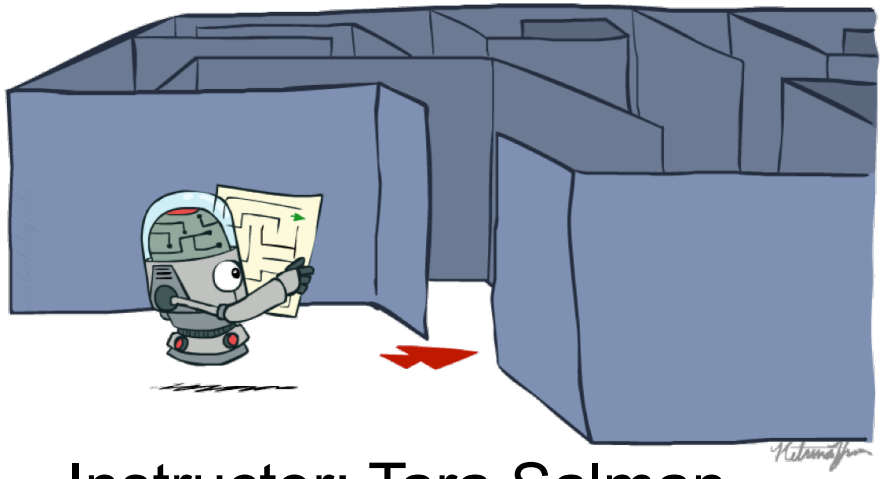
# Announcements

- Project 0: Python Tutorial
  - Due September 7th
  - Submitted via Blackboard
- Homework 0: Math self-diagnostic
  - Due September 7th. Optional, but important to check your preparedness for second half
  - Submitted via Gradescope
- Pinned posts on piazza
- Reminder:
  - Sign up for Gradescrope
  - Check Piazza for Announcement
  - Both Course website and Blackboard are for course content (slides, recordings, and other resources)
  - If you see a mismatch, please inform by a Piazza post or email
- I am still waiting for the TA assignment. Hopefully it will be announced by next week

# CS 3568: Intelligent Systems

## Search (Part 1)



Instructor: Tara Salman

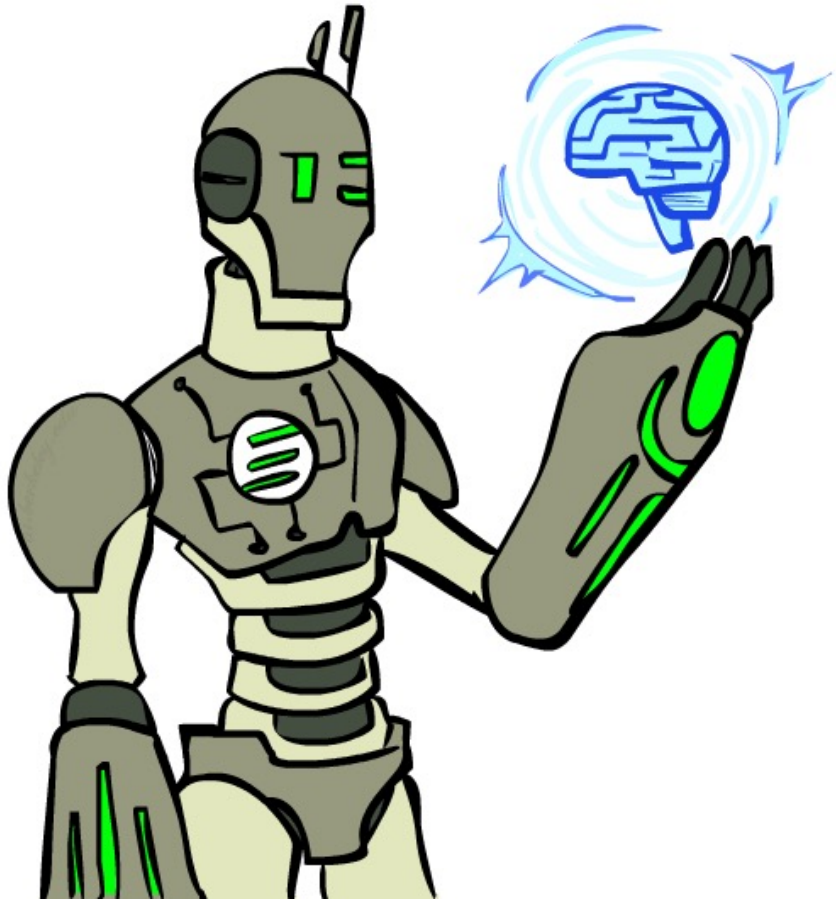
Texas Tech University

Computer Science Department

[These slides were created by Dan Klein and Pieter Abbeel for CS188 Intro to AI at UC Berkeley (ai.berkeley.edu).]

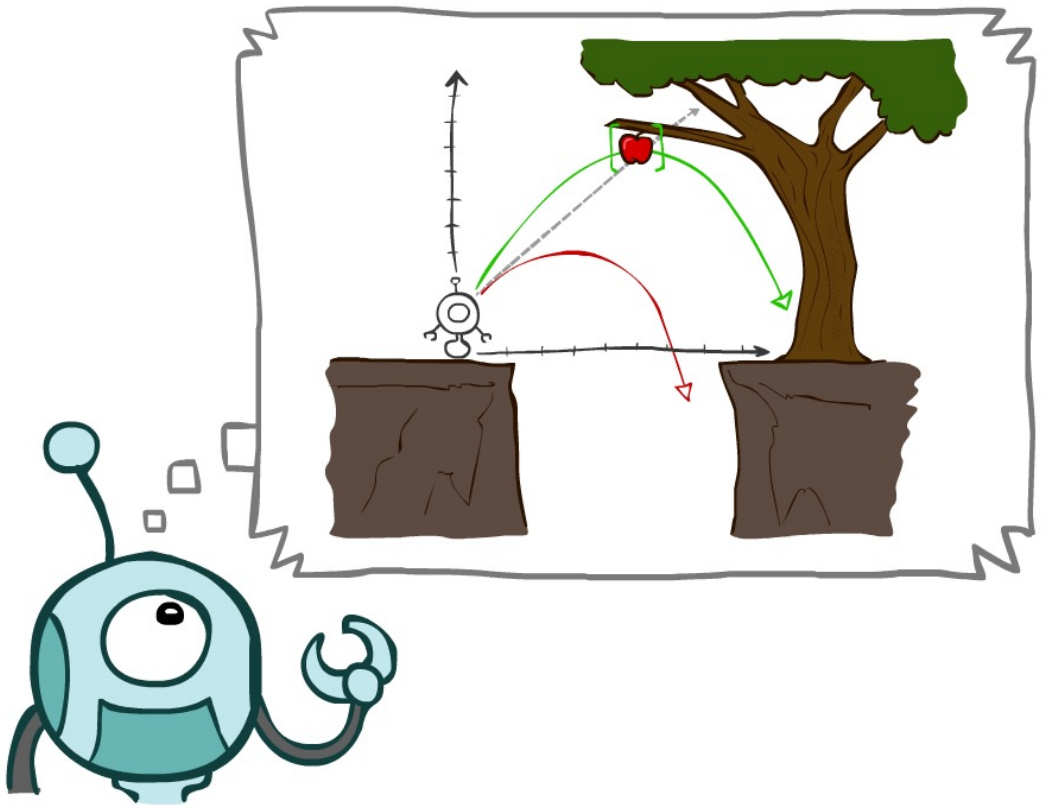
# Last Lecture

- Course information
- What is AI?
- History of AI
- What can we currently AI do?
  - Different applications?
- What is this course?

