Elective Course
Course Code: CS4103
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Lecture #04

Artificial Intelligence for Data Science

Week-2: PROBLEM SOLVING BY SEARCH
Problem formulation, Concept of state space search

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Problem Solving Agent

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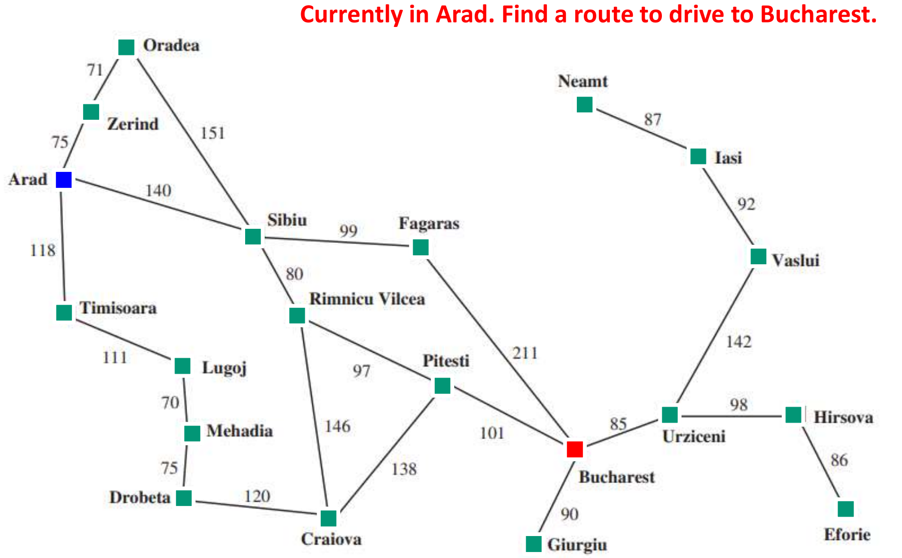
- **Goal-based agent**
  - Agent needs to achieve certain goals
  - Decides what to do by finding sequences of actions that lead to desirable states/goals
  - Many problems can be represented as a set of rules of how one state is transformed to another. The goal-based agent must choose a sequence of action to achieve the desired goal
  - Must have a model of how the world evolves in response to actions
  - Optimal: Achieve goal at least cost

Problem Solving by Search

- **Formulate Problem**
  - **Initial State:** The description of the starting configuration of the agent
    - **Each state is an abstract representation** of the agent's environment and its configuration
  - **Actions/Operators:** Takes the agent from one state to another state. A state can have a number of successor states.
  - **Successor Function** (represented as Transition Model or Conditions of applicability)
    - Applied on a given state-action pair; returns a **successor state** which is reachable from the given state by applying the action.
    - **State Space:** The set of all the states reachable from an initial state
  - **Goal test:** determines whether a given state is a **goal state**
  - **Path Cost:** Usually, **path cost** is the sum of step cost. Step cost is the cost of transition from a state to its successor
- **Search:**
  - Is the process of imagining sequences of actions/operators applied to the initial state, and checking which sequence reaches a goal state
  - A **solution** is a **sequence of actions** leading from the initial state to a goal state
  - Optimal solution: Least-cost solution

Example Problem: Traveling in Romania

Currently in Arad. Find a route to drive to Bucharest.



- **State space:**
  - Cities
- **Initial state:**
  - Arad
- **Actions:**
  - Drive between cities
- **Transition model:**
  - Reach adjacent city
- **Action cost/Step cost:**
  - Road distance from s to its successor s'
- **Goal test:**
  - s = IN(Bucharest)?
- **Solution?**

