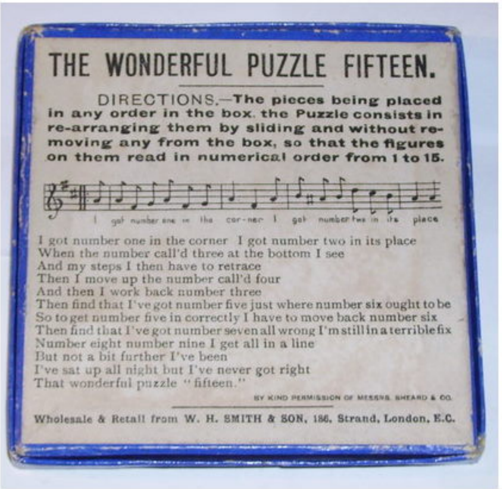
Solving problems by searching

Chapter 3



THE WONDERFUL PUZZLE FIFTEEN.

DIRECTIONS.—**The pieces being placed in any order in the box, the Puzzle consists in re-arranging them by sliding and without removing any from the box, so that the figures on them read in numerical order from 1 to 15.**

I got number one in the cor-ner I got number two in its place

I got number one in the corner I got number two in its place
When the number call'd three at the bottom I see
And my steps I then have to retrace
Then I move up the number call'd four
And then I work back number three
Then find that I've got number five just where number six ought to be
So to get number five in correctly I have to move back number six
Then find that I've got number seven all wrong I'm still in a terrible fix
Number eight number nine I get all in a line
But not a bit further I've been
I've sat up all night but I've never got right
That wonderful puzzle "fifteen."

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Types of agents

Reflex agent

- Consider how the world IS
- Choose action based on current percept
- Do not consider the future consequences of actions

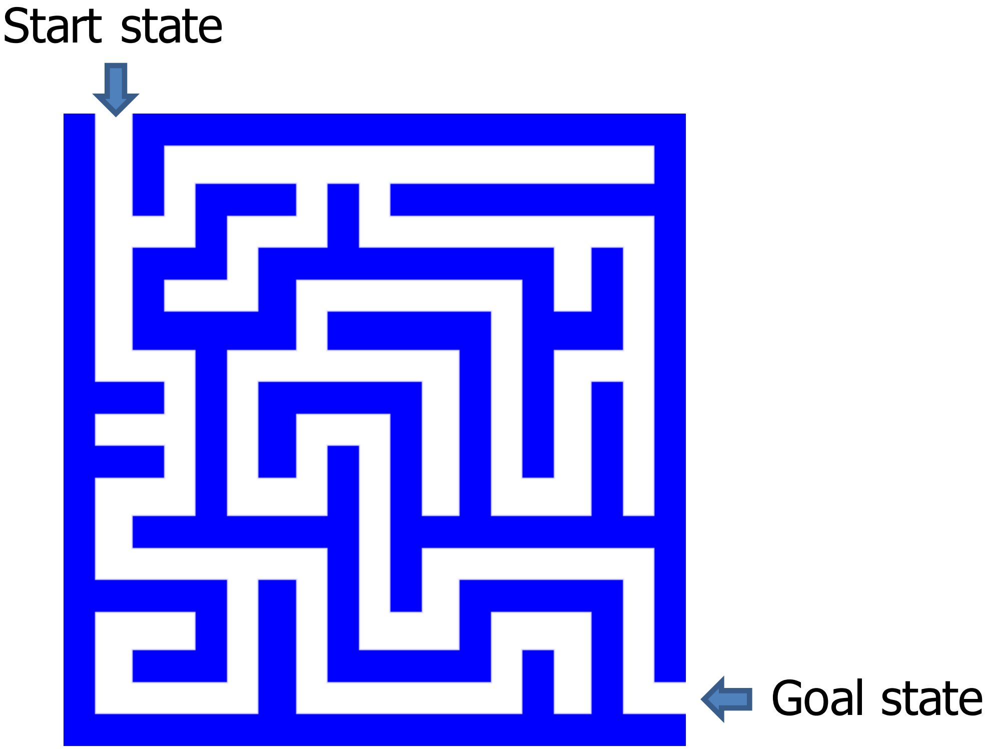
Planning agent

- Consider how the world WOULD BE
- Decisions based on (hypothesized) consequences of actions
- Must have a model of how the world evolves in response to actions
- Must formulate a goal