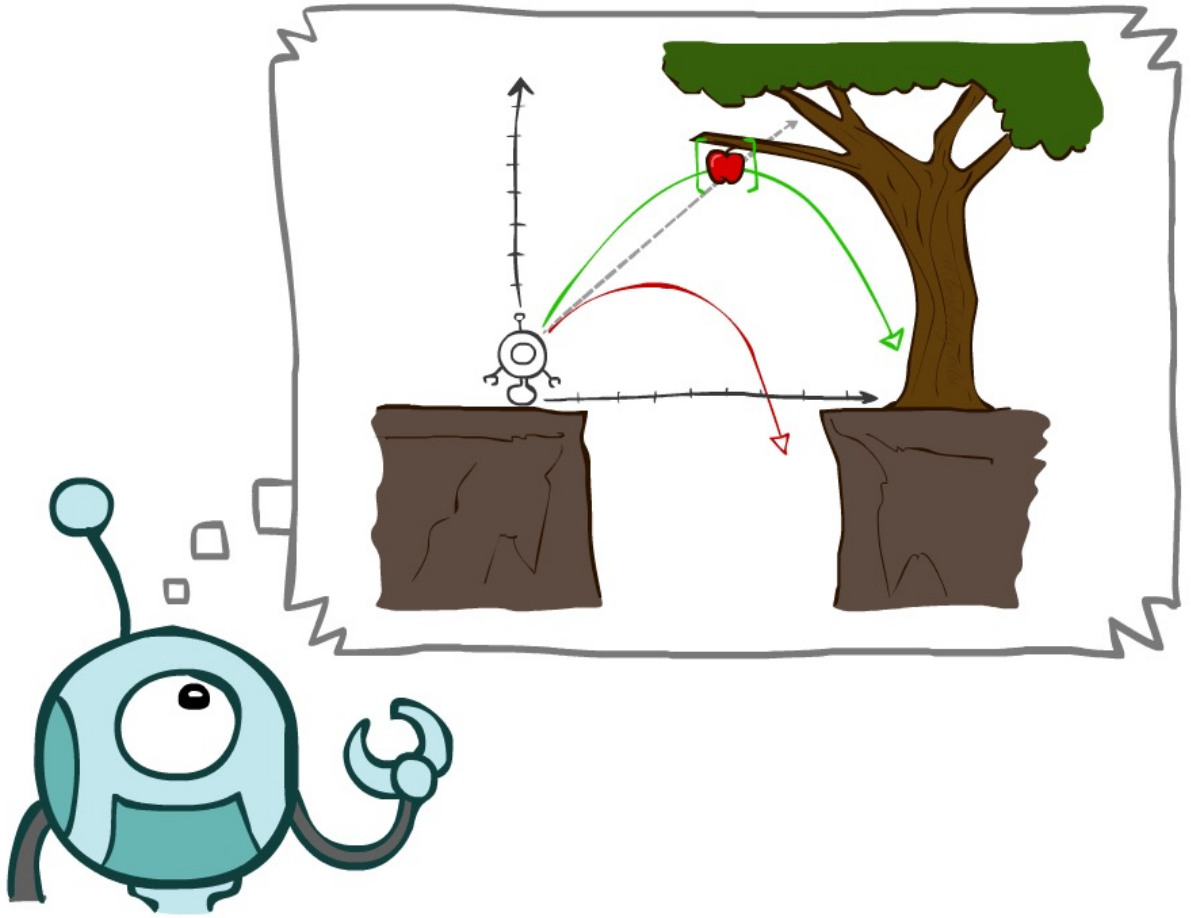


# Today's Lecture

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



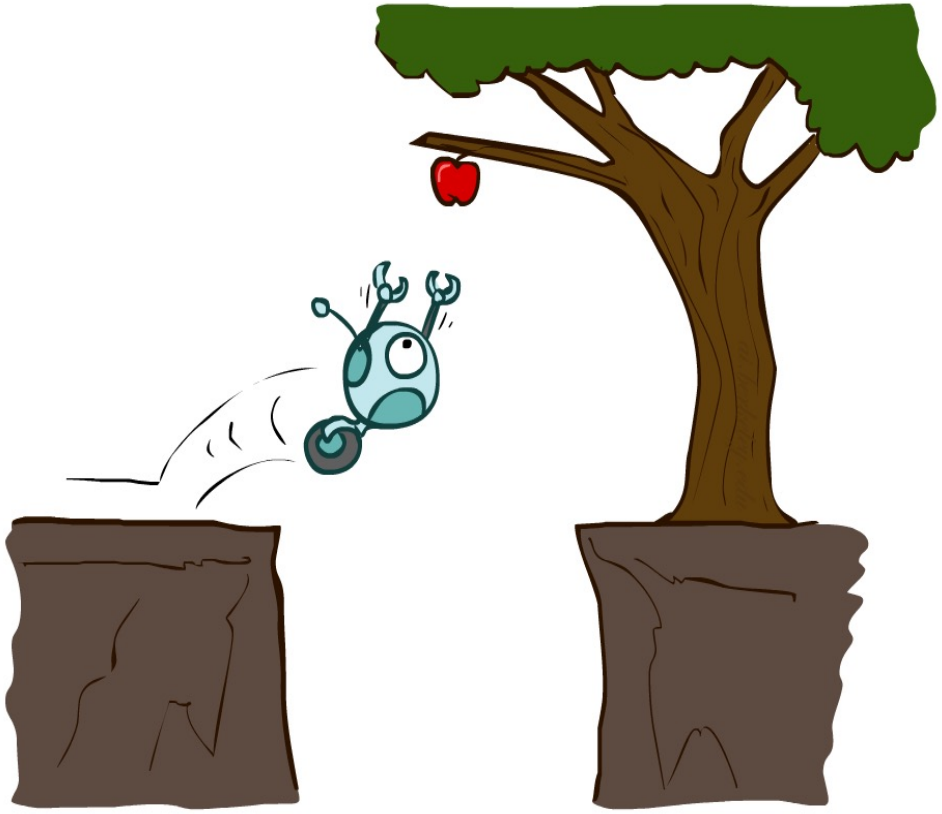
# Agents that Plan



# Reflex Agents

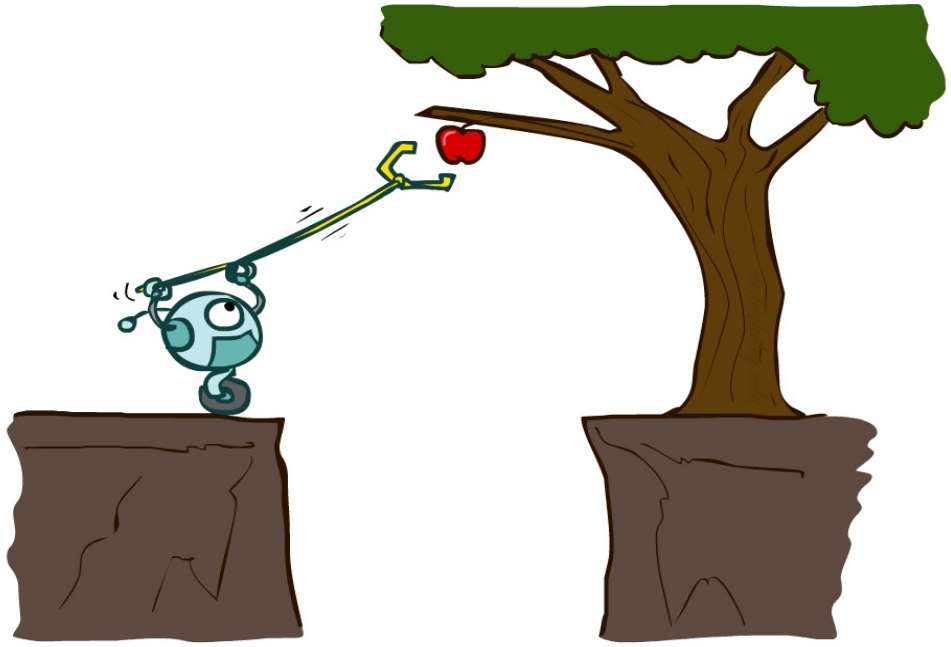
- Reflex agents:
  - Choose action based on current percept (and maybe memory)
  - May have memory or a model of the world's current state
  - Do not consider the future consequences of their actions
  - Consider how the world IS

- When do you need to be a reflex agent?
- Can a reflex agent be rational?