Search Problem

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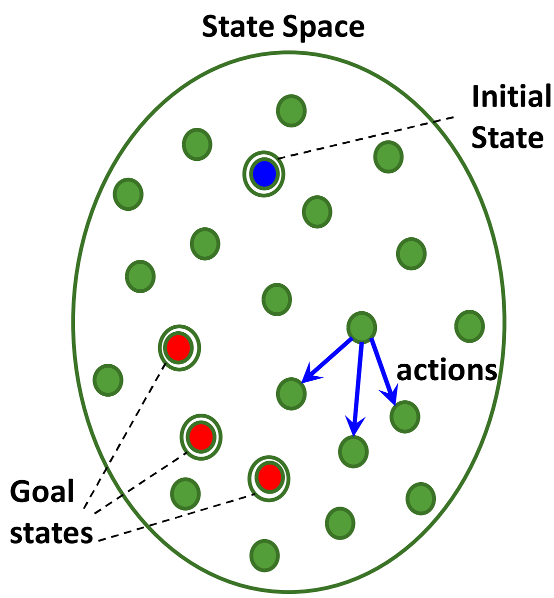
- $\boldsymbol{S}$: the full set of states
- $\boldsymbol{s_0}$: the initial state
- $\boldsymbol{A}: \boldsymbol{S} \rightarrow \boldsymbol{S}$ set of operators/actions
- $\boldsymbol{G}$: the set of final states. $G \subseteq S$

- **Search problem:** Find a sequence of actions which transforms the agent from the initial state to a goal state $g \in G$



Searching Process

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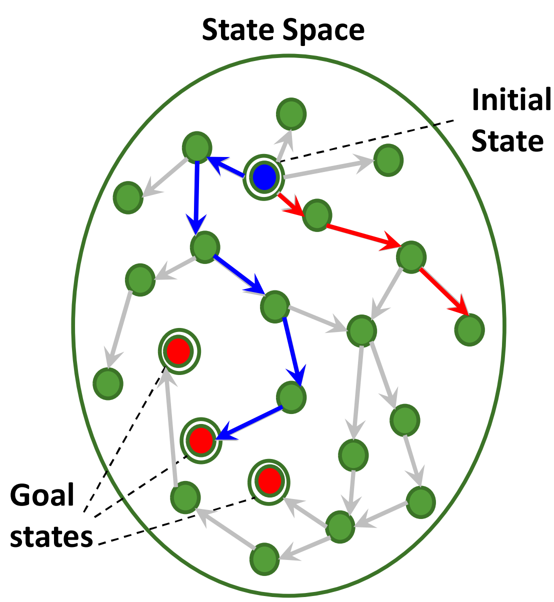
- Check the current state

- Execute allowable actions to move to the next state

- Check if the new state is a solution state
  - If it is not, the new state becomes the current state and the process is repeated until a solution is found or the state space is exhausted



Problem: Three-Disk Tower of Hanoi Puzzle

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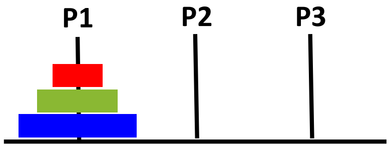
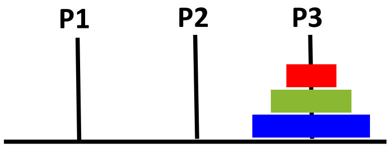
- **Start State**



- **Goal State**



- **Rules:**
  - Only one disk may be moved at a time.
  - Each move involves taking disk on the top of a peg and place it on the top of another peg.
  - A disk of a larger diameter should never be placed on the top of a disk of smaller diameter.