Source: D. Klein, P. Abbeel

Search

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

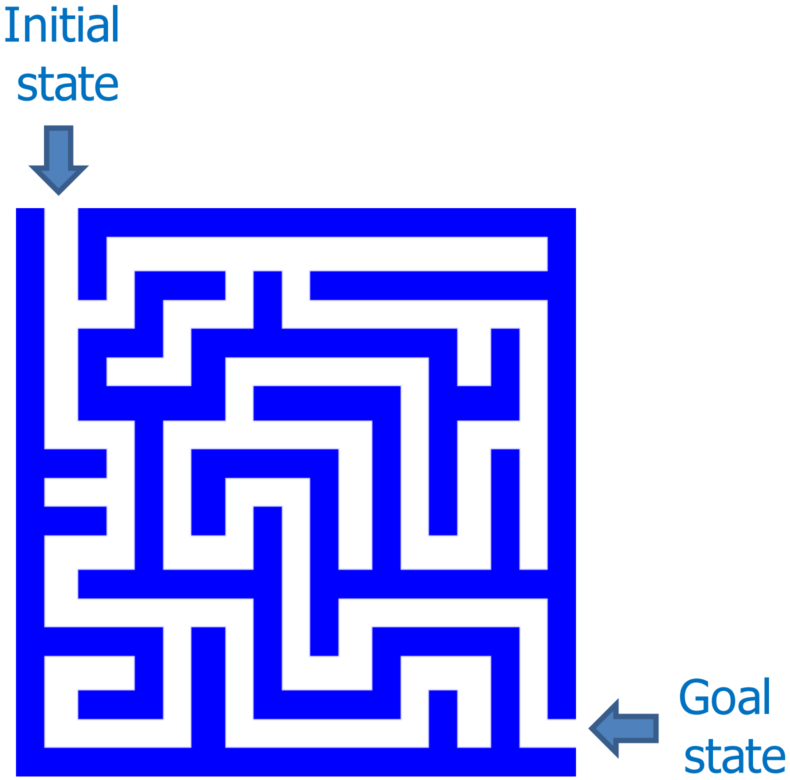


Search

- We will consider the problem of designing **goal-based agents** in **fully observable, deterministic, discrete, known** environments
  - The agent must find a *sequence of actions* that reaches the goal
  - The **performance measure** is defined by (a) reaching the goal and (b) how "expensive" the path to the goal is
  - We are focused on the process of finding the solution; while executing the solution, we assume that the agent can safely ignore its percepts (**open-loop system**)