# Planning Agents

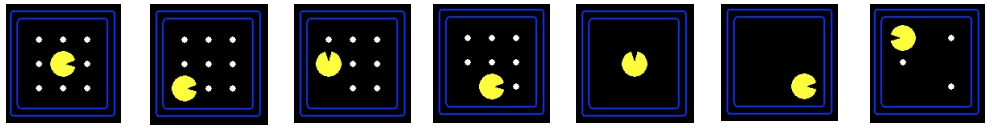
- Planning agents:
  - Ask “what if”
  - Decisions based on (hypothesized) consequences of actions
  - Must have a model of how the world evolves in response to actions
  - Must formulate a goal (test)
  - Consider how the world WOULD BE
- Optimal vs. complete planning
  - Optimal: achieve goal with minimum co
  - Complete: If there is a solution, it can find it.
- Planning vs. replanning



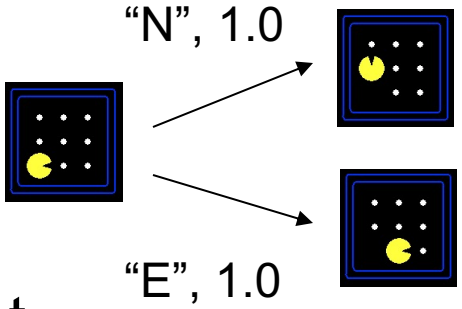
# Search Problems

# Search Problems

- A search problem consists of:
  - A state space



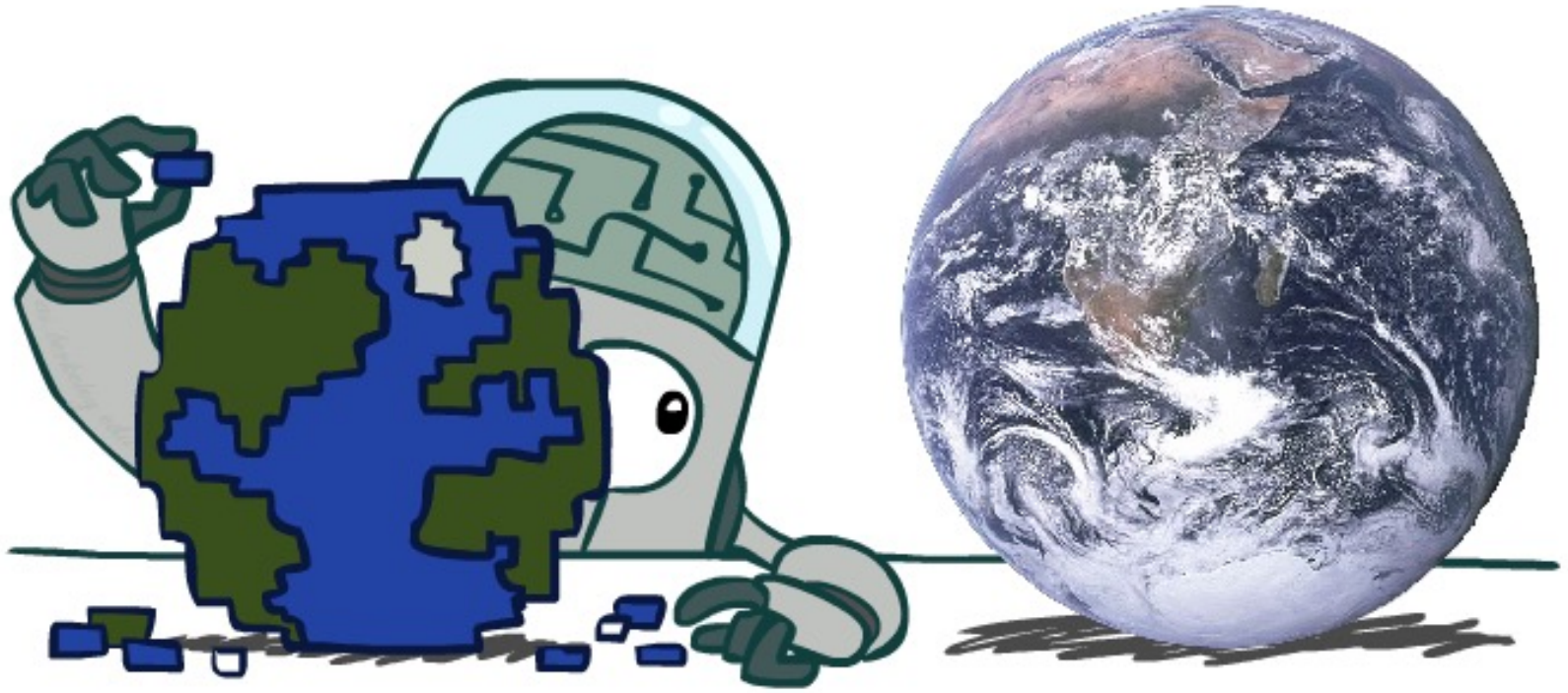
  - A successor function (with actions, costs)



