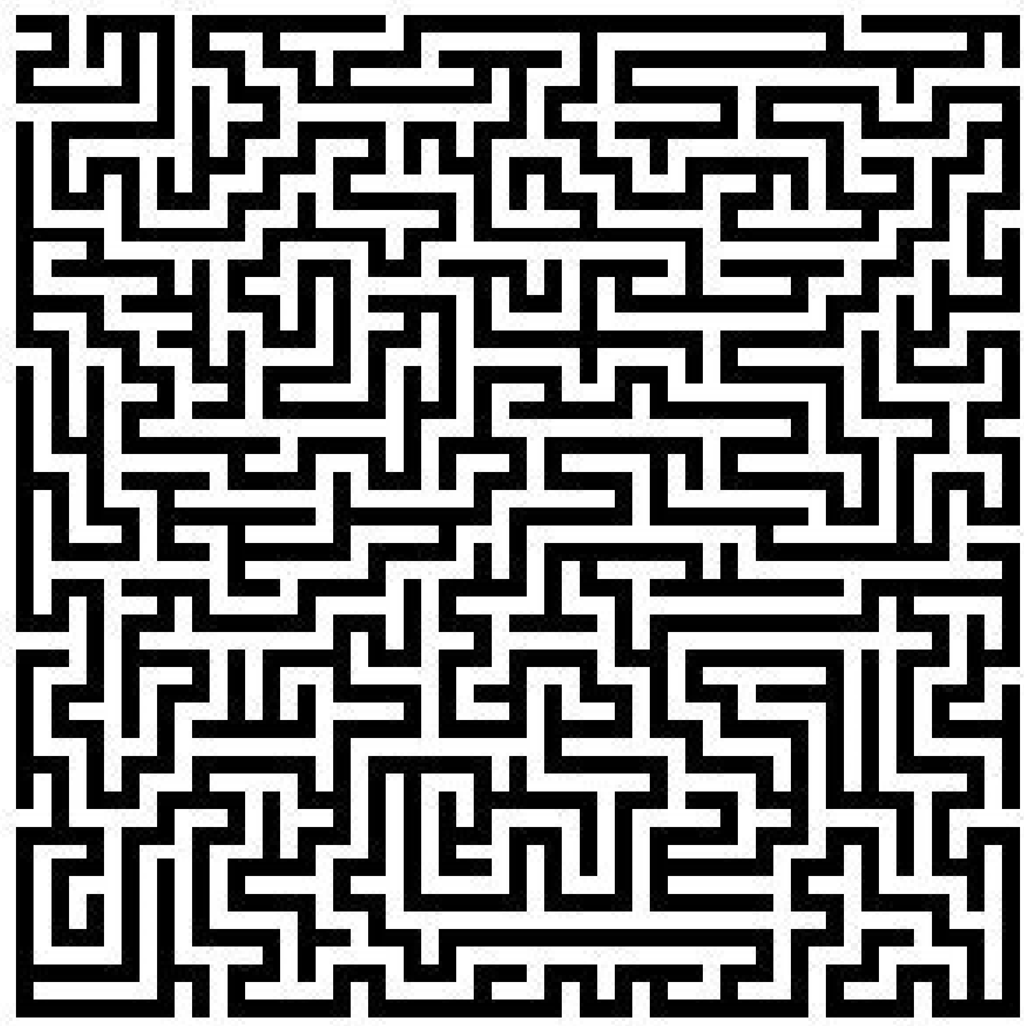
Announcements

- Course TA: Danny Kumar (ndkumar@cs.unc.edu)
- Guest lectures next week
- Assignment 1 out, due Tuesday, September 14
- Course discussion board
  - You should be able to find the discussion thread "AI in the news/on the Web" on Blackboard
  - For participation points: at least two posts during the semester