State Space for the Three-Disk Tower of Hanoi Puzzle

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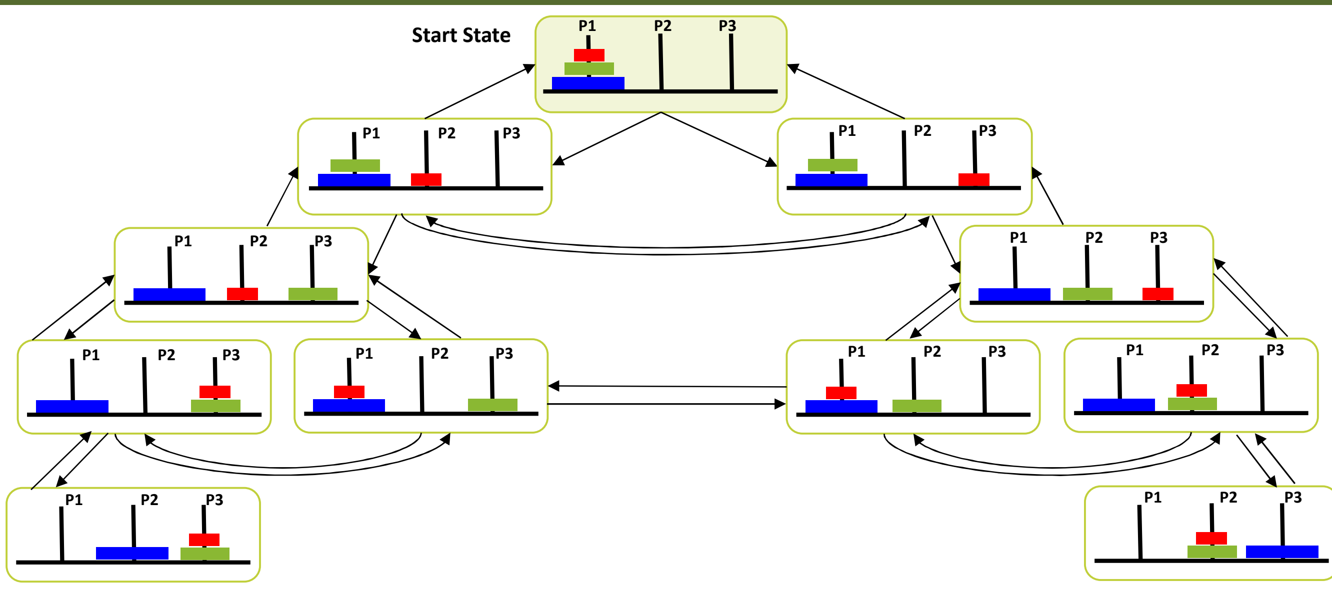

State Space for the Three-Disk Tower of Hanoi Puzzle

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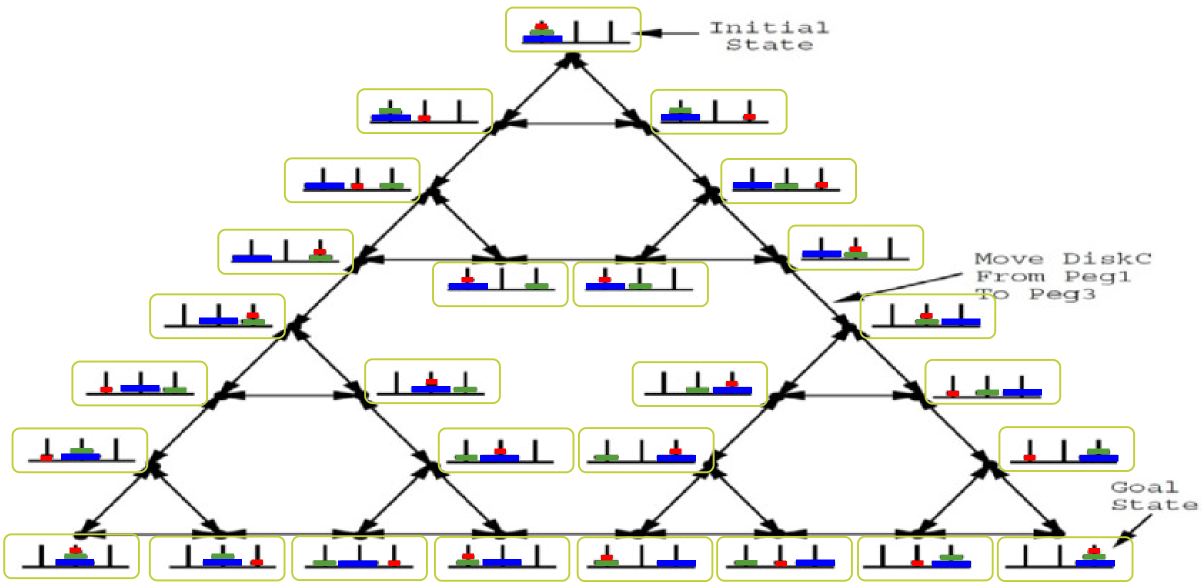