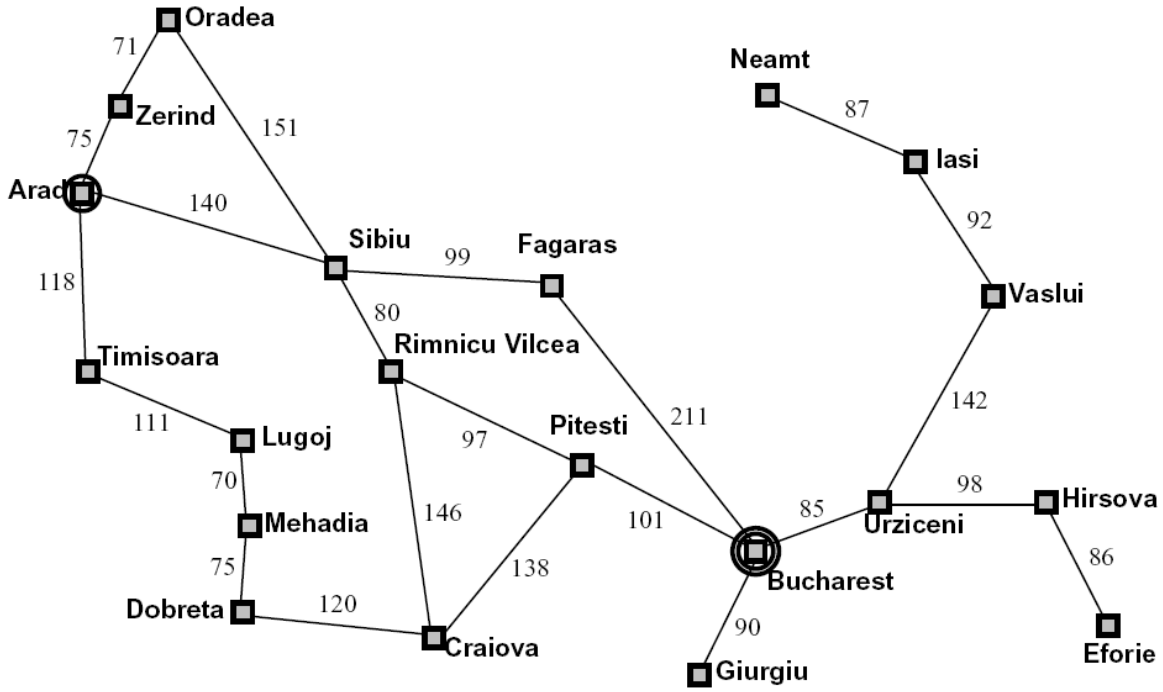

  - A start state and a goal test

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

# Search Problems Are Models



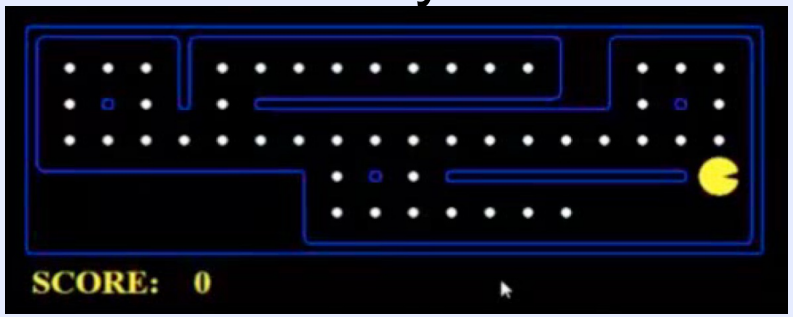
# Example: Traveling in Romania




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

# What's in a State Space?

The world state includes every last detail of the environment




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

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

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

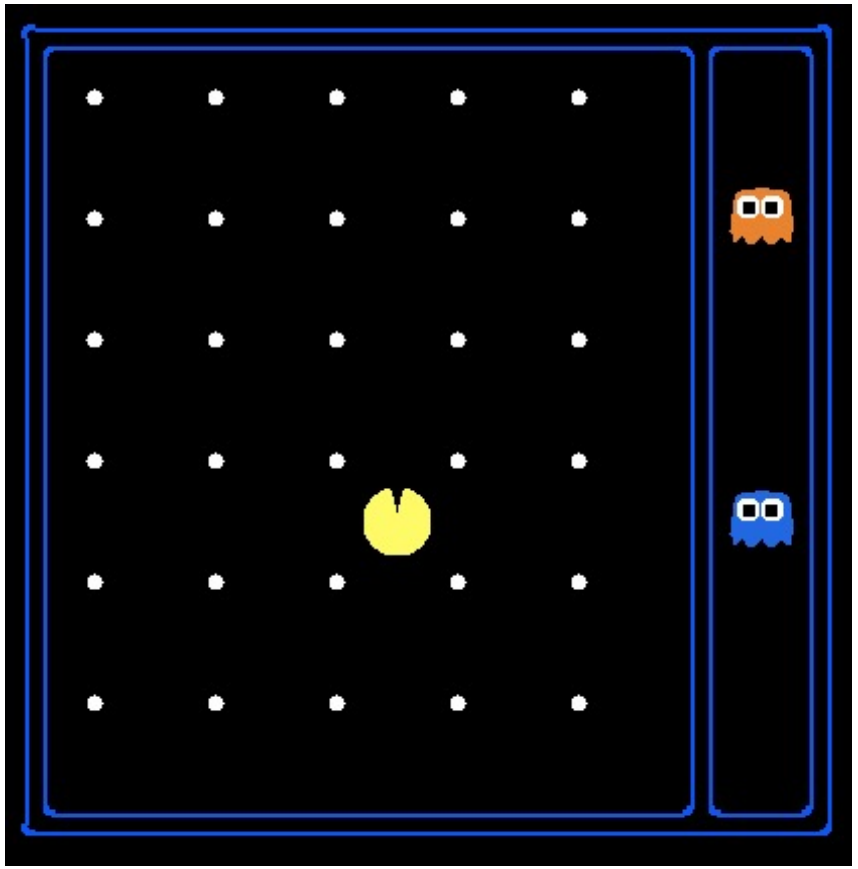
# State Space Sizes?

- World state:
  - Agent positions: 120
  - Food count: 30
  - Ghost positions: 12
  - Agent facing: NSEW
- How many
  - World states?

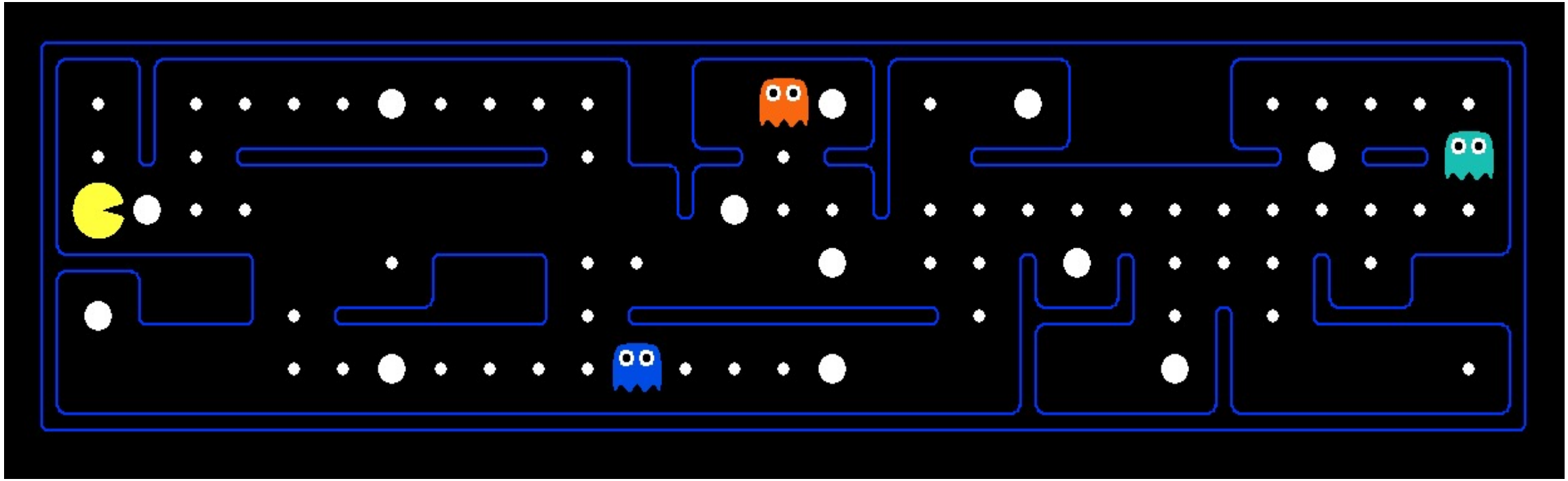
    $120x(2^{30})x(12^2)x4$
  - States for pathing?

    120
  - States for eat-all-dots?

    $120x(2^{30})$

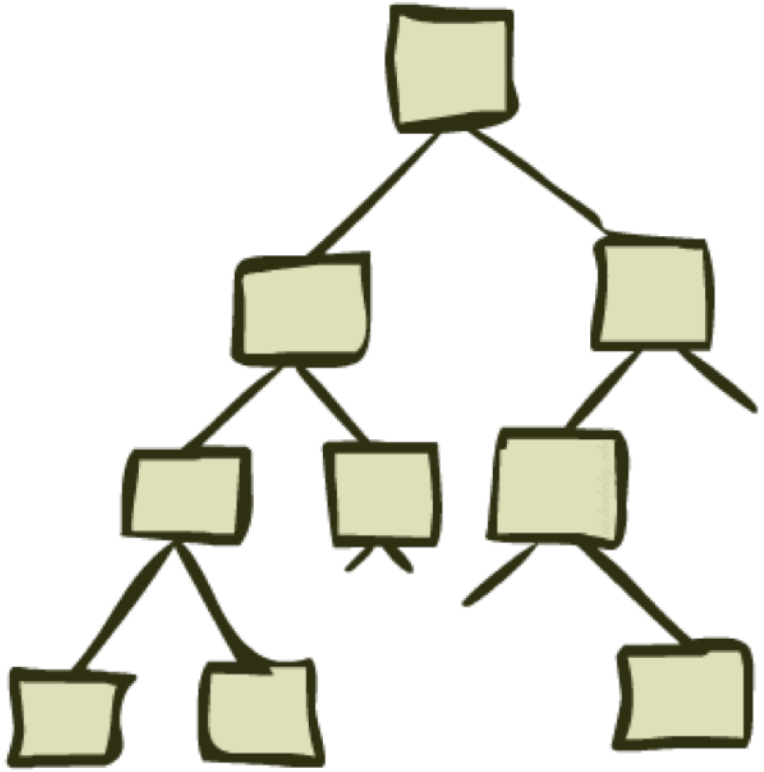


# Quiz: Safe Passage



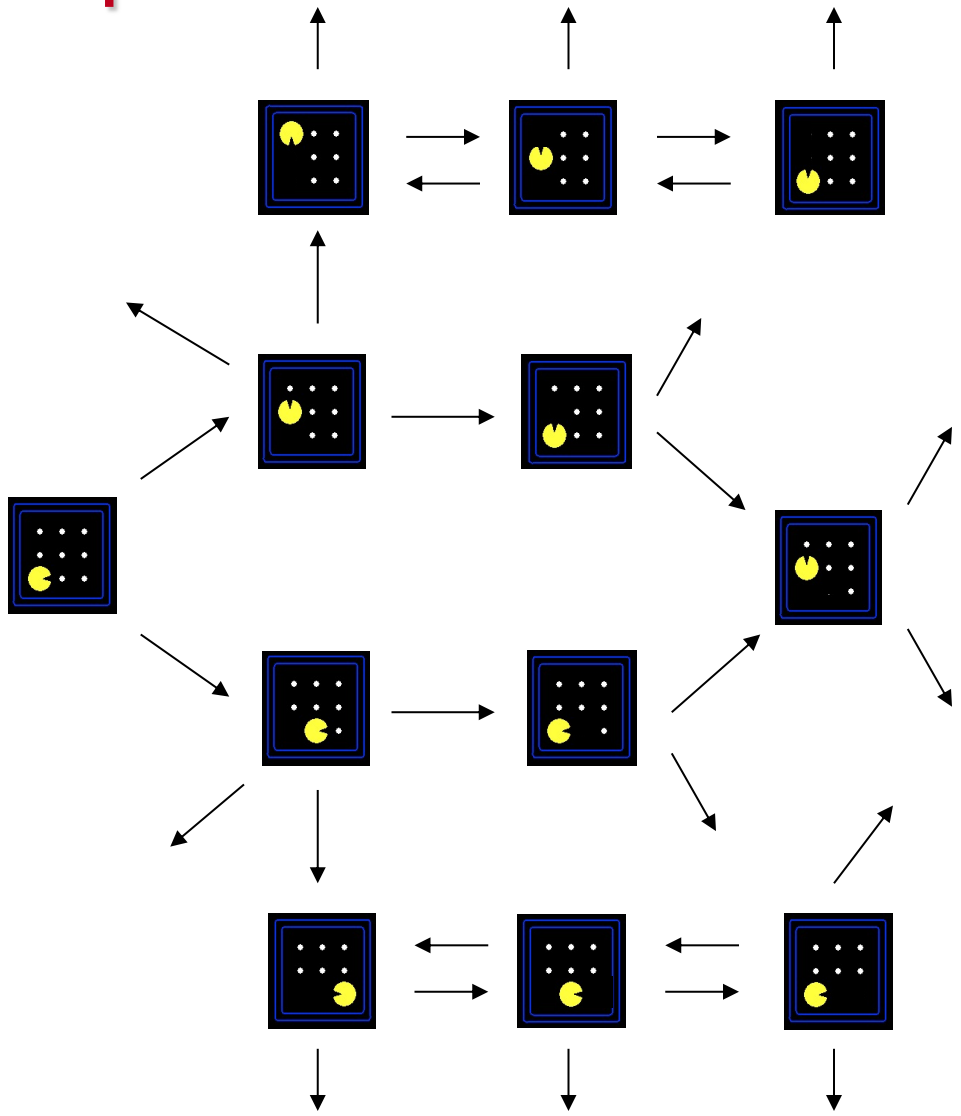
- Problem: eat all dots while keeping the ghosts perma-scared
- What does the state space have to specify?
  - (agent position, dot booleans, power pellet booleans, remaining scared time)

