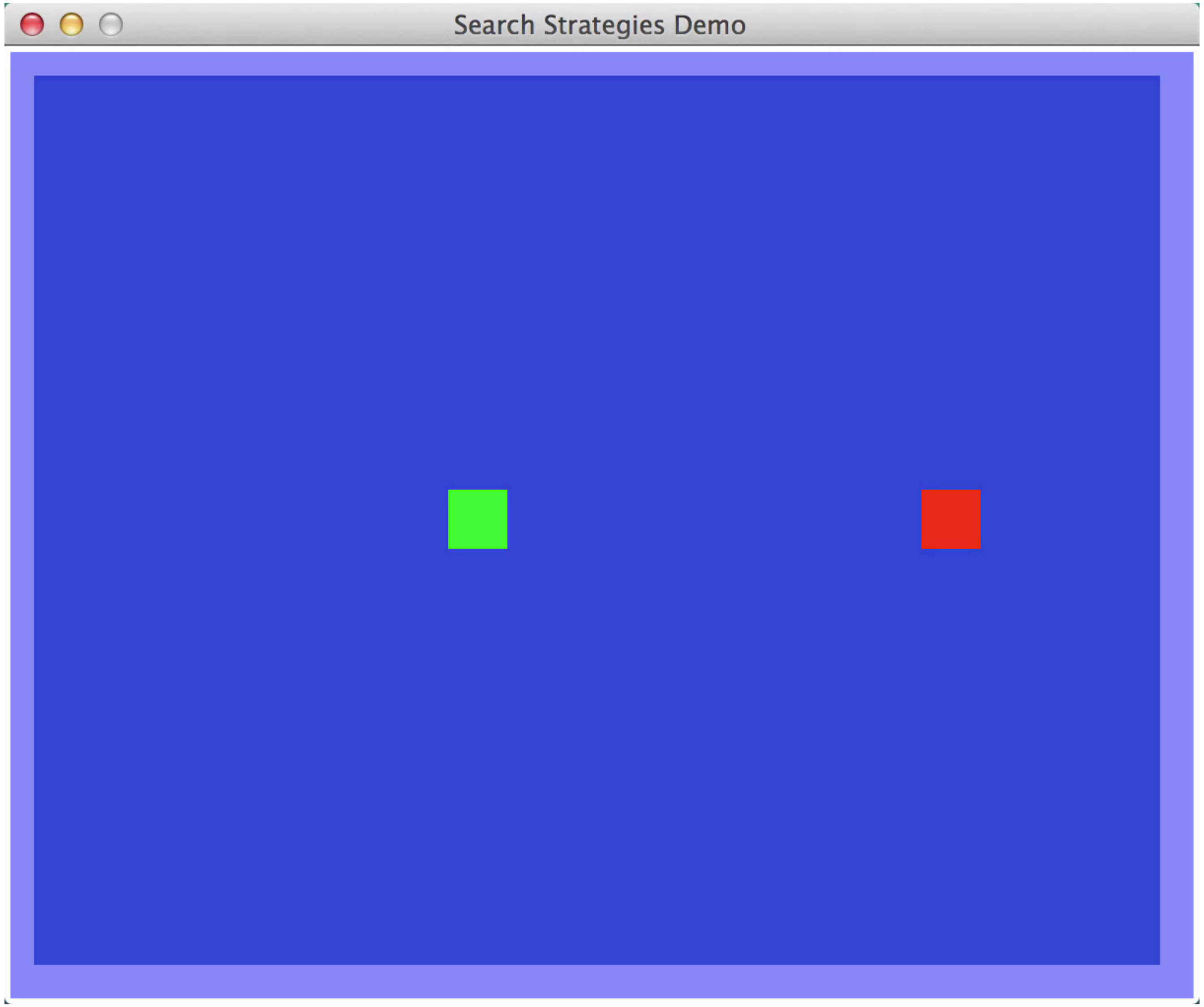
Video of Demo Empty UCS



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