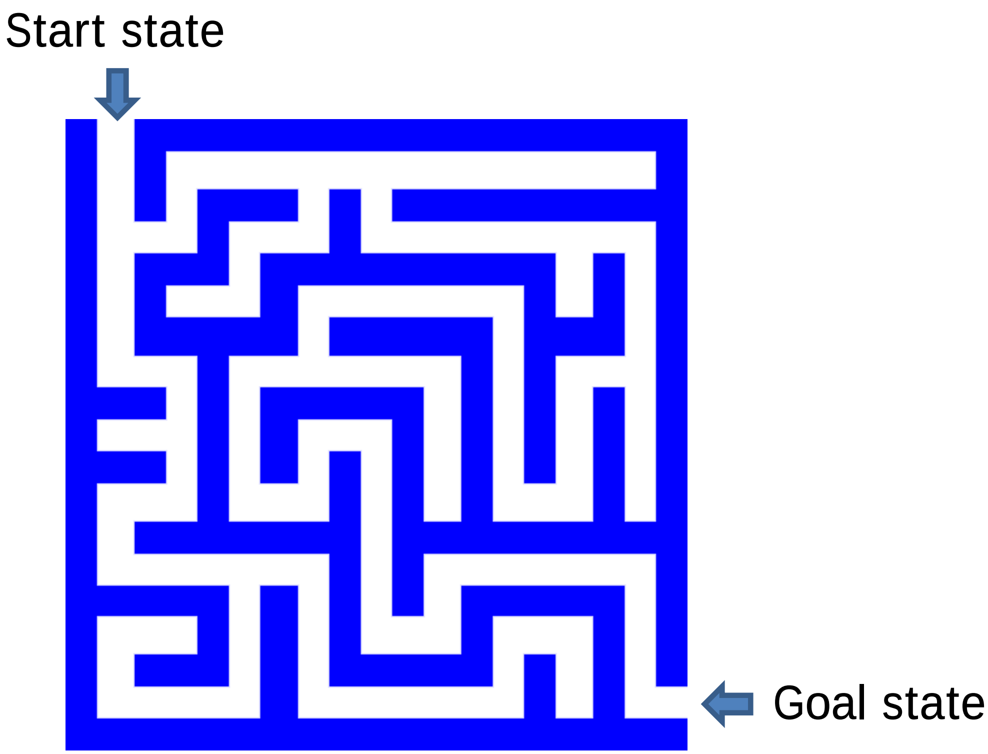
Solving problems by searching

Chapter 3



Search

- We will consider the problem of designing **goal-based agents** in **observable, deterministic, discrete, known** environments
- Example:

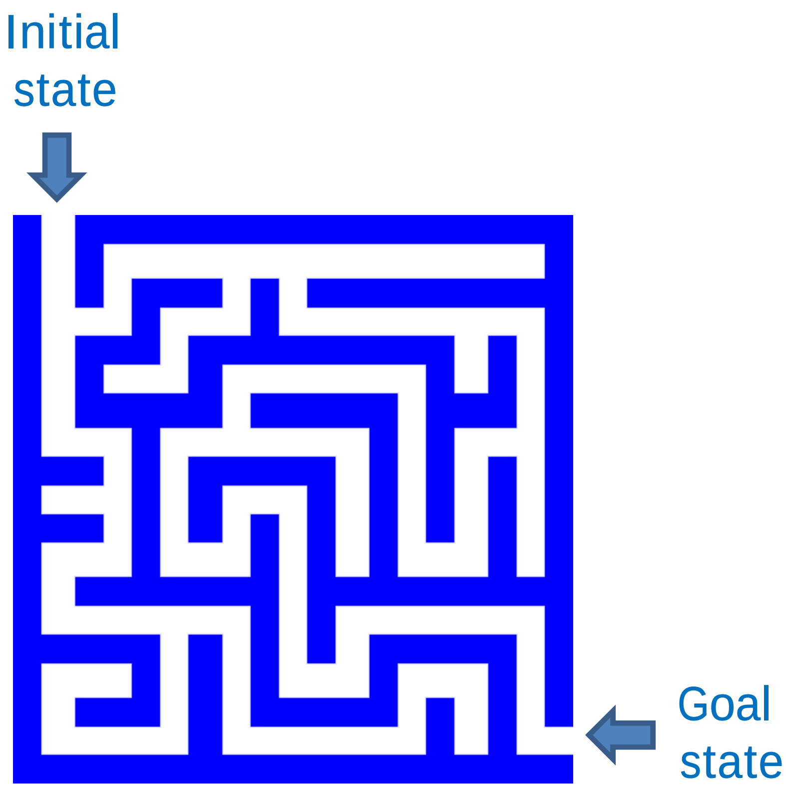


Search

- We will consider the problem of designing **goal-based agents** in **observable**, **deterministic**, **discrete**, **known** environments
  - The solution is a fixed sequence of actions
  - Search is the process of looking for the sequence of actions that reaches the goal
  - Once the agent begins executing the search solution, it can ignore its percepts (**open-loop system**)