Search problem components

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

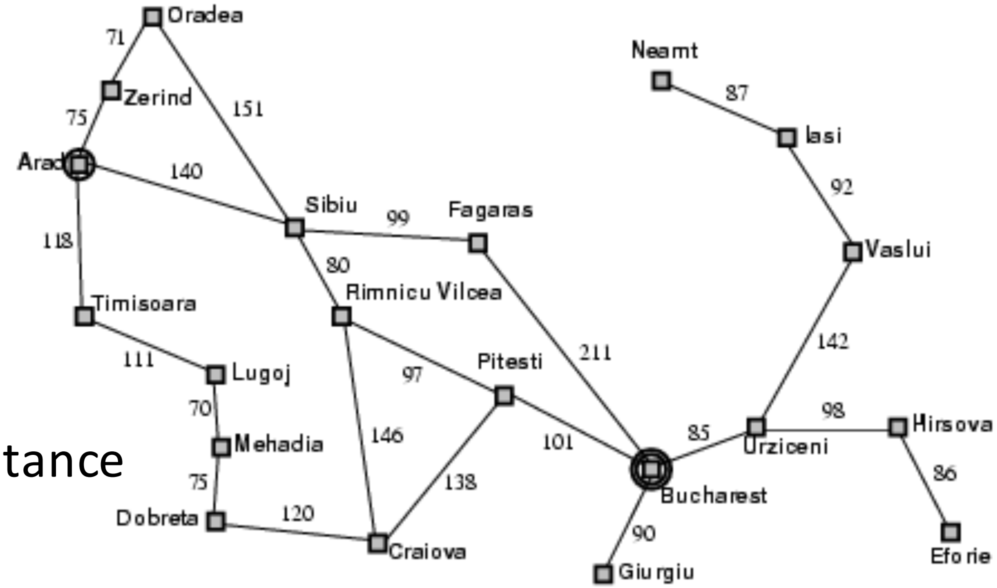


- The **optimal solution** is the sequence of actions that gives the *lowest* path cost for reaching the goal

Example: Romania

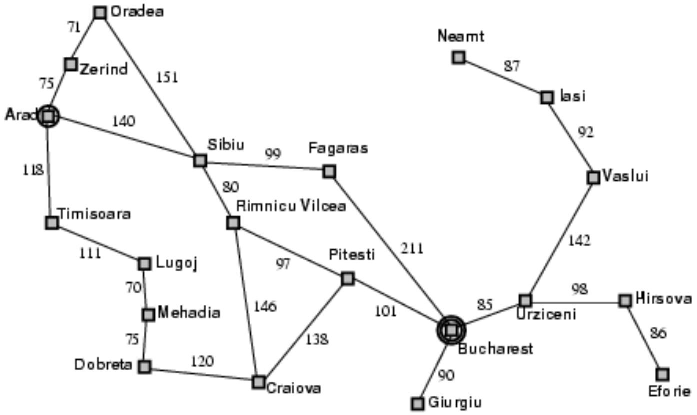
- On vacation in Romania; currently in Arad
- Flight leaves tomorrow from Bucharest

- **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 (total distance traveled)

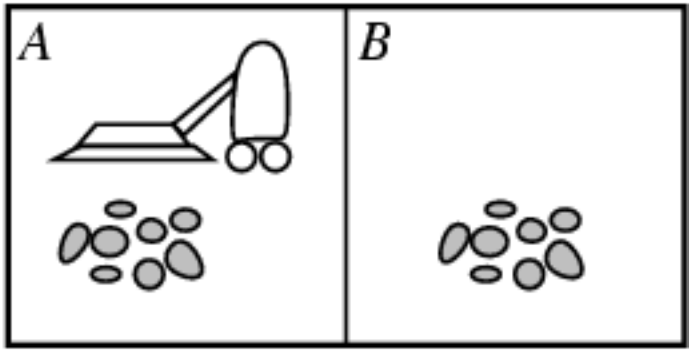


State space

- 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?