# State Space Graphs and Search Trees



# State Space Graphs

- State space graph: A mathematical representation of a search problem
  - Nodes are (abstracted) world configurations
  - Arcs represent successors (action results)
  - The goal test is a set of goal nodes (maybe only one)
- In a state space graph, each state occurs only once!
- We can rarely build this full graph in memory (it's too big), but it's a useful idea



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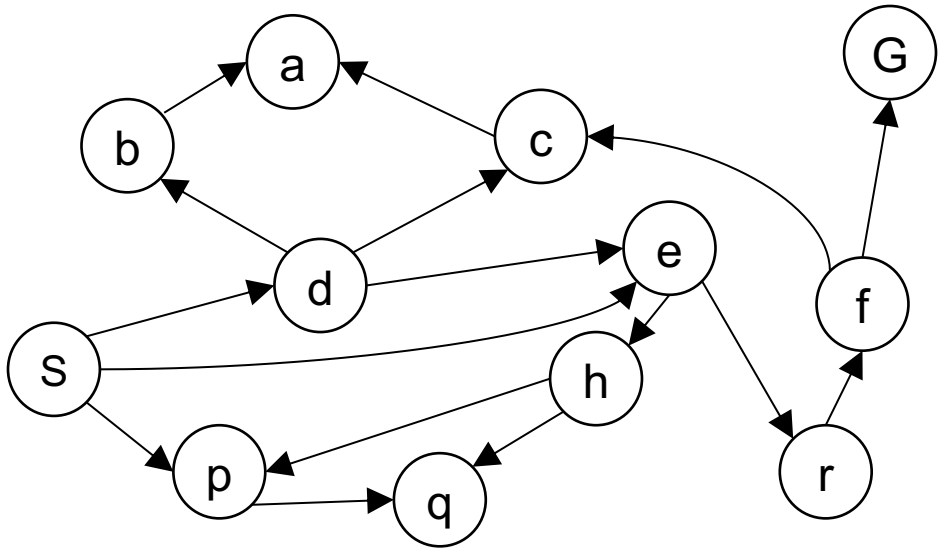
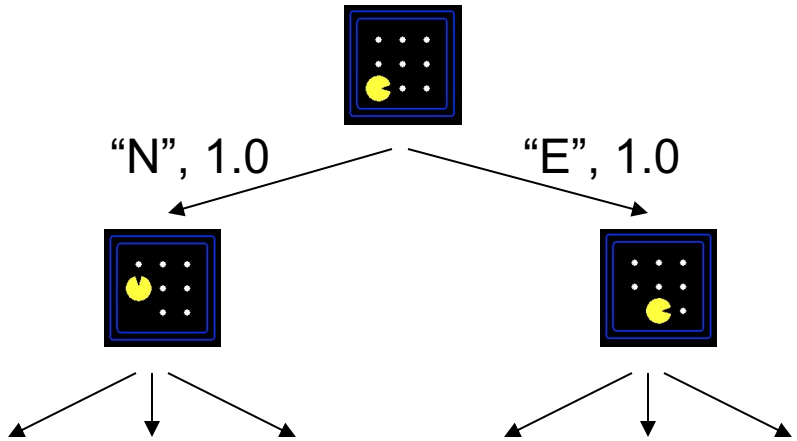



Tiny state space graph for a tiny search problem

# Search Trees



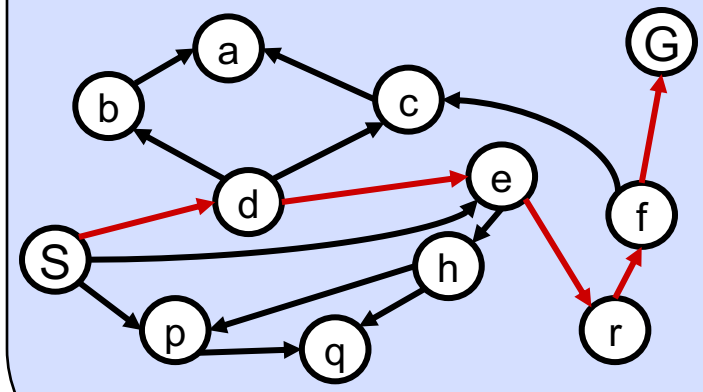

This is now / start

Possible futures

- 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

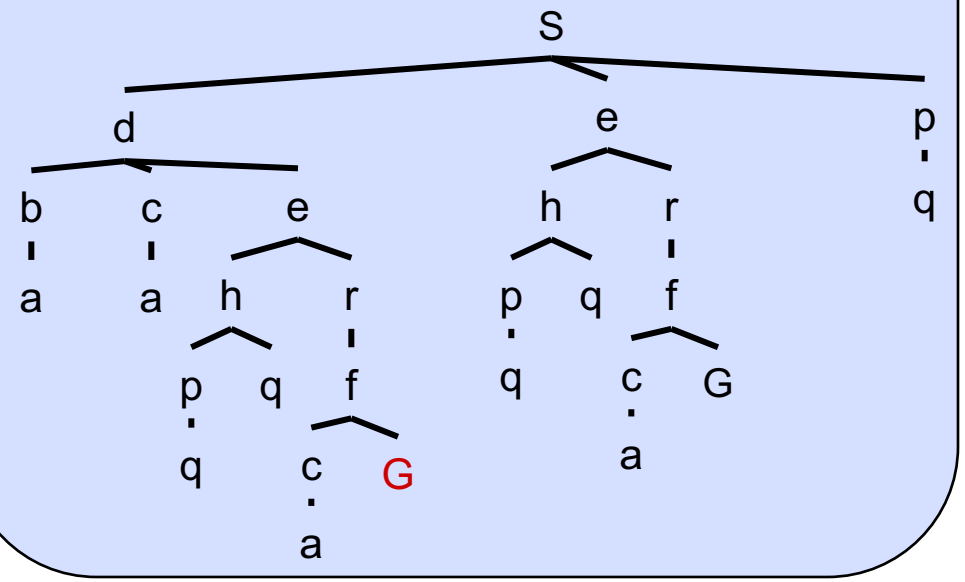
## State Space Graph




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

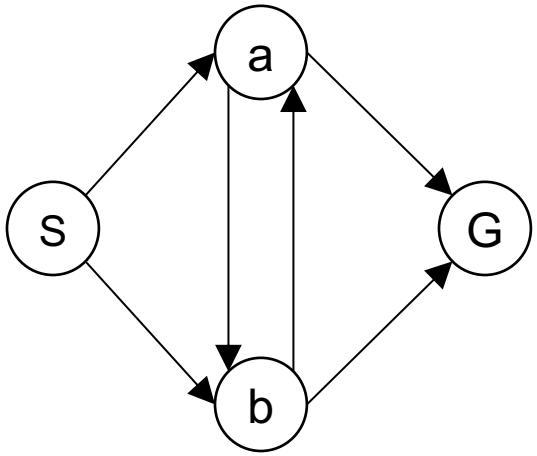
We construct both on demand – and we construct as little as possible.