8 Queens Problem

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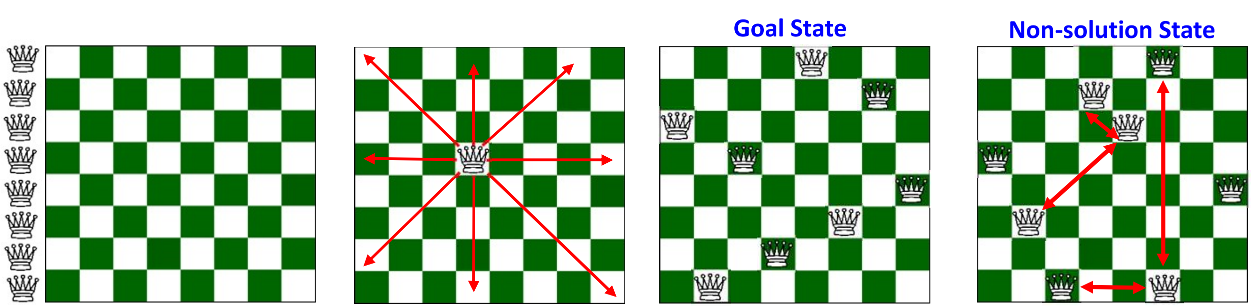
- **Place 8 queens on chessboard so that no two queens are in the same row, column, or diagonal**



Formulation-1 for 8-Queen Problem

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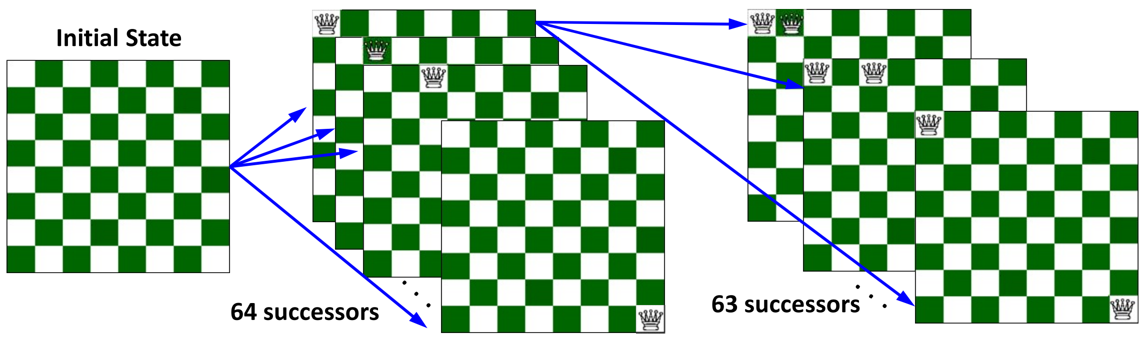
- **States:** Any arrangements of 0 to 8 queens on the board
- **Initial State:** 0 queens on the board
- **Actions:** Add a queen to any empty square
- **Successor Function:** Returns the board with a queen added to the specified square.
- **Goal Test:** 8 queens on the board and none are attacked



Formulation-2 for 8-Queen Problem

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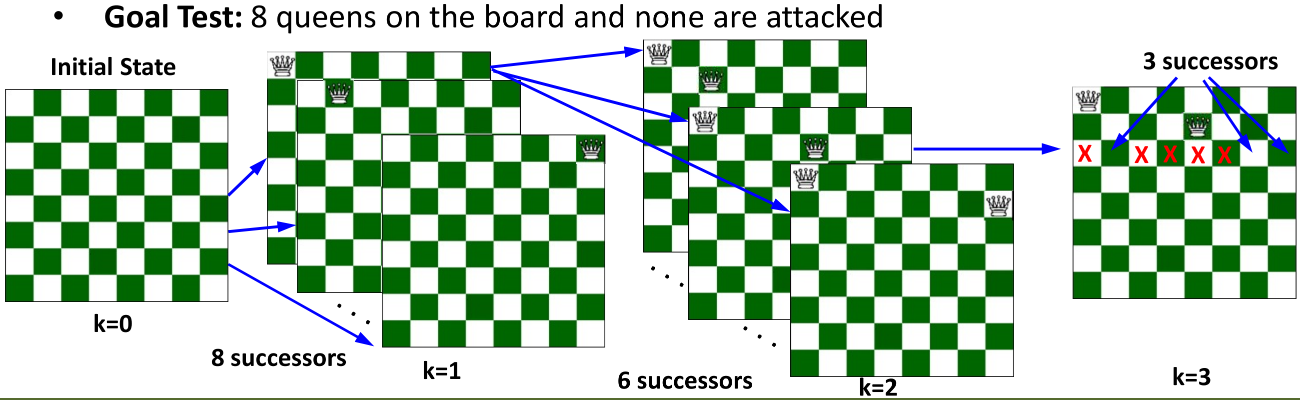
- **States:** Any arrangement of k queens in the first k rows such that none are attacked
- **Initial State:** 0 queens on the board
- **Actions:** Add a queen to the (k+1)-th row so that none are attacked
- **Successor Function:** Returns the board with a queen added to the specified square.
- **Goal Test:** 8 queens on the board and none are attacked