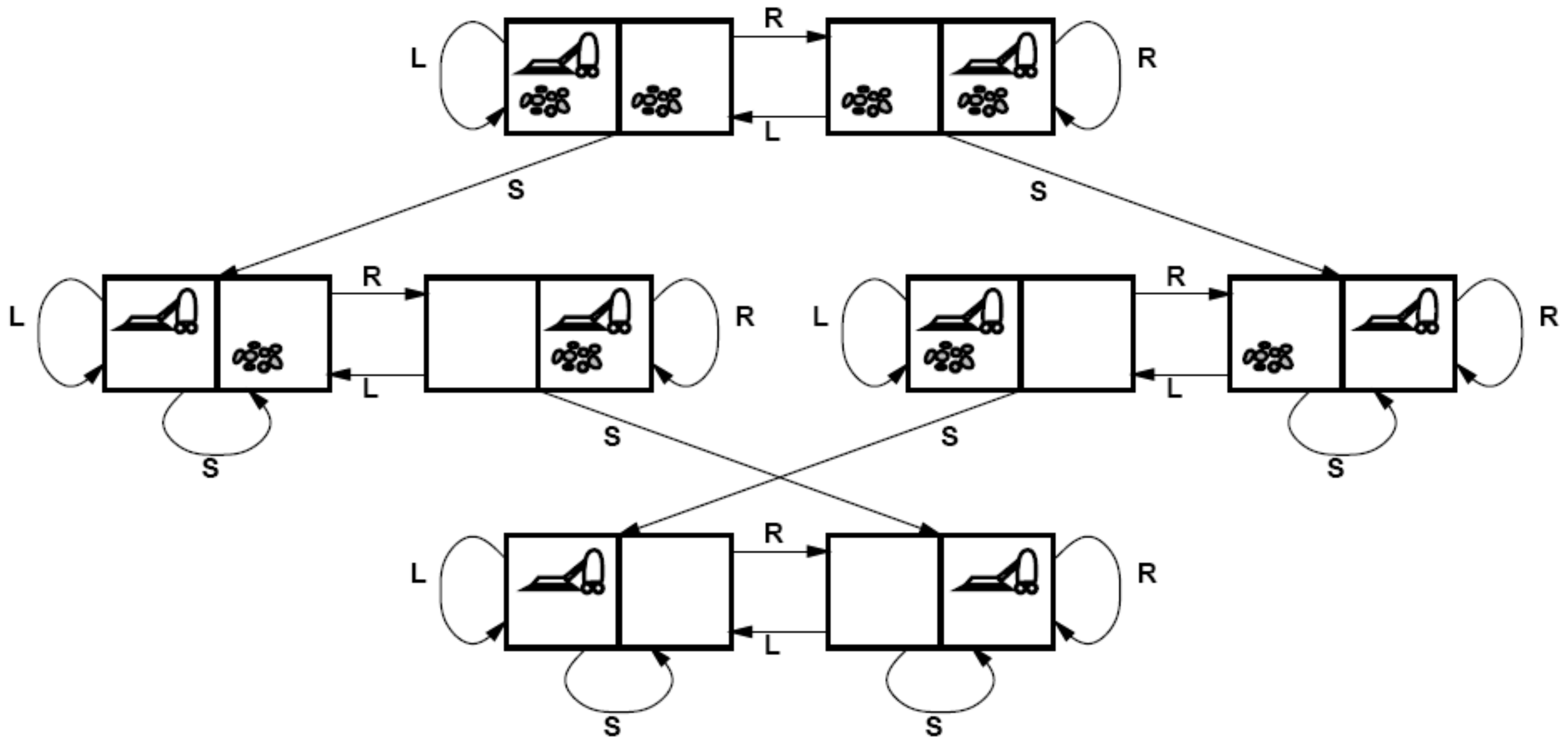


Example: Vacuum world



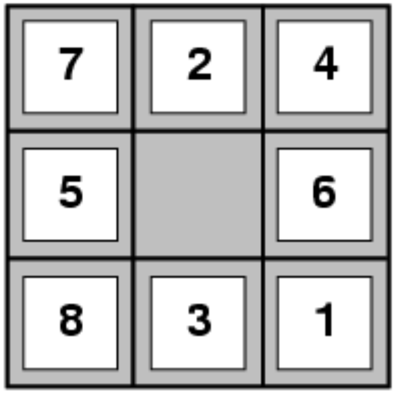
- **States**
  - Agent location and dirt location
  - How many possible states?
  - What if there are *n* possible locations?
    - The size of the state space grows exponentially with the “size” of the world!
- **Actions**
  - Left, right, suck
- **Transition model**

Vacuum world state space graph



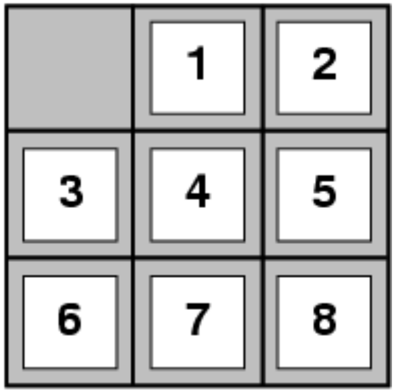
Example: The 8-puzzle

- **States**
  - Locations of tiles
    - 8-puzzle: 181,440 states (9!/2)
    - 15-puzzle: ~1.3 trillion states
    - 24-puzzle: ~10^{25} states
- **Actions**
  - Move blank left, right, up, down
- **Path cost**
  - 1 per move