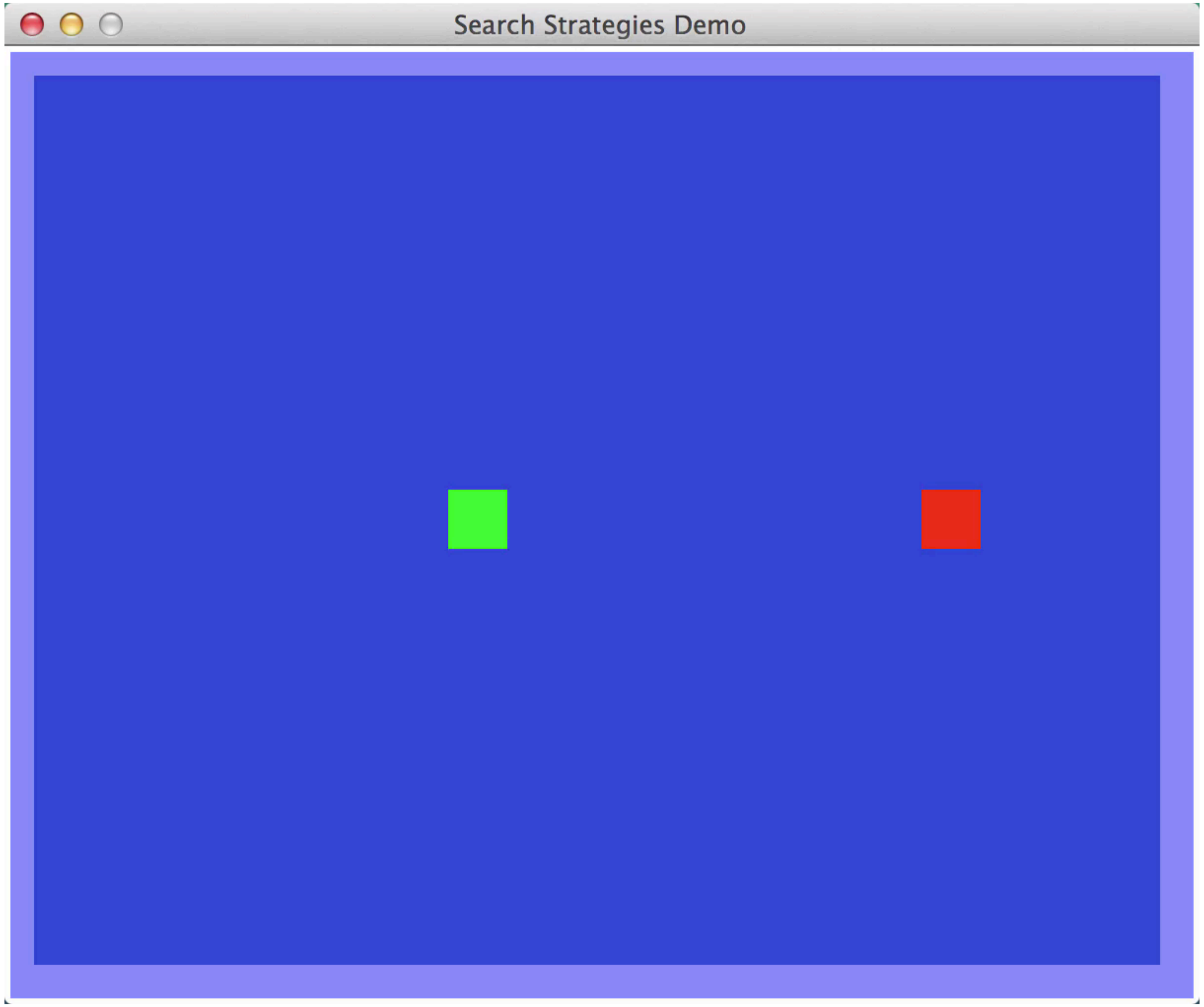
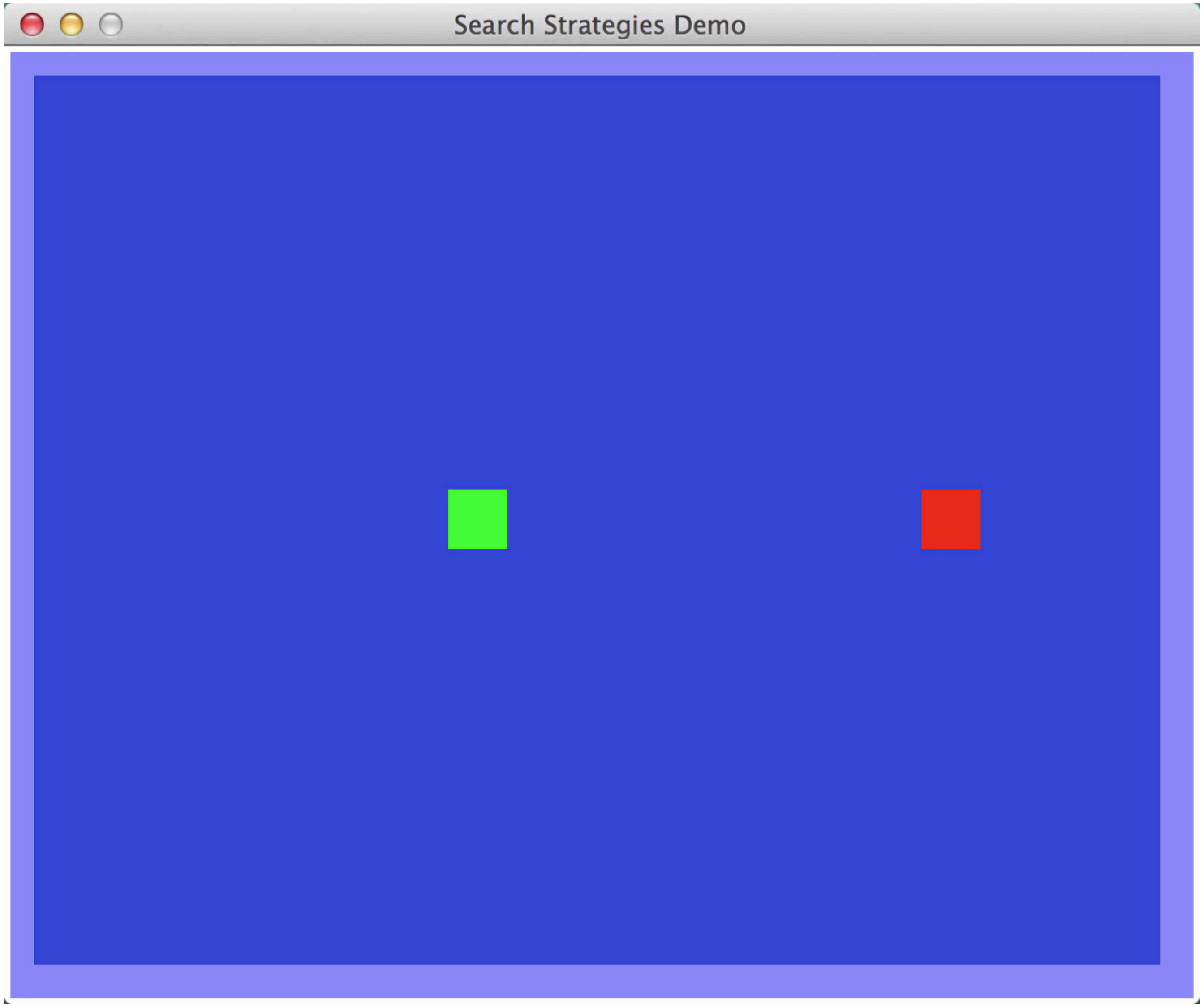
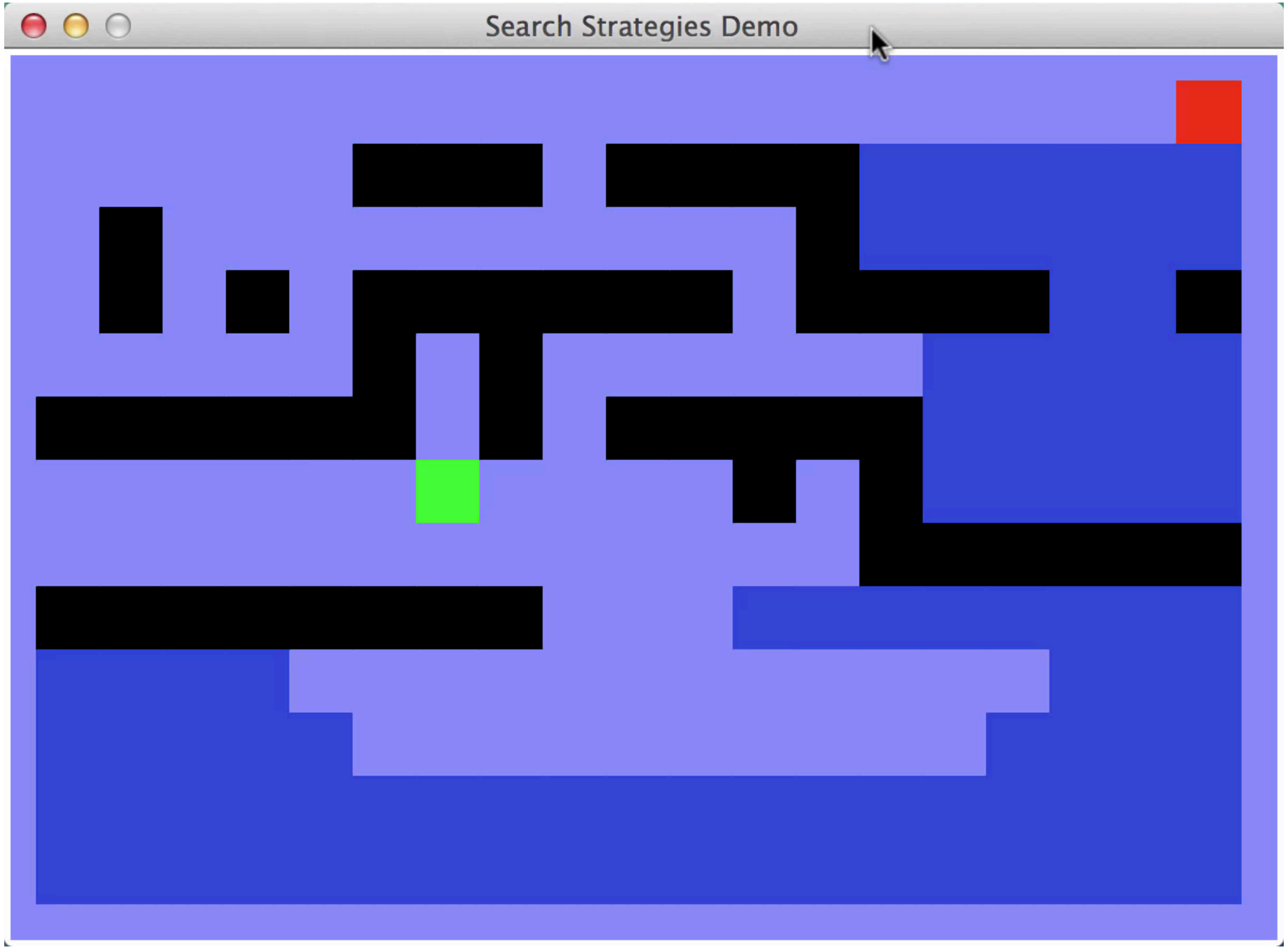