Formulation: 8 Puzzle Problem

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- **States**
  - A description of each of the eight tiles in each location that it can occupy
- **Operators/Actions**
  - The blank moves left, right, up or down (ML, MR, MU, MD)
- **Transition model**
  - Given a state and action, this returns the resulting state;
- **Goal Test**
  - The current state matches a certain state (e.g. see the fig.)
- **Path Cost**
  - Each move of the blank costs 1

5	4	
6	1	8
7	3	2

Initial State

1	4	8
5	6	2
7	3	

Goal State

8 Puzzle Partial State Space

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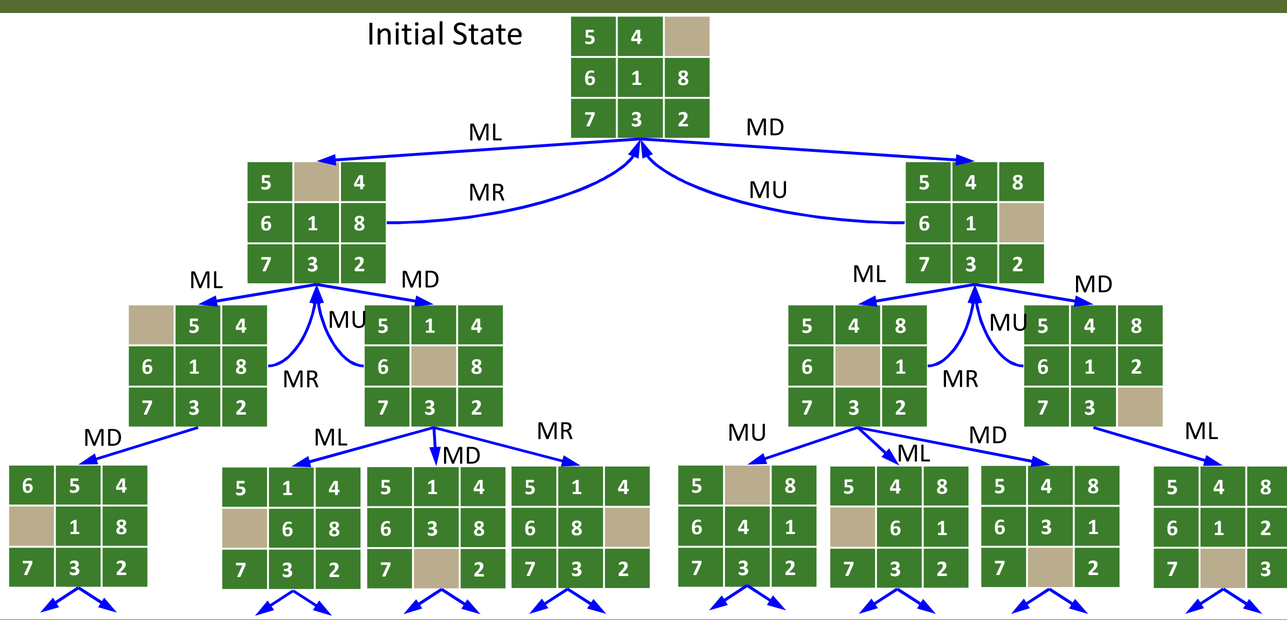
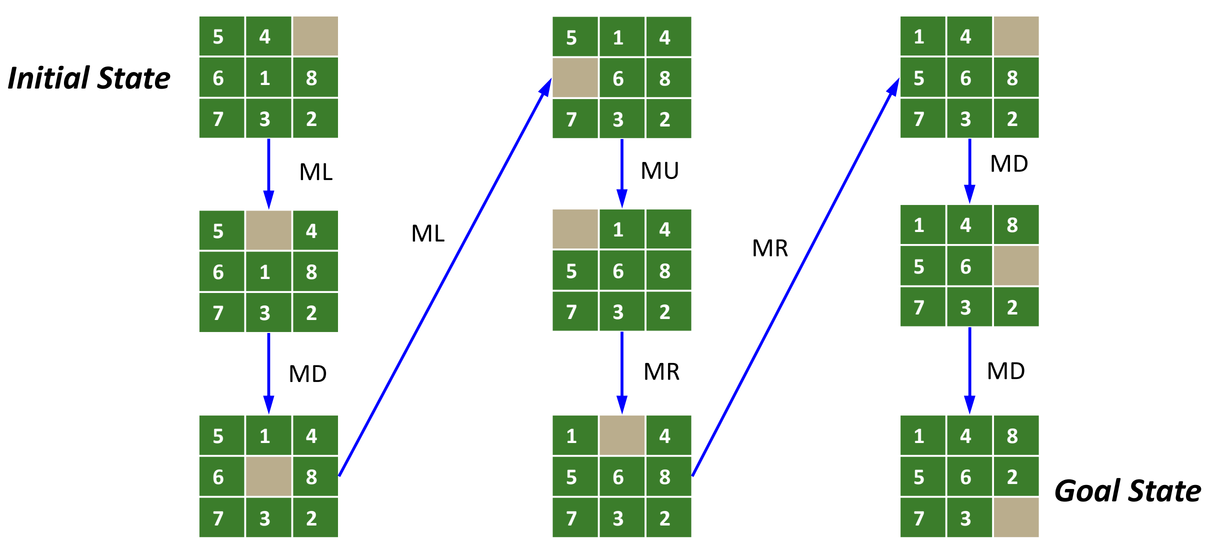