## Search Tree



# Quiz: State Space Graphs vs. Search Trees

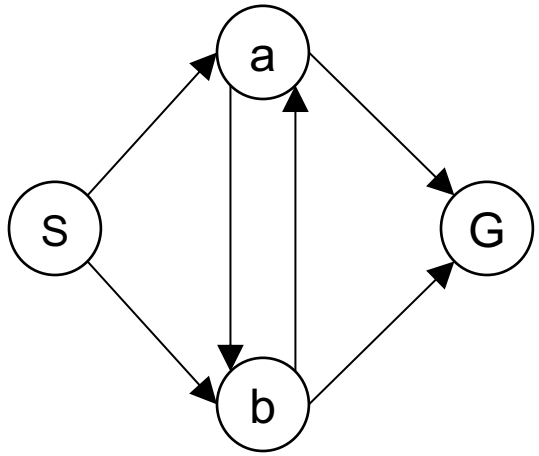
Consider this 4-state graph:



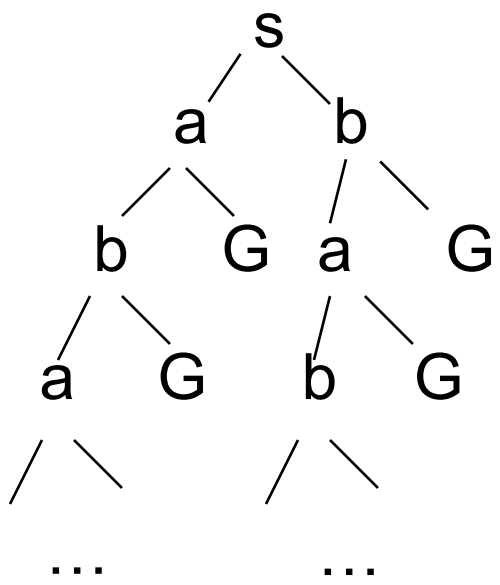

How big is its search tree (from S)?

# Quiz: State Space Graphs vs. Search Trees

Consider this 4-state graph:

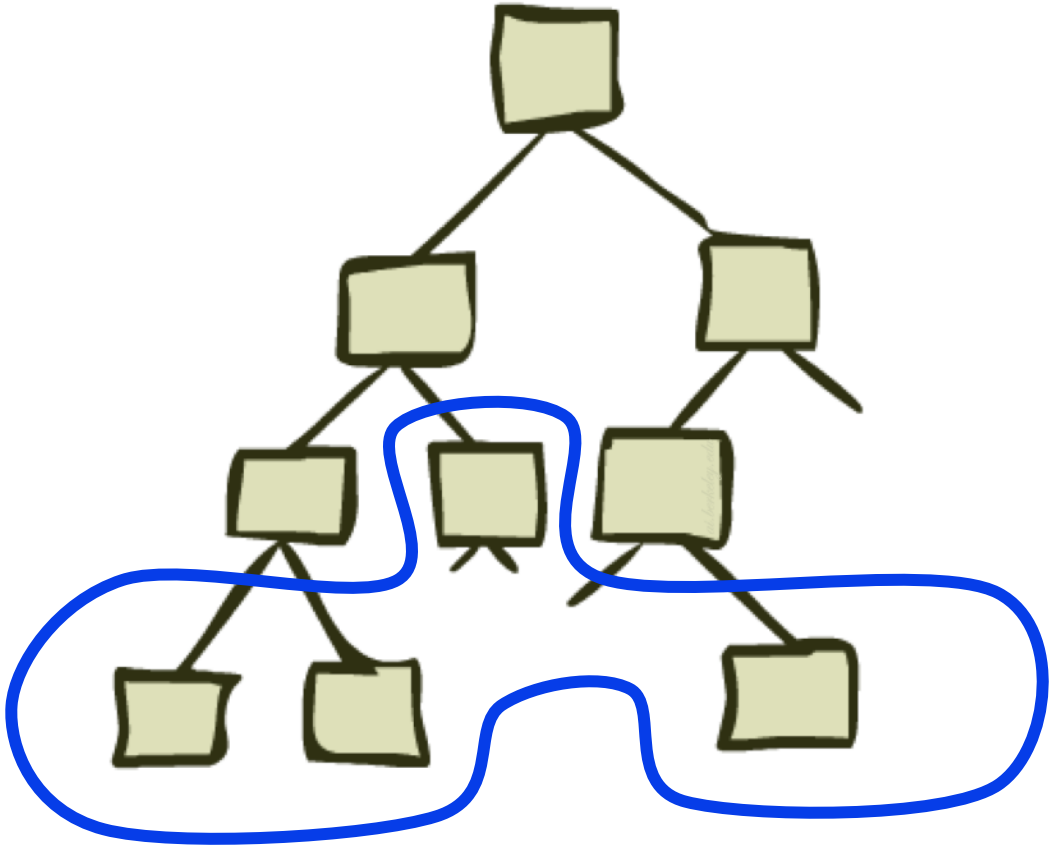



How big is its search tree (from S)?

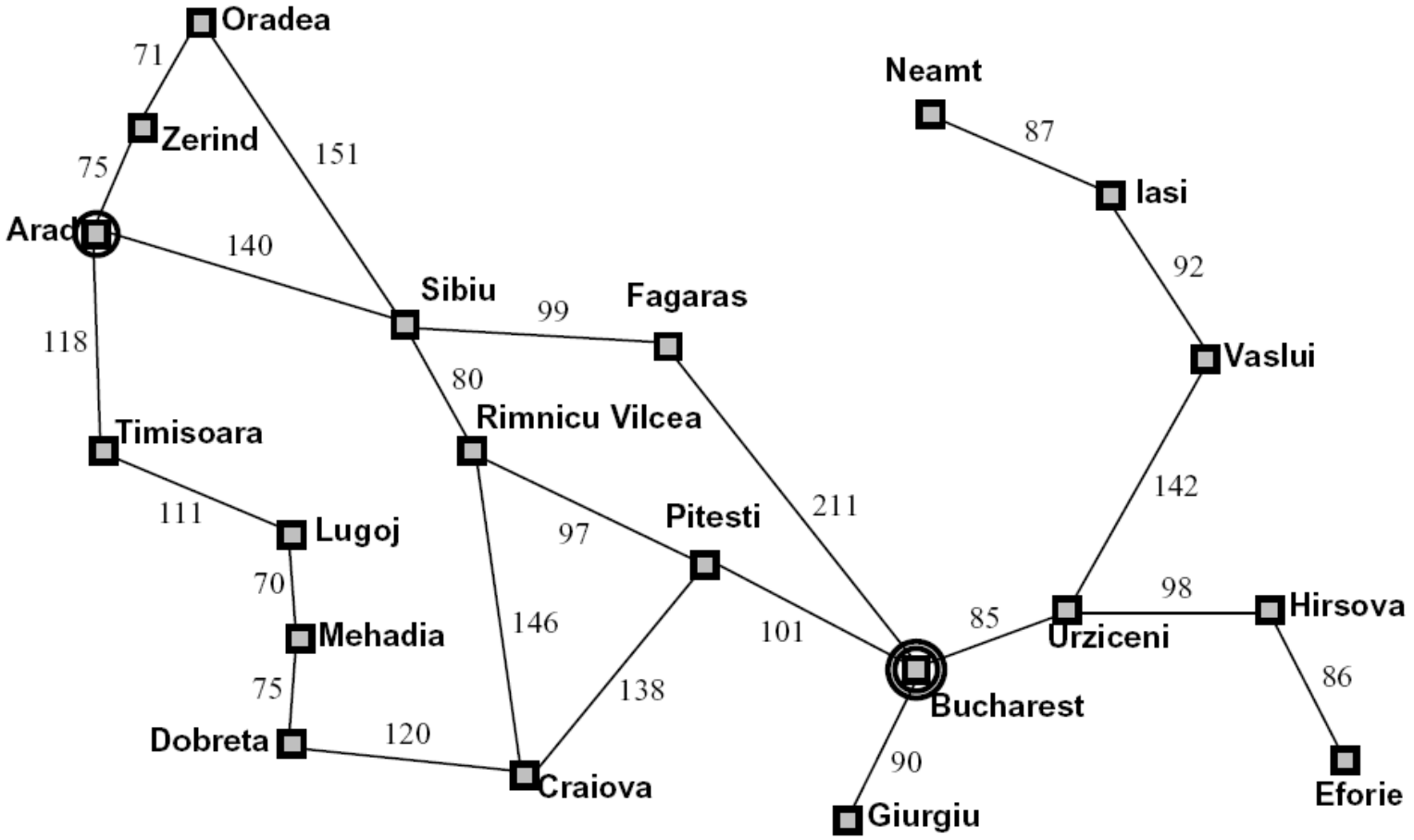



Important: Lots of repeated structure in the search tree!