Search problem components

- **Initial state**
- **Actions**
- **Transition model**
  - What is the result of performing a given action in a given state?
- **Goal state**
- **Path cost**
  - Assume that it is a sum of nonnegative *step costs*

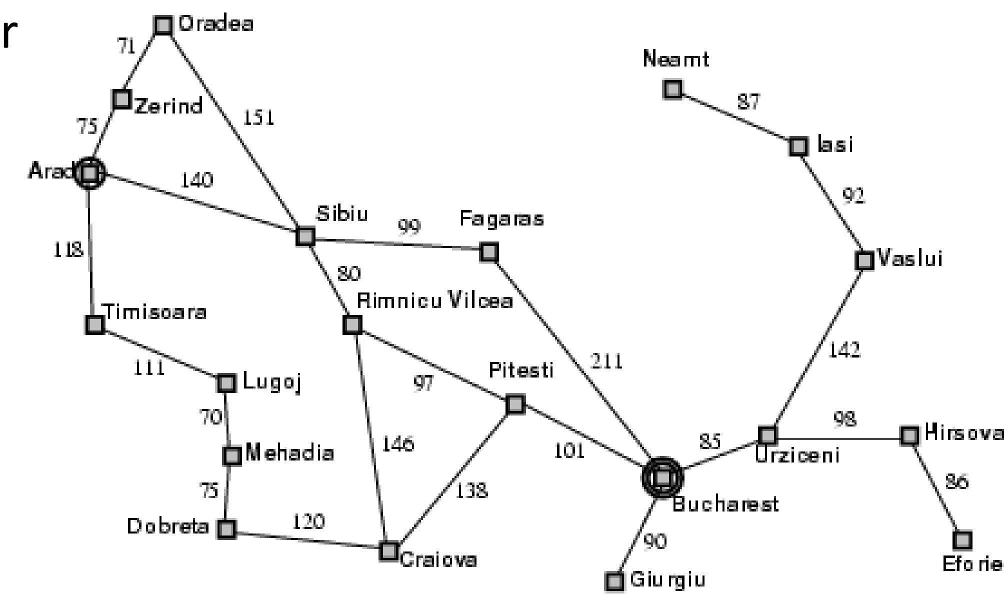


- The **optimal solution** is the sequence of actions that gives the lowest path cost for reaching the goal

Example: Romania

- On vacation in Romania; currently in Arad
- Flight leaves tomorrow from Bucharest

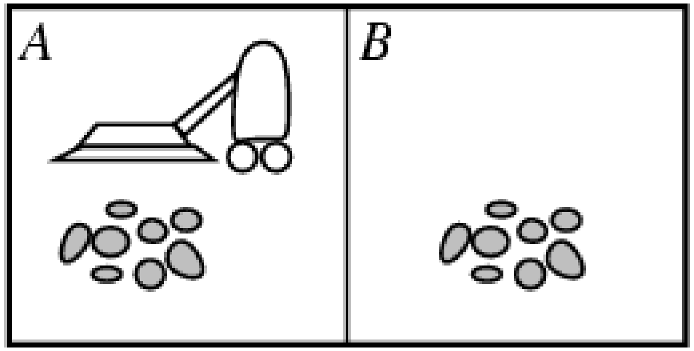
- **Initial state**
  - Arad
- **Actions**
  - Go from one city to another
- **Transition model**
  - If you go from city A to city B, you end up in city B
- **Goal state**
  - Bucharest
- **Path cost**
  - Sum of edge costs