Video of Demo Empty UCS



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



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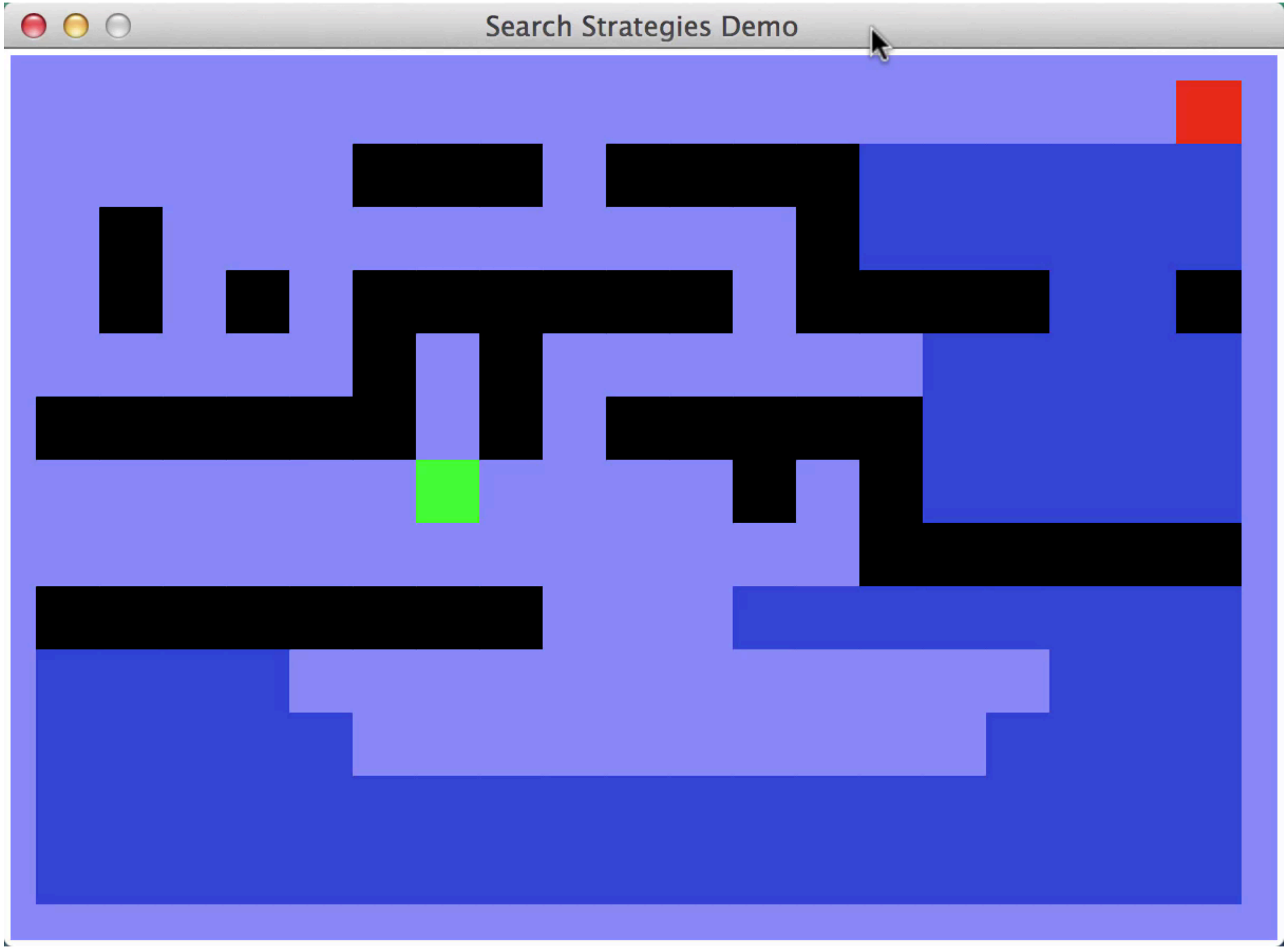