State Space Search Problem

- **General problem:**
  Find a path from a ***start state*** to a ***goal state*** given:
  - **Set of states**
  - **Start/Initial State**
  - **Goal state [test]**
  - **Operators/Actions/**
  - **Successor Function [and costs]**

- **Output variants:**
  - **Find a path** vs. **a least-cost path**
  - Goal is completely specified, task is just to find the path
    - **Route Planning**
  - Path doesn't matter, only finding the goal state
    - **N Queen**

8 Puzzle: A Solution Path



Three-Disk Tower of Hanoi Puzzle: Solution Path

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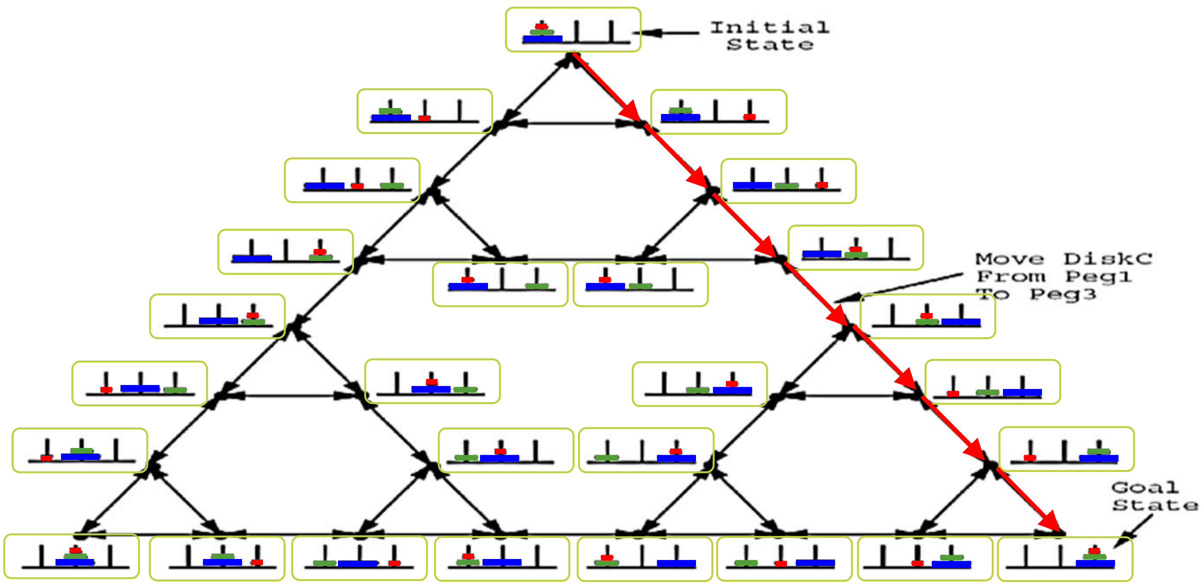

Explicit vs. Implicit State Space

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- The state space may be explicitly represented
- Typically, it is implicitly represented and generated when required
- The agent knows
  - The initial state
  - The successor function which “expands” a node
    - Compute the successor node(s)

Search Trees

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- Every search process can be viewed as traversal of tree structure in which each node represents a problem state and each arc represents a relationship between states represented by states it connects.