7	2	4
5		6
8	3	1

Start State

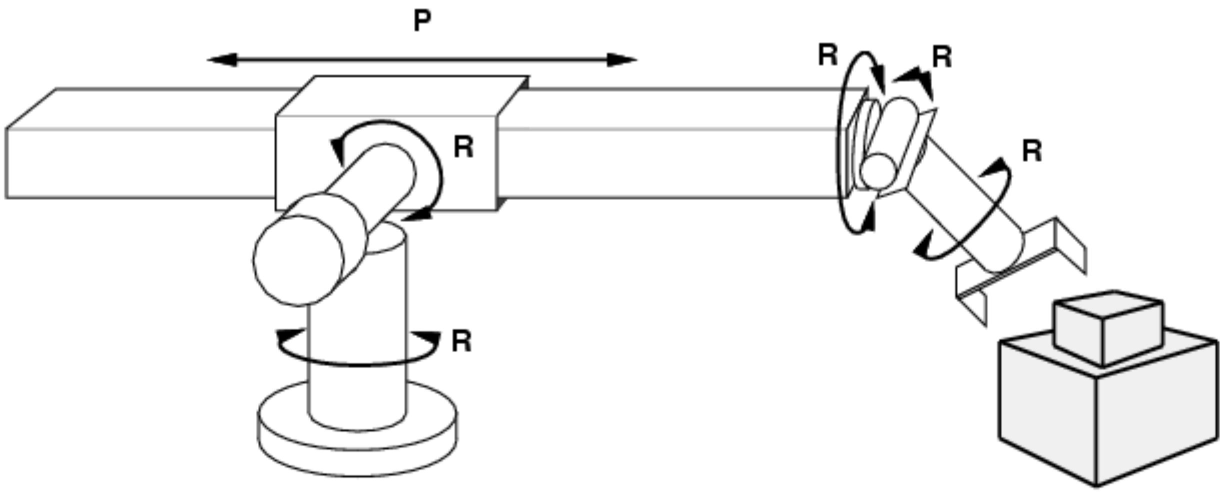


	1	2
3	4	5
6	7	8

Goal State

- Finding the optimal solution of n-Puzzle is NP-hard

Example: Robot motion planning



- **States**
  - Real-valued joint parameters (angles, displacements)
- **Actions**
  - Continuous motions of robot joints
- **Goal state**
  - Configuration in which object is grasped
- **Path cost**
  - Time to execute, smoothness of path, etc.

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?
    - Complexity of Dijkstra’s is $O(E + V \log V)$, where V is the size of the state space
    - The state space may be huge!

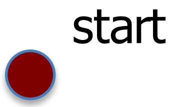
Search: Basic idea

- Let’s begin at the start state and **expand** it by making a list of all possible successor states (we use a **Successor function** here!)
- Maintain a **frontier** or a list of unexpanded states
- At each step, pick a state from the frontier to expand
- Keep going until you reach a goal state
- Try to expand as few states as possible

Successor Function

- We usually don’t have a full representation of the state space
- Instead, we define a Successor Function to capture the transition model
  - Given a state, apply all applicable actions and generate a list of the resulting (Successor) states

Search: Basic idea



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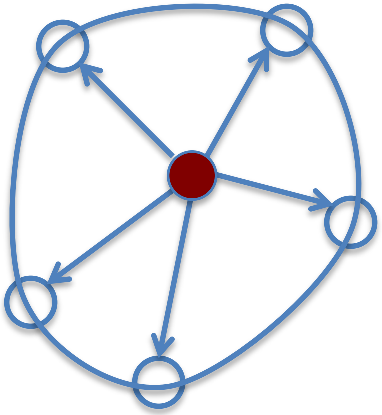