State space

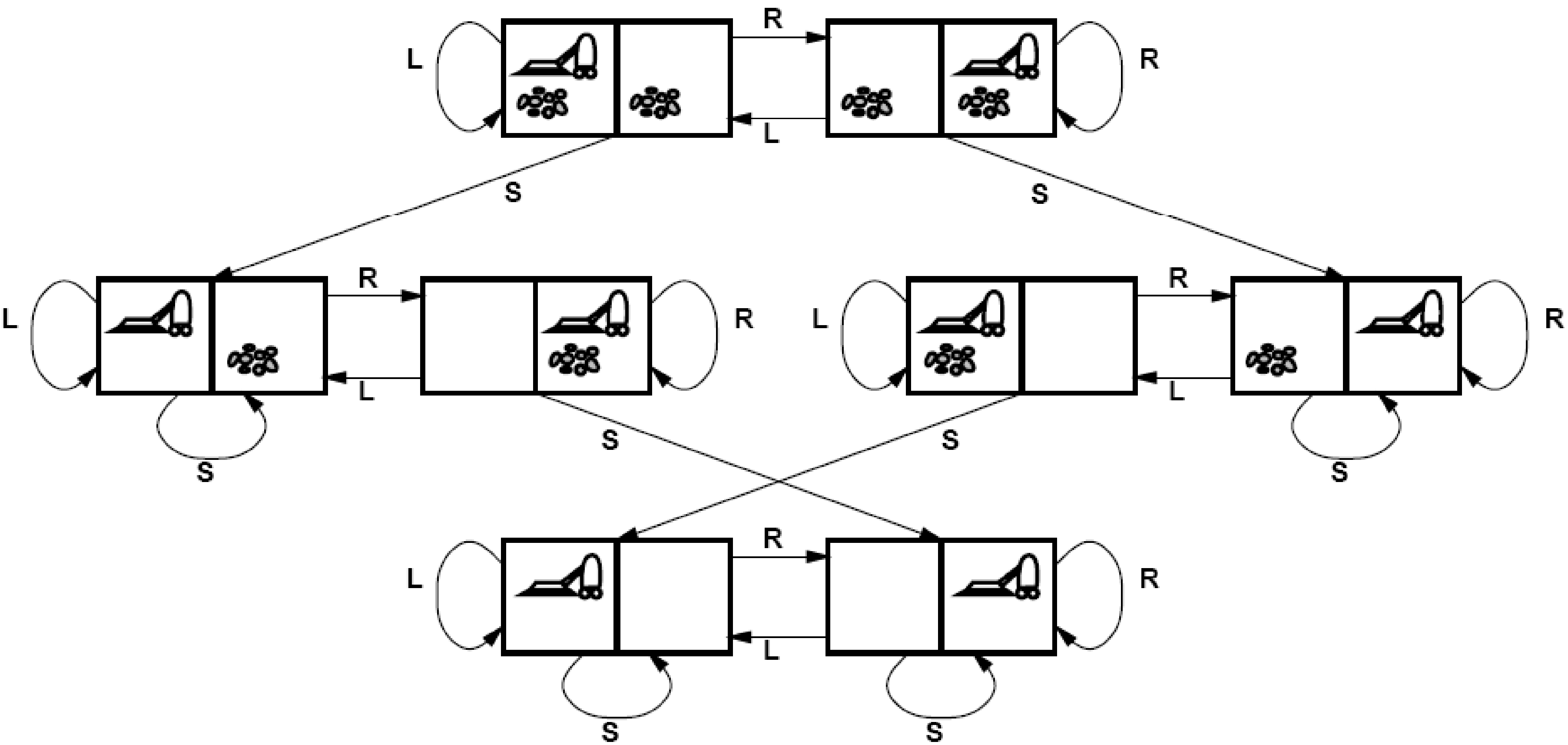
- The initial state, actions, and transition model define the **state space** of the problem
  - The set of all states reachable from initial state by any sequence of actions
  - Can be represented as a **directed graph** where the nodes are states and links between nodes are actions
- What is the state space for the Romania problem?

Example: Vacuum world



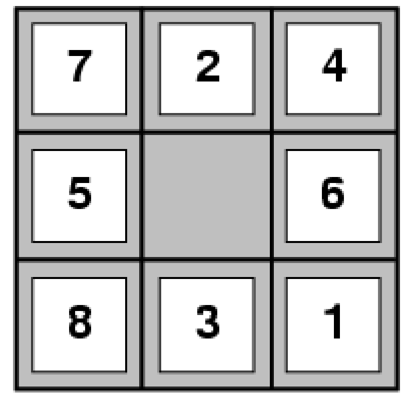
- **States**
  - Agent location and dirt location
  - How many possible states?
  - What if there are *n* possible locations?
- **Actions**
  - Left, right, suck
- **Transition model**

Vacuum world state space graph

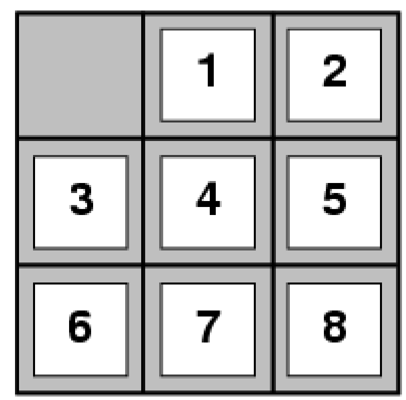


Example: The 8-puzzle

- **States**
  - Locations of tiles
    - 8-puzzle: 181,440 states
    - 15-puzzle: 1.3 trillion states
    - 24-puzzle: 10^{25} states
- **Actions**
  - Move blank left, right, up, down
- **Path cost**
  - 1 per move