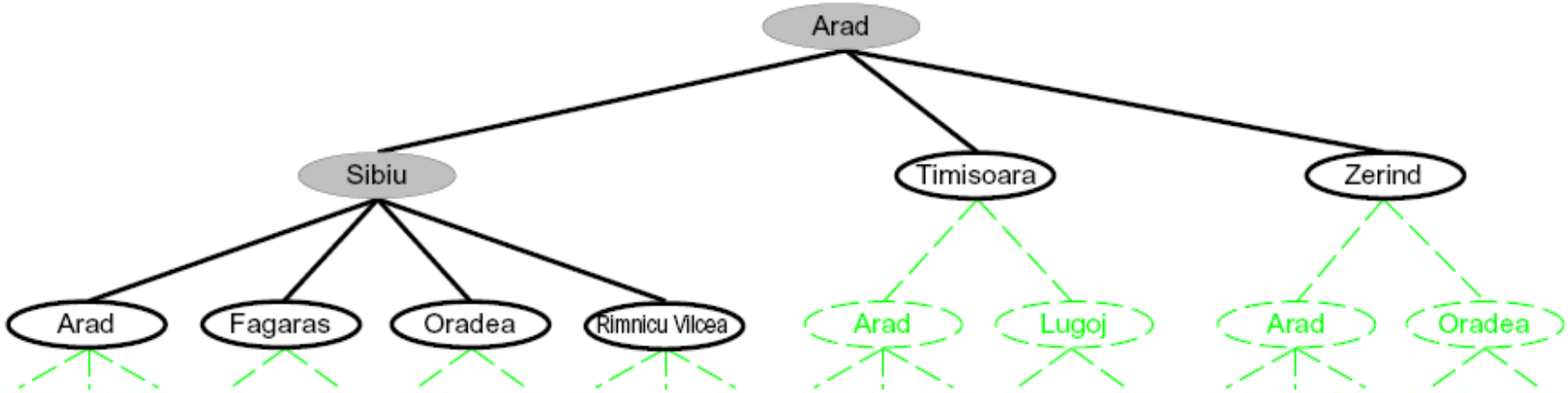
# Tree Search



# Search Example: Romania



# Searching with a Search Tree




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

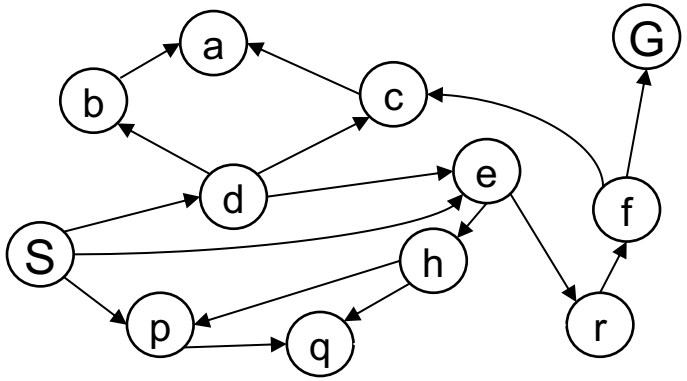
# General Tree Search

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

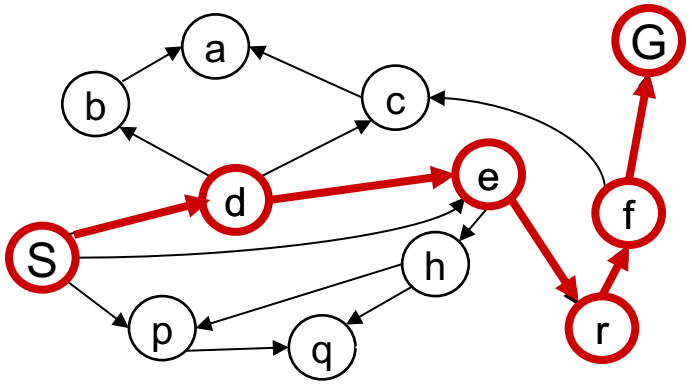
- Important ideas:
  - Fringe
  - Expansion
  - Exploration strategy

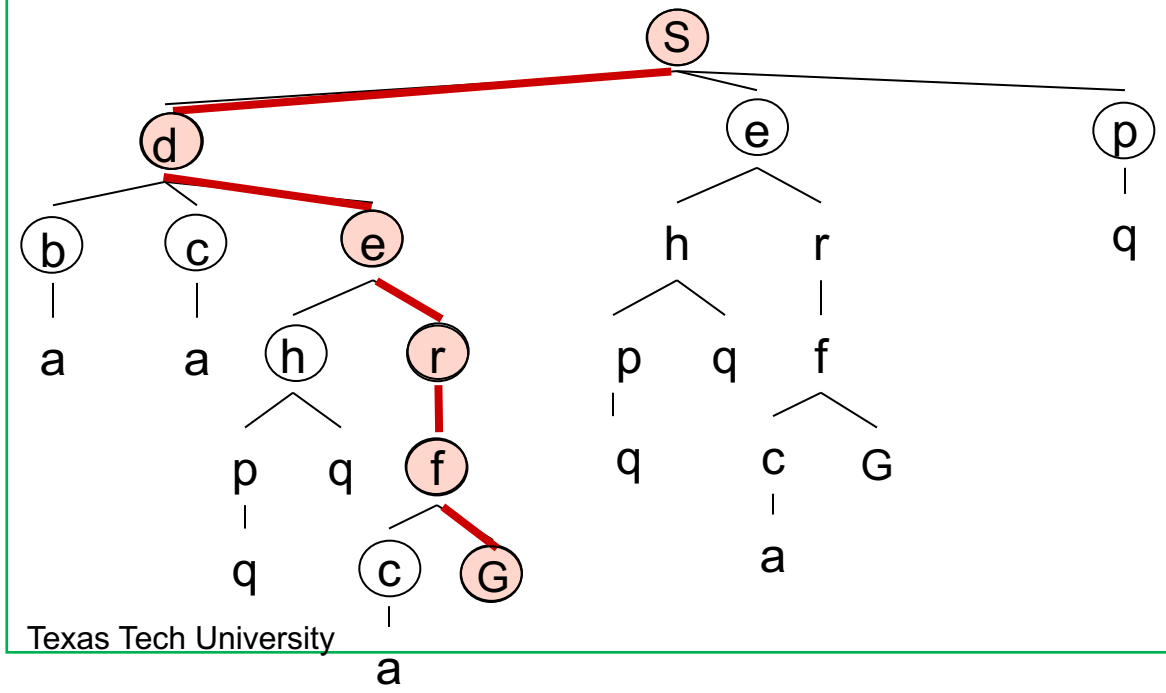
- Main question: which fringe nodes to explore?