- **A search tree:**
  - **Root** = Start state
  - **Children** = successor states
  - **Edges** = actions and costs
  - **Path from Start to a node is a “plan” to get to that state**
  - **For most problems, we can never actually build the whole tree (why?)**

State Space Graph versus Search Trees

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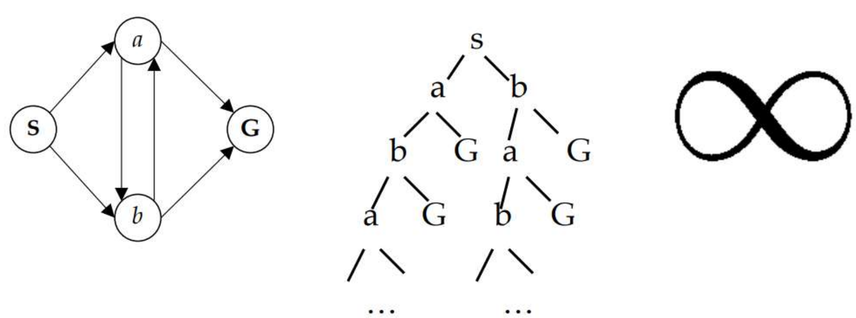
Consider this 4-state graph: How big is its search tree (from S)?



Important: Lots of repeated structure in the search tree!

slides adapted from Dan Klein, Pieter Abbeel ai.berkeley.edu And Dan Weld, Luke Zettelmoyer

State Space Graph versus Search Trees

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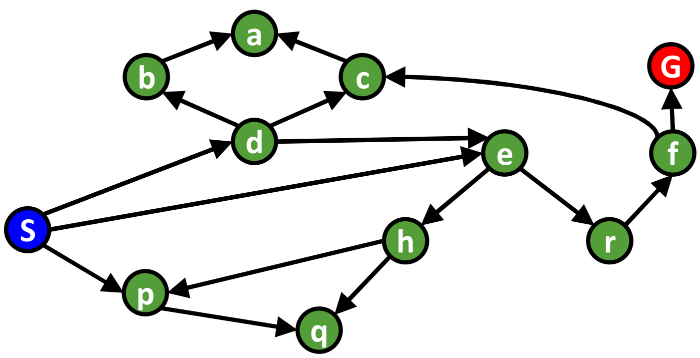

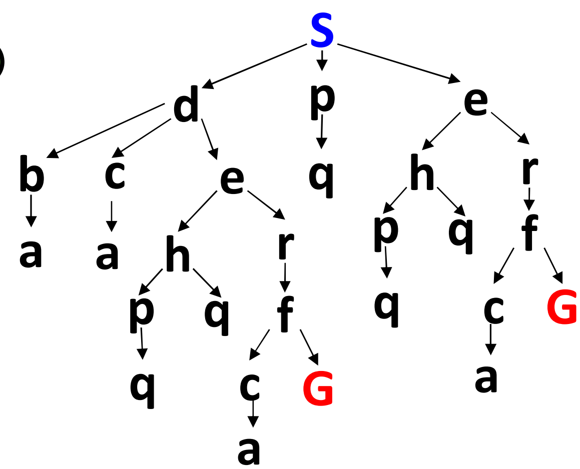

In a search graph, each state occurs only once!

Basic Search Algorithm

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Let L be a list containing the initial state (L=the fringe)

Loop

if L is empty return *failure*

Node ← **select**(L)

if Node is a goal

then return Node

(*the path from initial state to Node*)

else apply all applicable operators to Node

and **merge** the newly generated states into L

Basic Search Algorithm: Key Issues

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- **Search tree may be unbounded**
  - Because of loops
  - Because state space is infinite
- **Return a path or a node?**
- **How are merge and select done?**
  - Is the graph weighted or un-weighted?
  - How much is known about the quality of the intermediate states?
  - Is the aim to find a minimal cost path or any path as soon as possible?