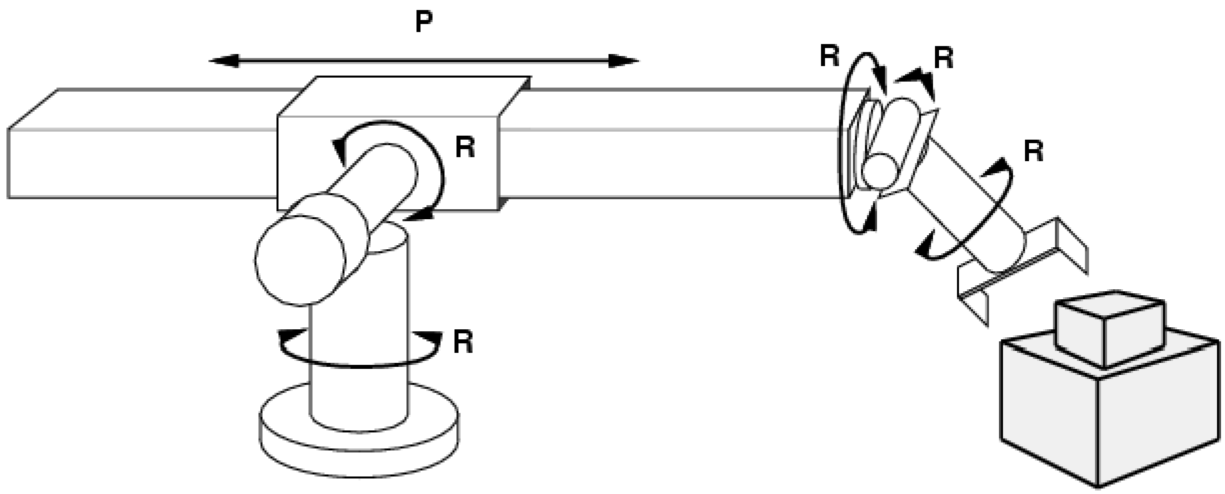
Start State



Goal State

- Optimal solution of n-Puzzle is NP-hard

Example: Robot motion planning



- **States**
  – Real-valued coordinates of robot joint angles
- **Actions**
  – Continuous motions of robot joints
- **Goal state**
  – Desired final configuration (e.g., object is grasped)
- **Path cost**
  – Time to execute, smoothness of path, etc.

Other Real-World Examples

- Routing
- Touring
- VLSI layout
- Assembly sequencing
- Protein design

Search

- Given:
  - **Initial state**
  - **Actions**
  - **Transition model**
  - **Goal state**
  - **Path cost**

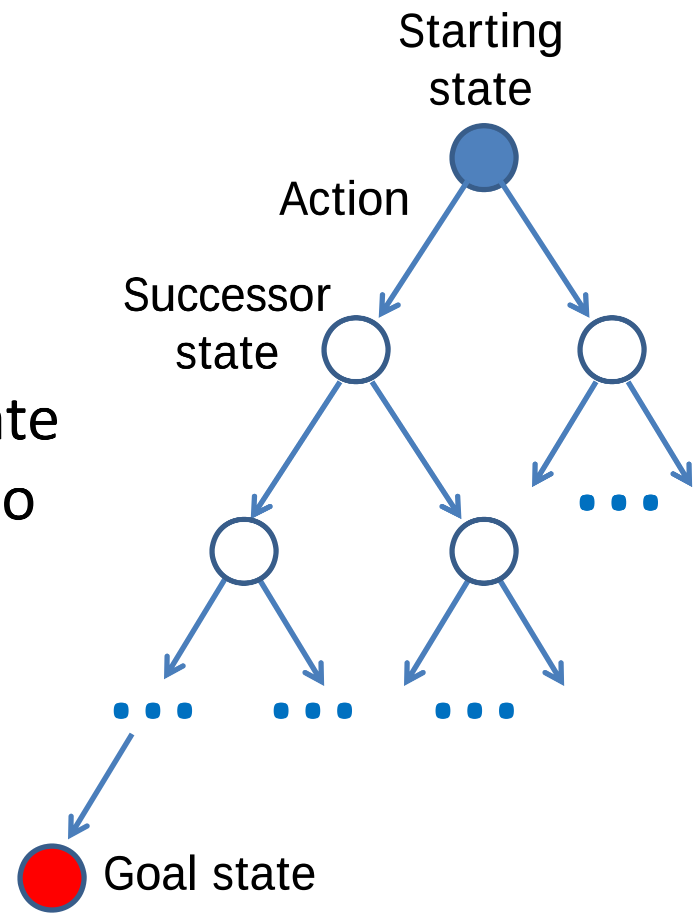
- How do we find the optimal solution?
  - How about building the state space and then using Dijkstra's shortest path algorithm?
    - The state space is huge!
    - Complexity of Dijkstra's is $O(E + V \log V)$, where V is the size of the state space