# Example: Tree Search



# Example: Tree Search




~~s~~

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s → d → e → r → f → c

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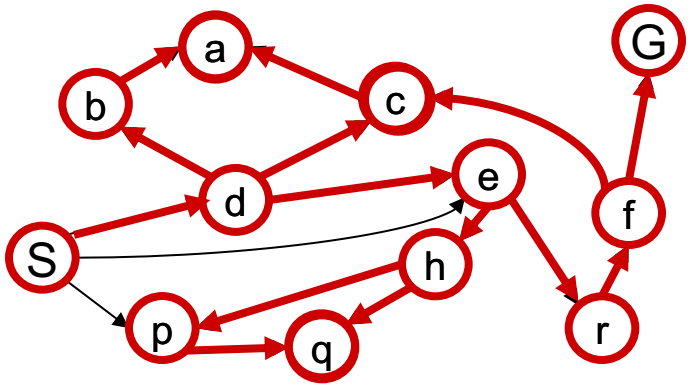
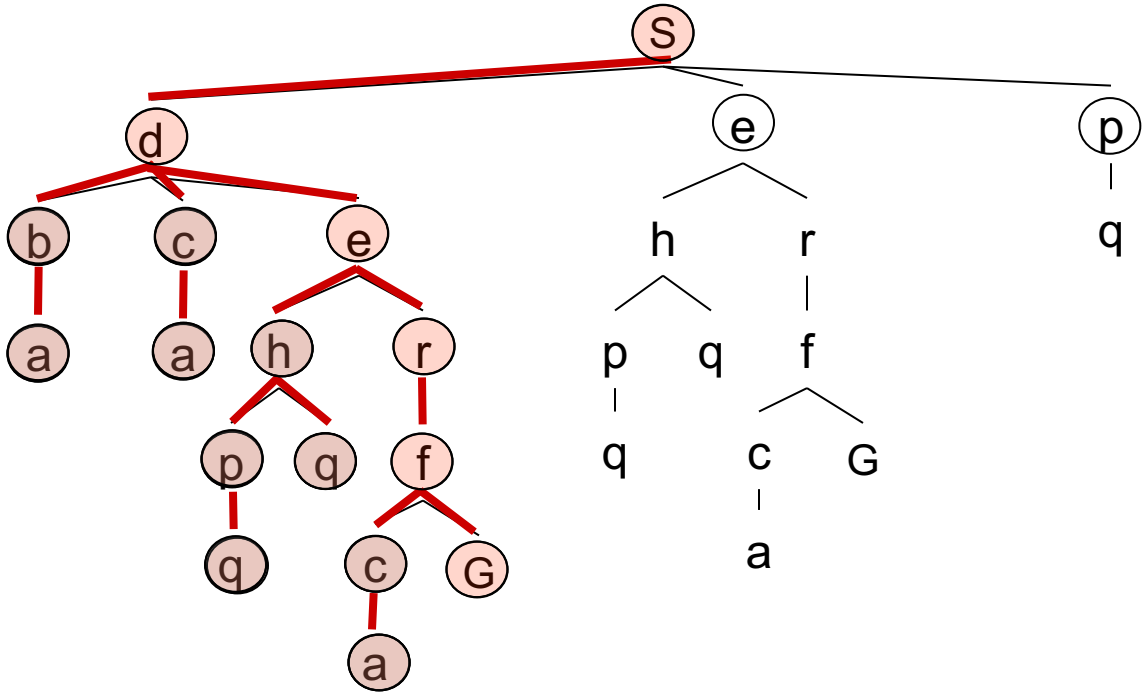
# Depth-First Search

# Depth-First Search

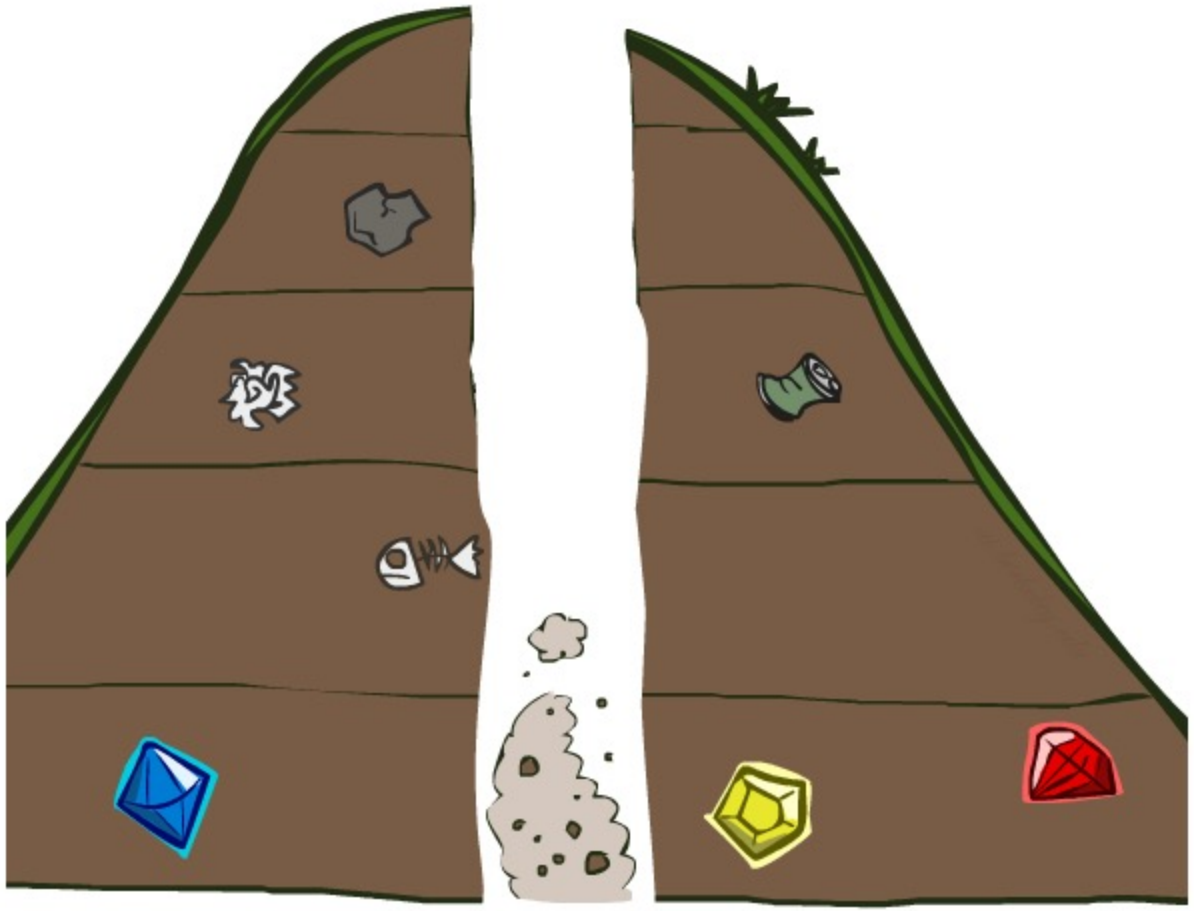
Strategy: expand a deepest node first

Implementation: Fringe is a LIFO stack



# Search Algorithm Properties

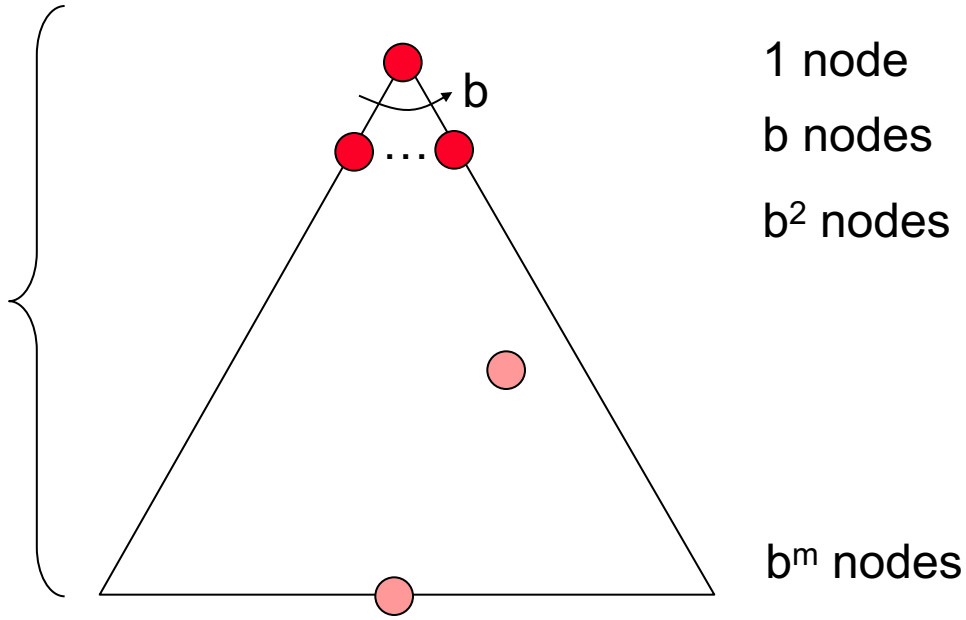


# Search Algorithm Properties

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

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

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



# Depth-First Search (DFS) Properties

- What nodes DFS expand?
  - Some left prefix of the tree.
  - Could process the whole tree!
  - If m is finite, takes time $O(b^m)$
- How much space does the fringe take?
  - Only has siblings on path to root, so O(bm)
- Is it complete?
  - m could be infinite, so only if we prevent cycles (more later)
- Is it optimal?
  - No, it finds the "leftmost" solution, regardless of depth or cost