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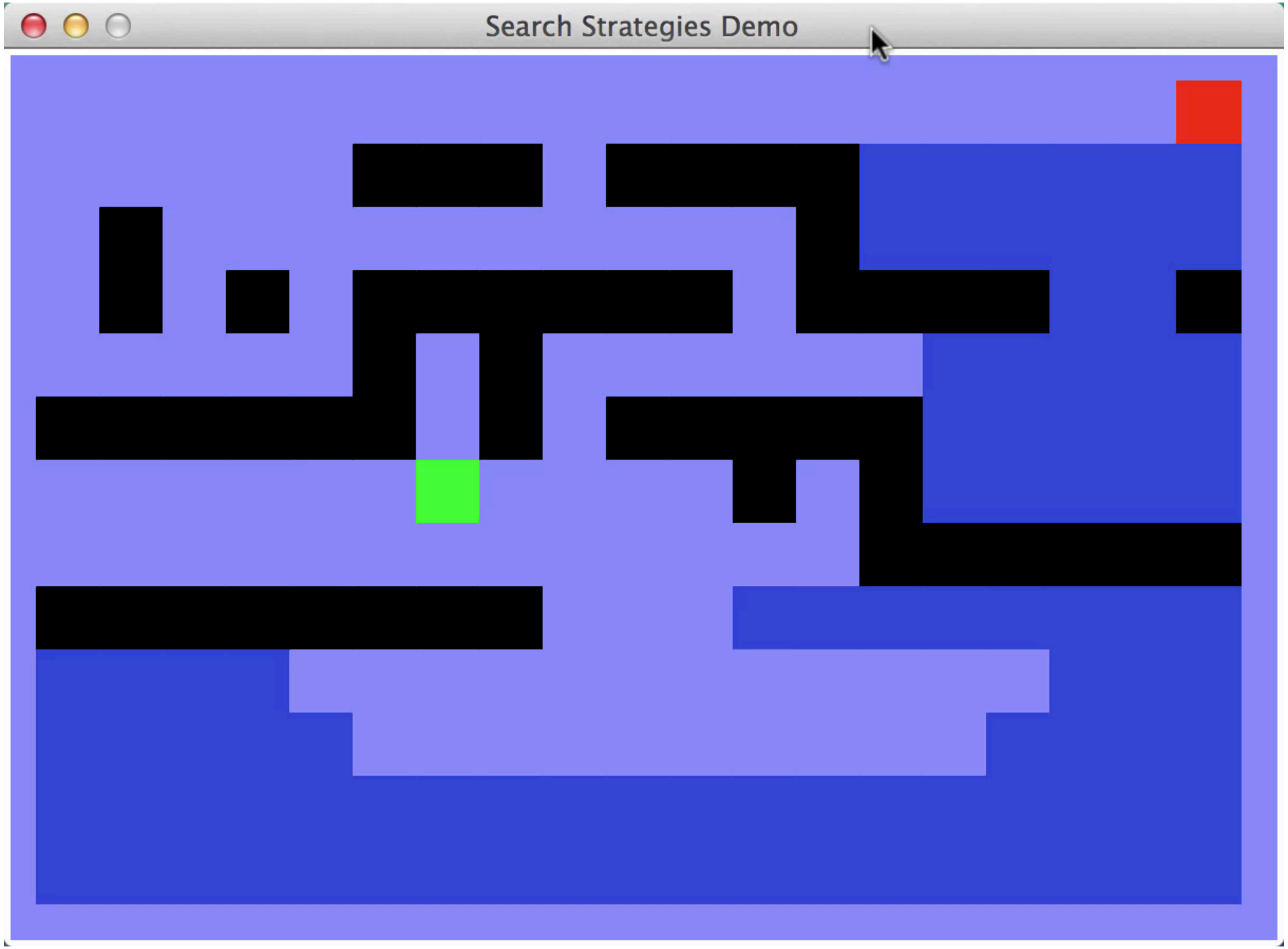
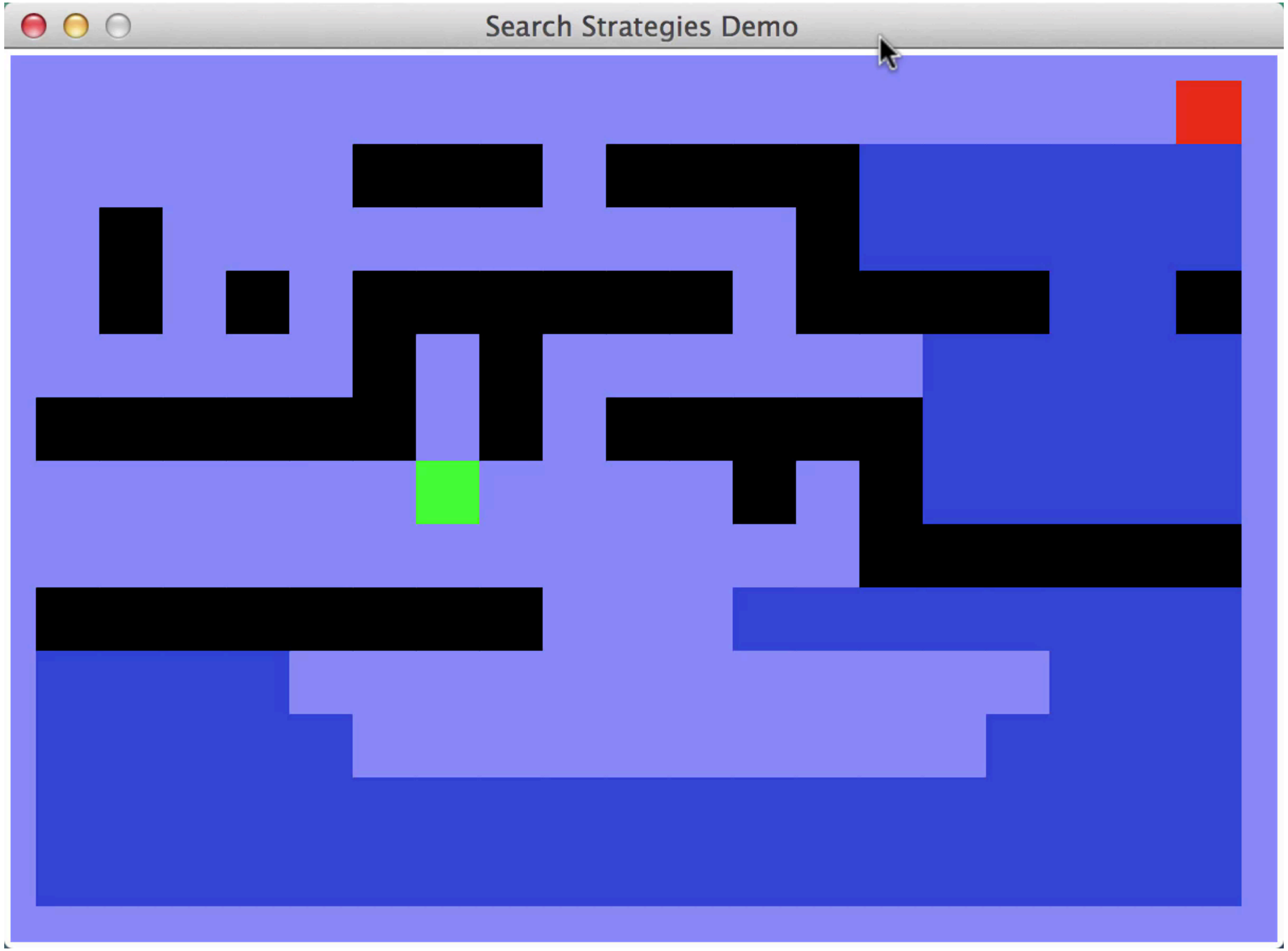
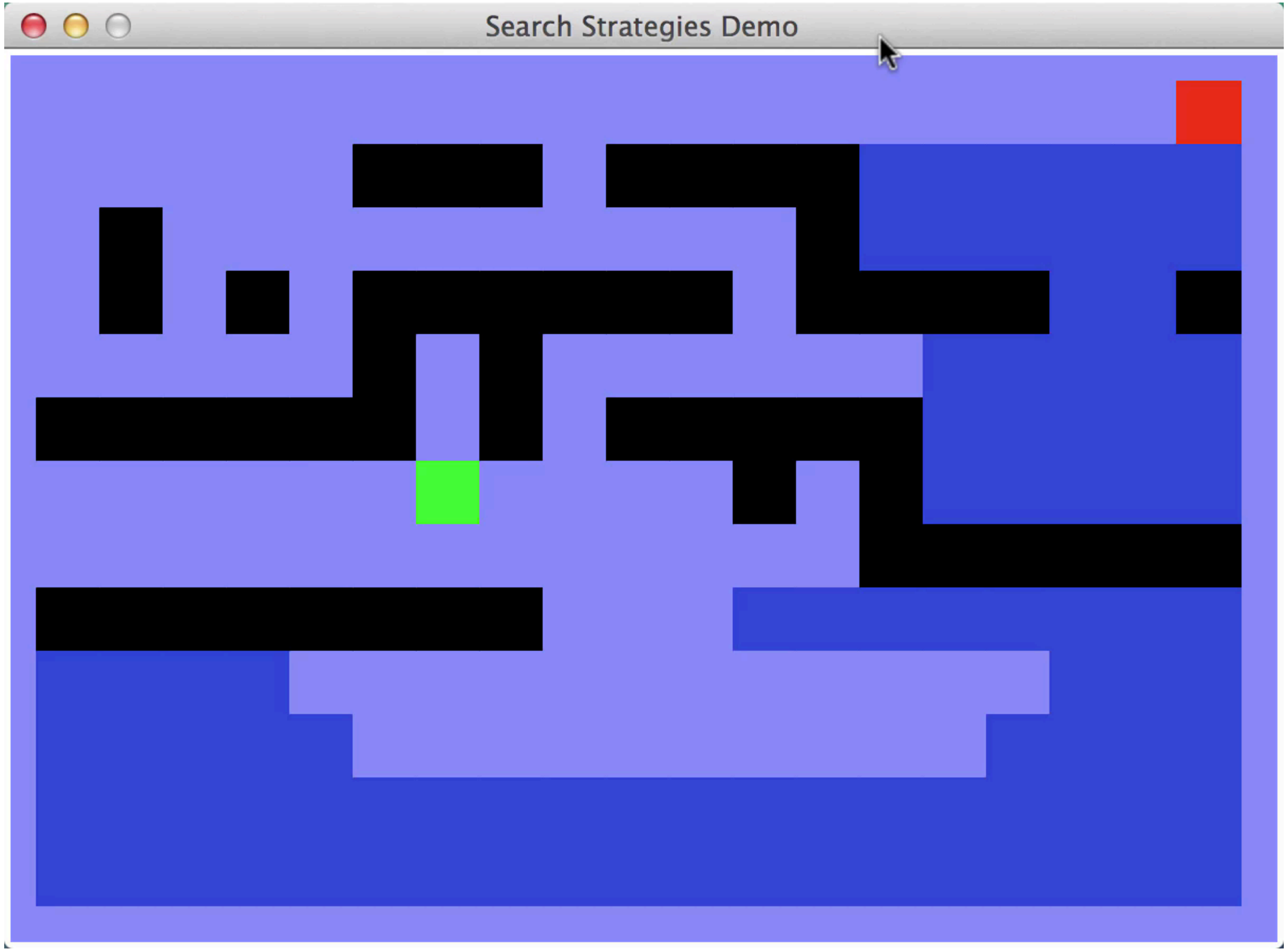