Tree Search

- Let’s begin at the start node and **expand** it by making a list of all possible successor states
- Maintain a **fringe** or a list of unexpanded states
- At each step, pick a state from the fringe to expand
- Keep going until you reach the goal state
- Try to expand as few states as possible

Search tree

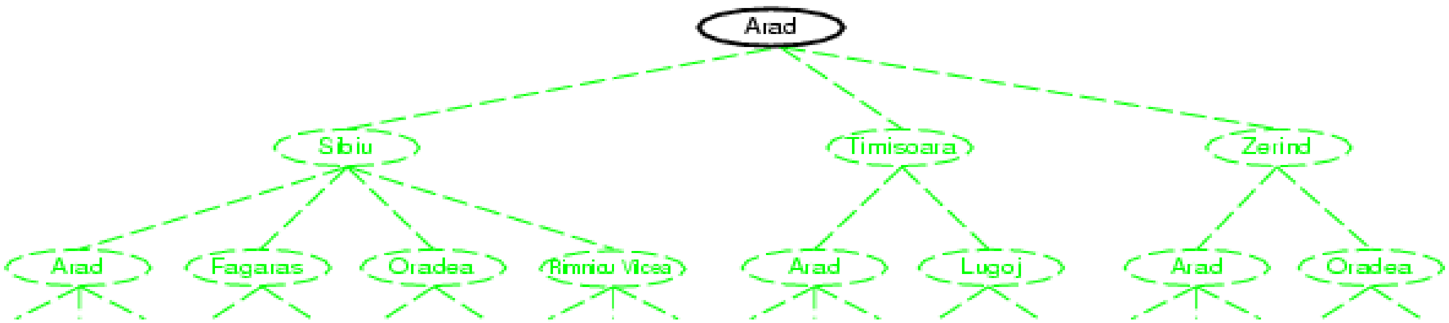
- “What if” tree of possible actions and outcomes
- The root node corresponds to the starting state
- The children of a node correspond to the **successor states** of that node’s state
- A path through the tree corresponds to a sequence of actions
  - A solution is a path ending in the goal state
- Nodes vs. states
  - A state is a representation of a physical configuration, while a node is a data structure that is part of the search tree