Search Strategy

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- **Blind/Uninformed Search**
  - Depth first search
  - Breadth first search
  - Iterative deepening search
  - Uniform-Cost search
- **Informed/Heuristic Search**
  - Best First Search
  - A*,
  - Hill climbing
  - Simulated Annealing

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Home Assignments

Problem-1: Missionaries and Cannibals Problem

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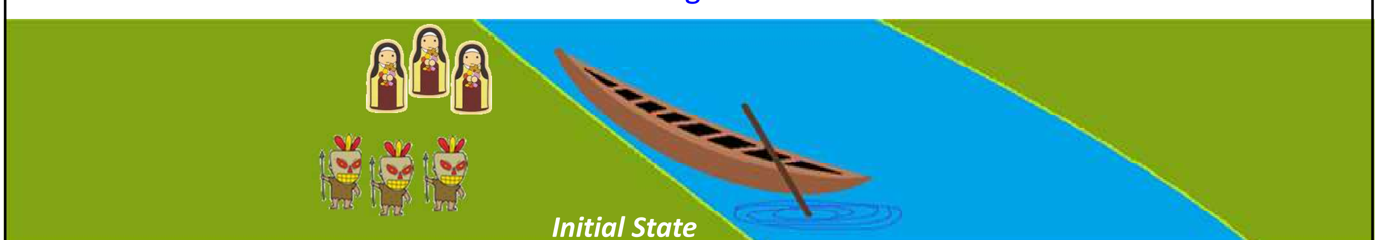
- Missionaries and Cannibals is a problem in which 3 missionaries and 3 cannibals want to cross from the left bank of a river to the right bank of the river. There is a boat on the left bank, but it only carries at most two people at a time (and can never cross with zero people). If cannibals ever outnumber missionaries on either bank, the cannibals will eat the missionaries.
- A state can be represented by a triple, (m c b), where m is the number of missionaries on the left, c is the number of cannibals on the left, and b indicates whether the boat is on the left bank or right bank.



Problem-1: Missionaries and Cannibals Problem

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- For example, the **initial state** is (3 3 L) and the **goal state** is (0 0 R).
- **Operators are:**
  - MM: 2 missionaries cross the river
  - CC: 2 cannibals cross the river
  - MC: 1 missionary and 1 cannibal cross the river
  - M: 1 missionary crosses the river
  - C: 1 cannibal crosses the river

Draw a diagram showing all the legal states and transitions from states corresponding to all legal operations.

Problem-2: Water Jug Problem

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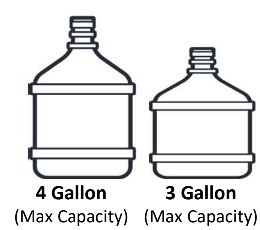
- You have a 4-gallon and a 3-gallon water jug
- You have a faucet with an unlimited amount of water
- You need to get exactly 2 gallons in 4-gallon jug

- **State representation:** (x, y)
  - x: Contents of 4-gallon jug
  - y: Contents of 3-gallon jug

- **Start state:** (0, 0)
- **Goal state:** (2, n)

Start state



Goal state

Problem-2: Water Jug Problem

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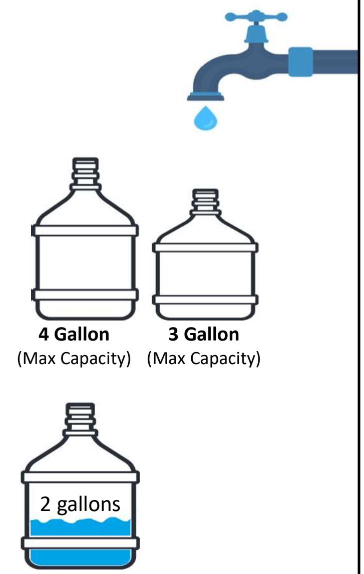
- **Operators**
  1. Fill 3-gallon from faucet
  2. Fill 4-gallon from faucet
  3. Fill 3-gallon from 4-gallon
  4. Fill 4-gallon from 3-gallon
  5. Empty 3-gallon into 4-gallon
  6. Empty 4-gallon into 3-gallon
  7. Dump 3-gallon down drain
  8. Dump 4-gallon down drain

Draw a diagram showing all the legal states and transitions from states corresponding to all legal operations.

Start state

Goal state



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Questions?