Video of Demo Maze with Deep/Shallow Water --- DFS, BFS, or UCS? (part 2)



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



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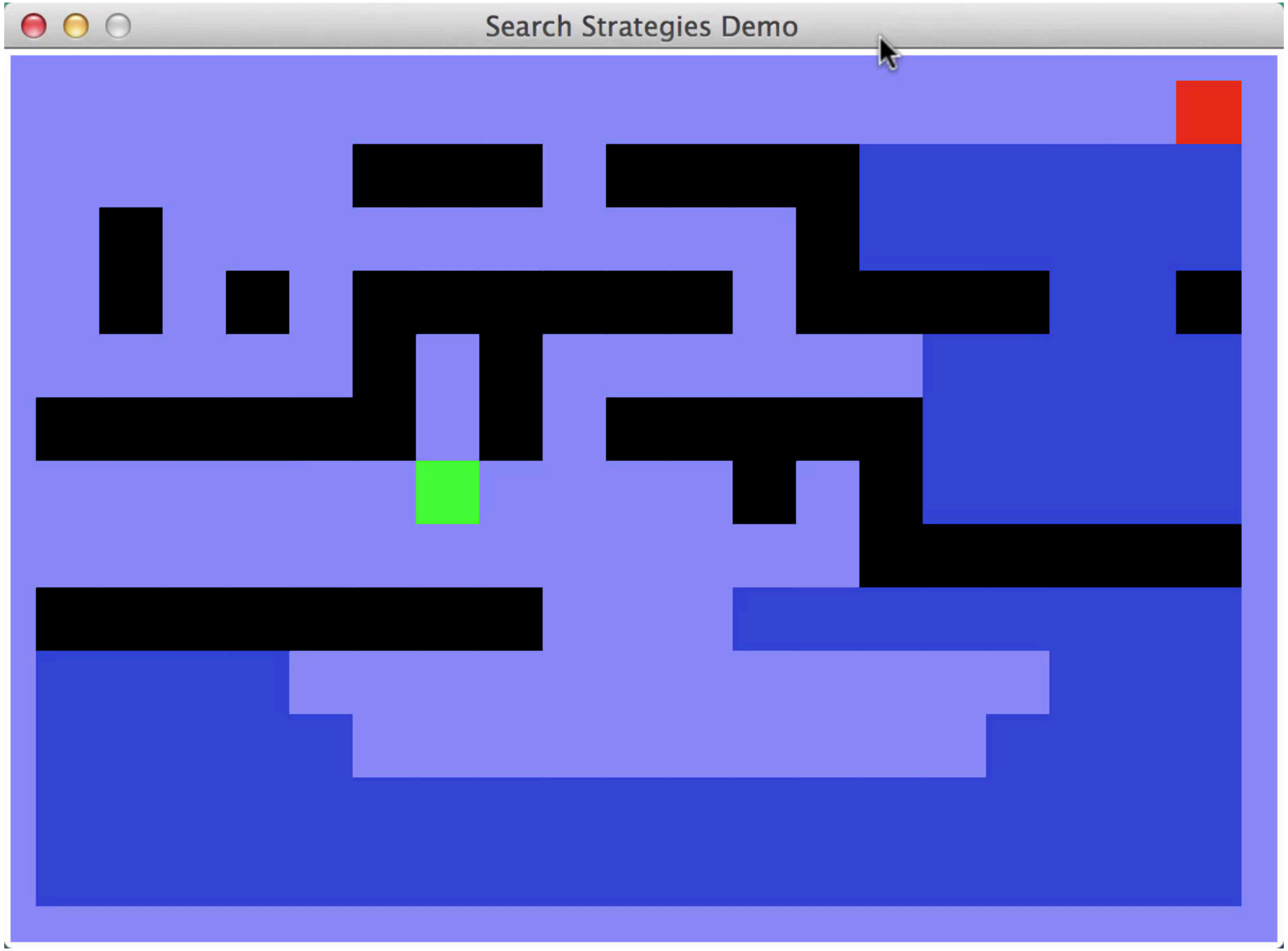
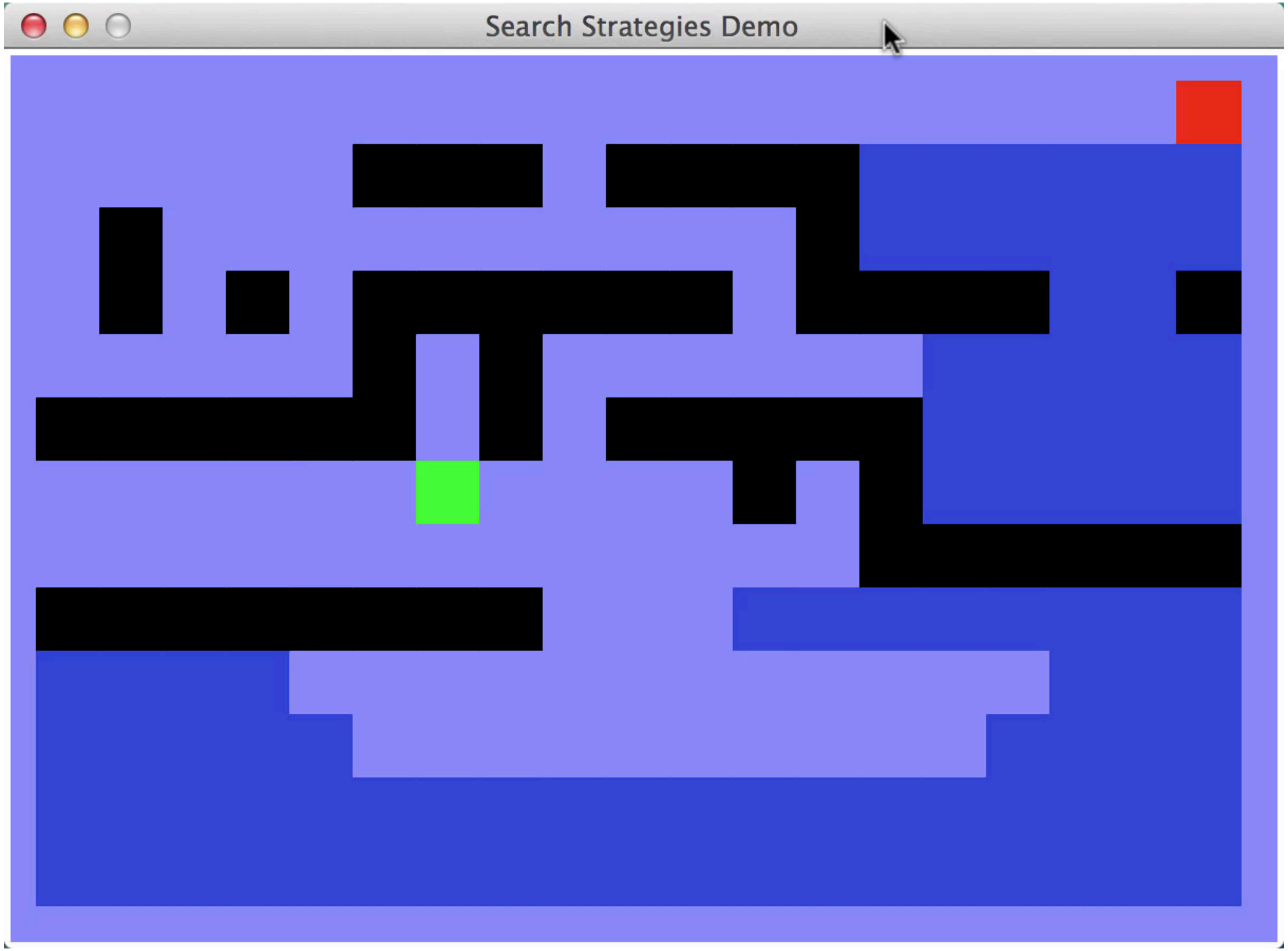
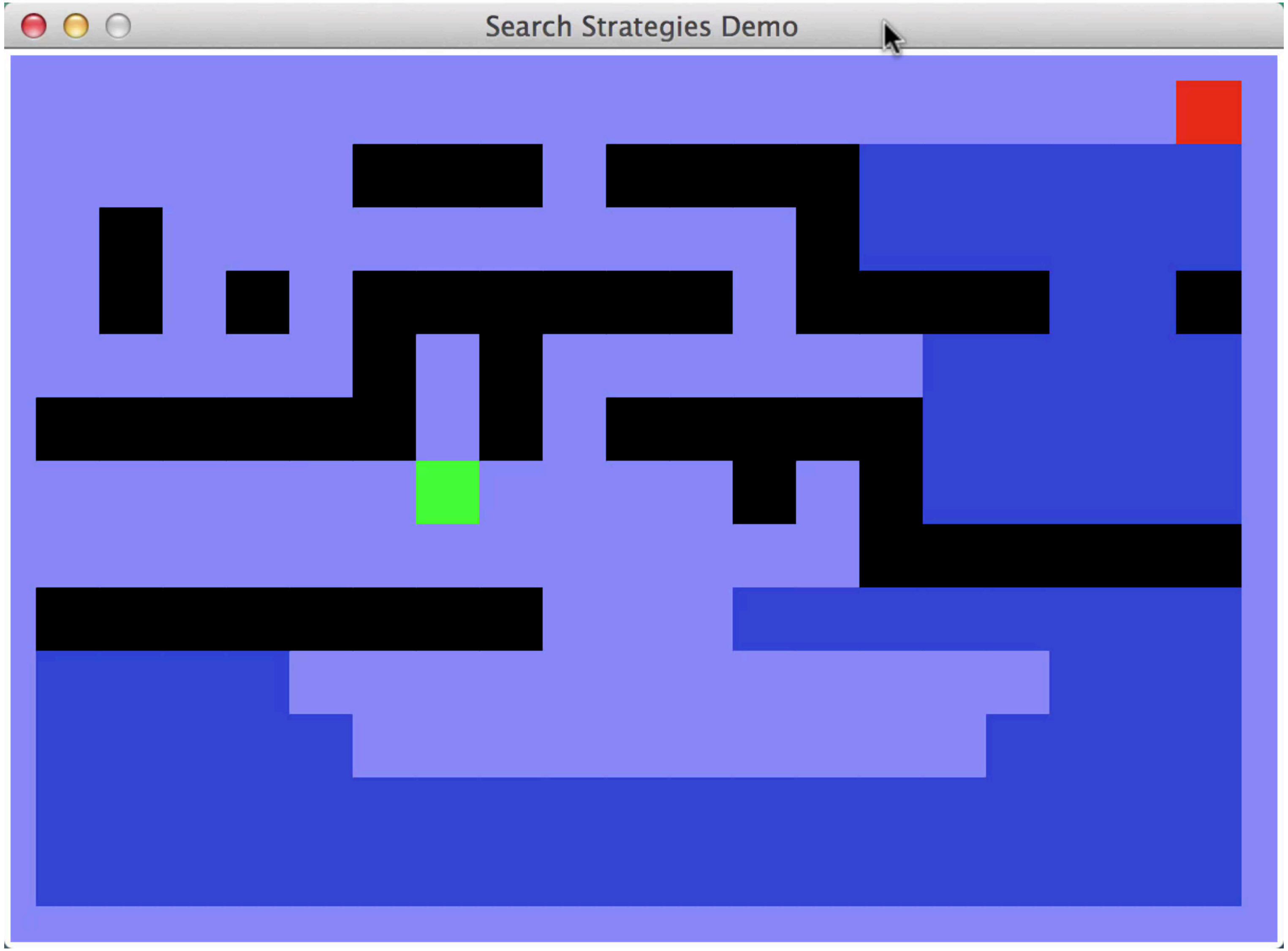