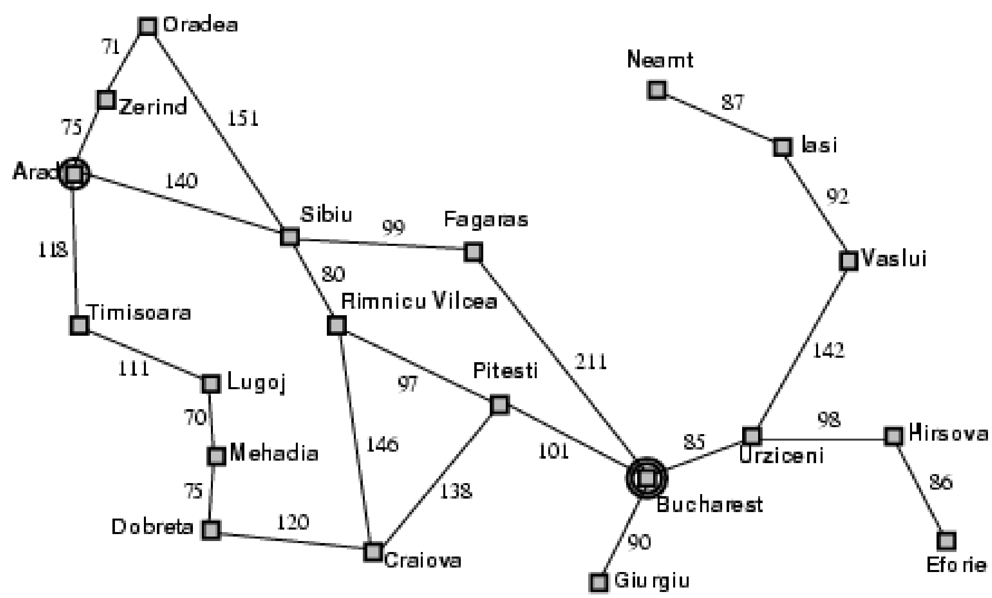


Tree Search Algorithm Outline

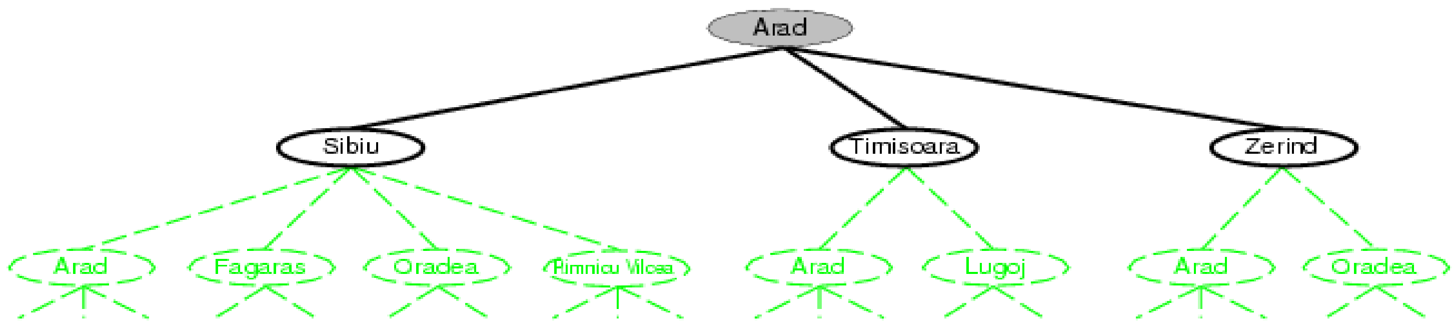
- Initialize the **fringe** using the **starting state**
- While the fringe is not empty
  - Choose a fringe node to expand according to **search strategy**
  - If the node contains the **goal state**, return solution
  - Else **expand** the node and add its children to the fringe