Video of Demo Maze with Deep/Shallow Water --- DFS, BFS, or UCS? (part 3)



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



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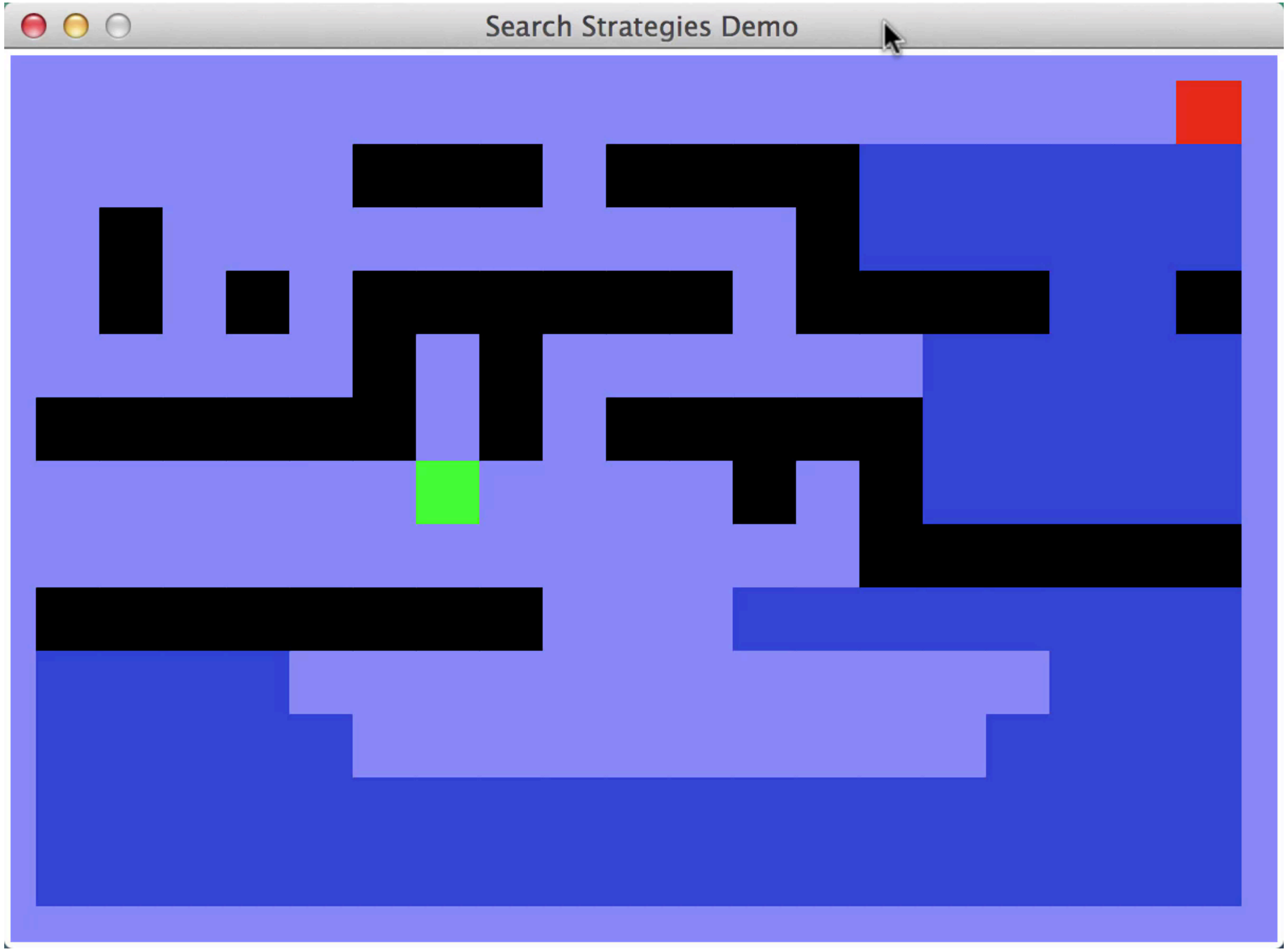
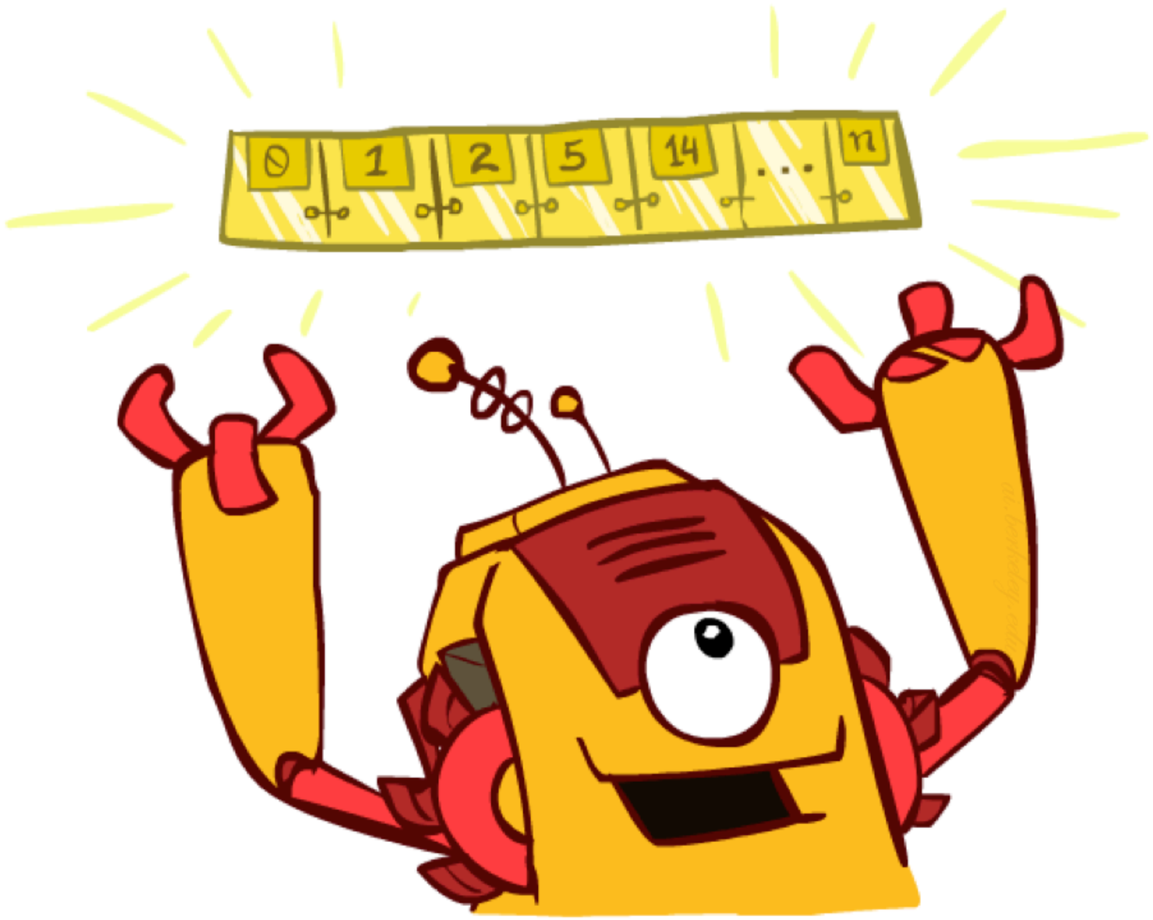


The One Queue

- 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…

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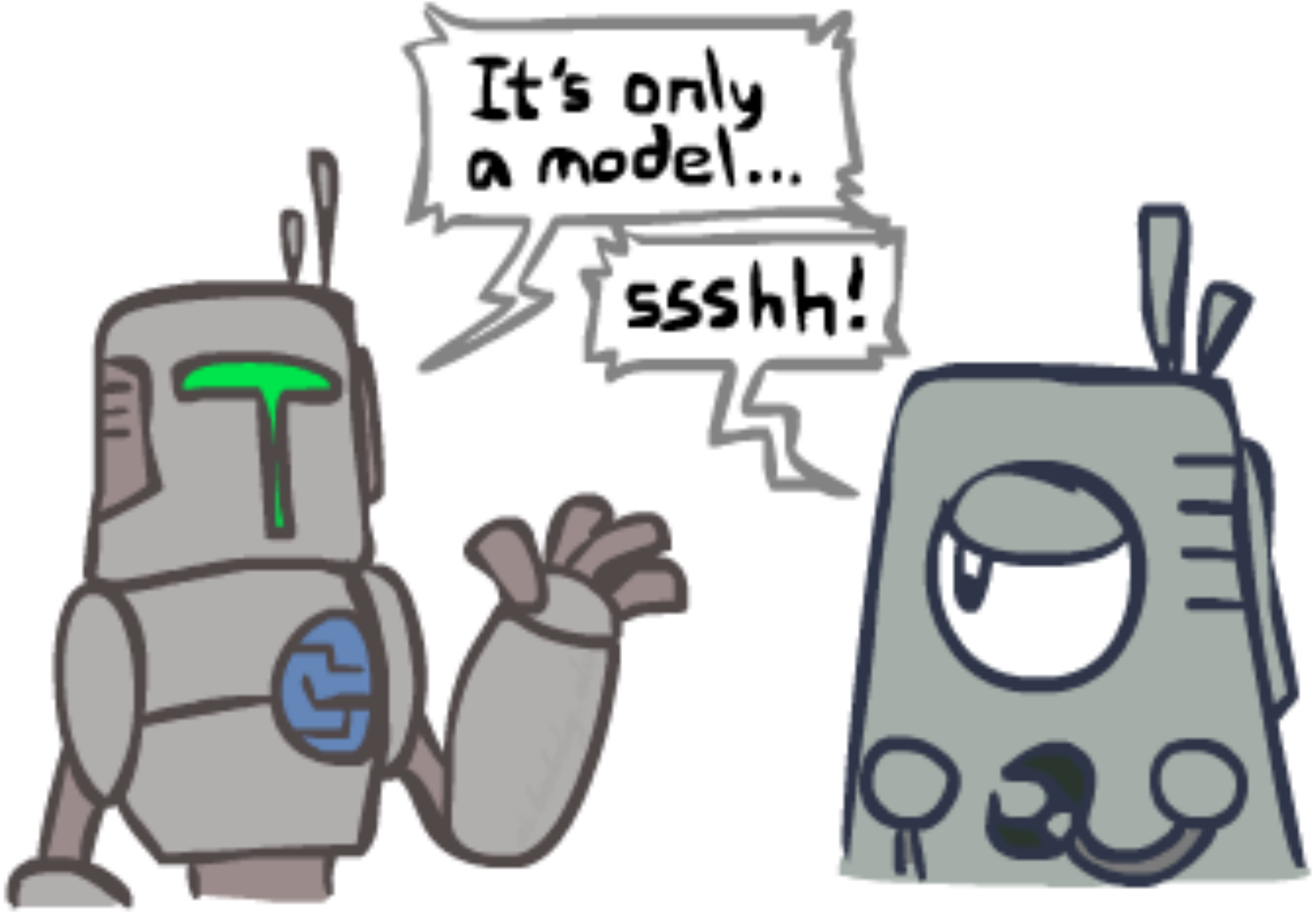

Search Gone Wrong?

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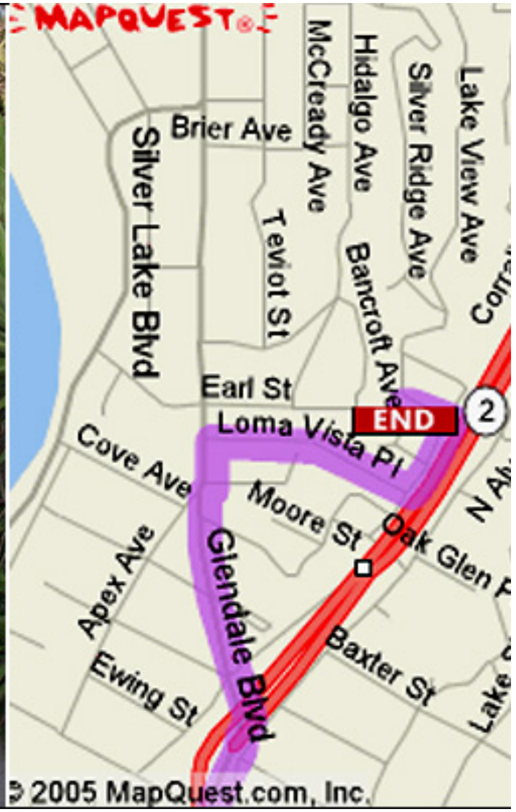

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