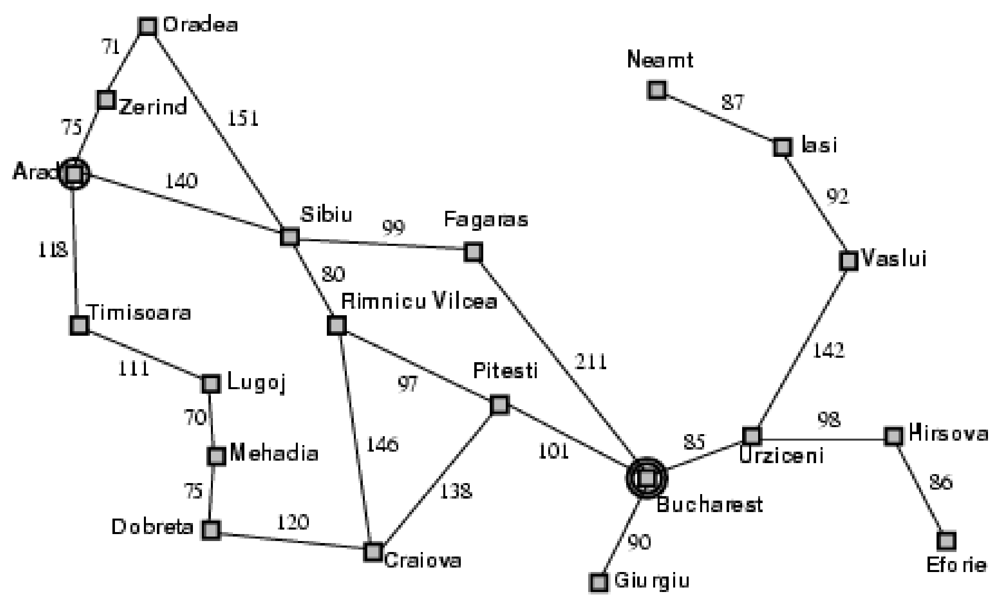
Tree search example



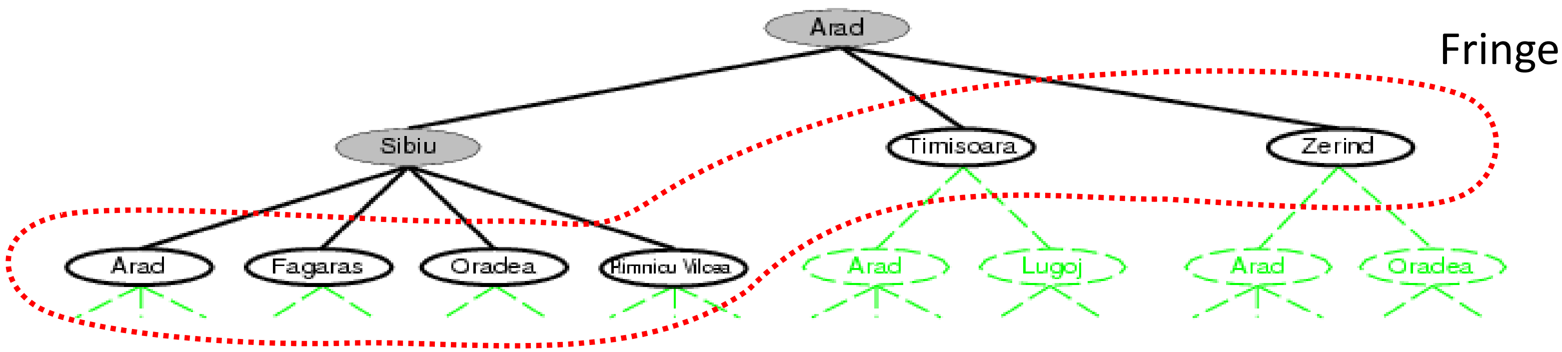


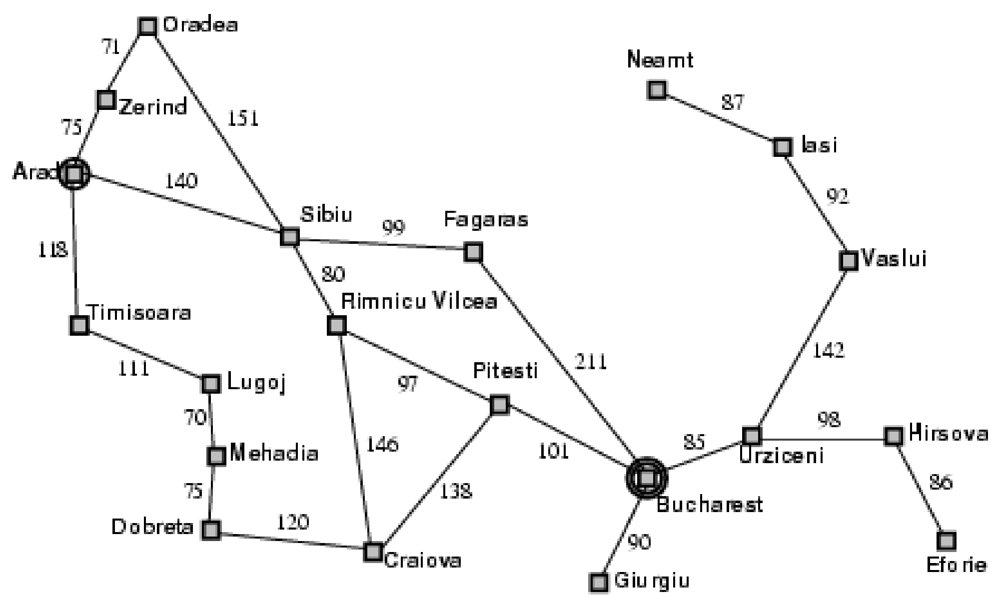
Tree search example





Tree search example





Search strategies

- A **search strategy** is defined by picking the order of node expansion
- Strategies are evaluated along the following dimensions:
  - **Completeness:** does it always find a solution if one exists?
  - **Optimality:** does it always find a least-cost solution?
  - **Time complexity:** number of nodes generated
  - **Space complexity:** maximum number of nodes in memory
- Time and space complexity are measured in terms of
  - *b:* maximum branching factor of the search tree
  - *d:* depth of the least-cost solution
  - *m*: maximum length of any path in the state space (may be infinite)

Uninformed search strategies

- Uninformed search strategies use only the information available in the problem definition

- Breadth-first search
- Uniform-cost search
- Depth-first search
- Iterative deepening search