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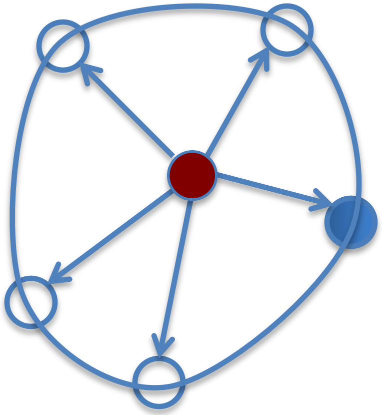

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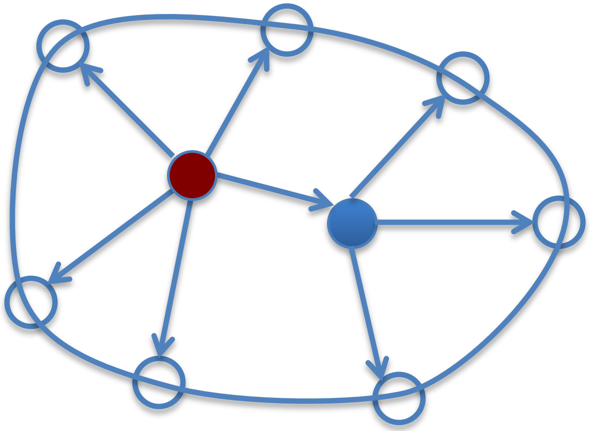

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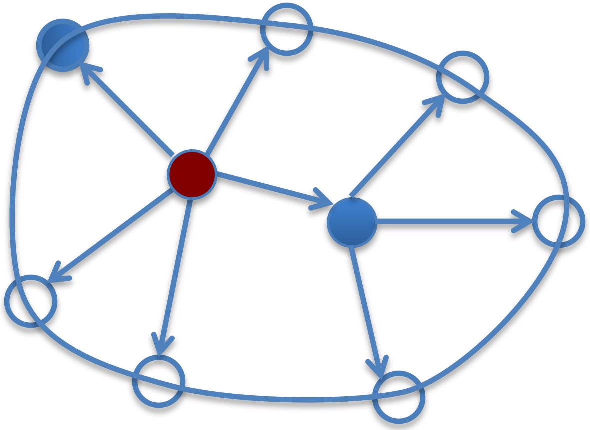

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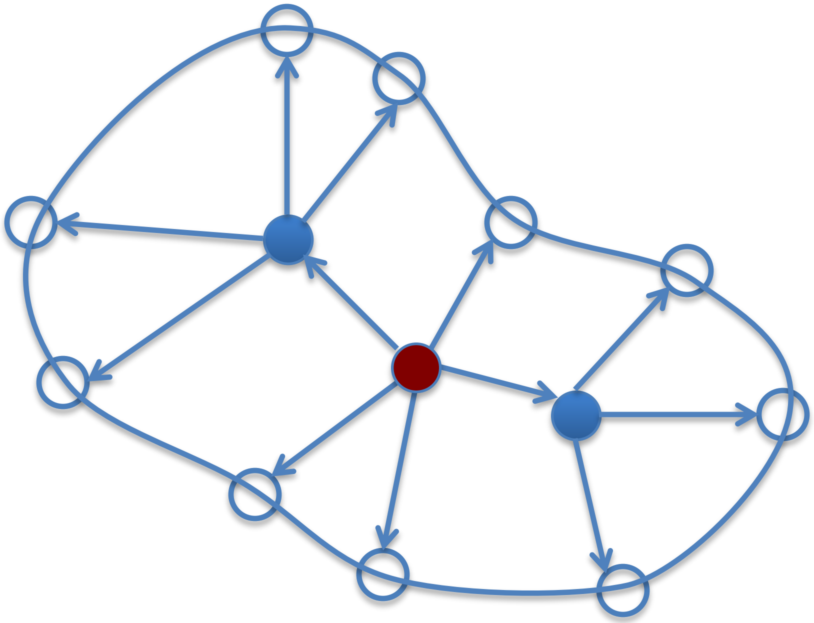

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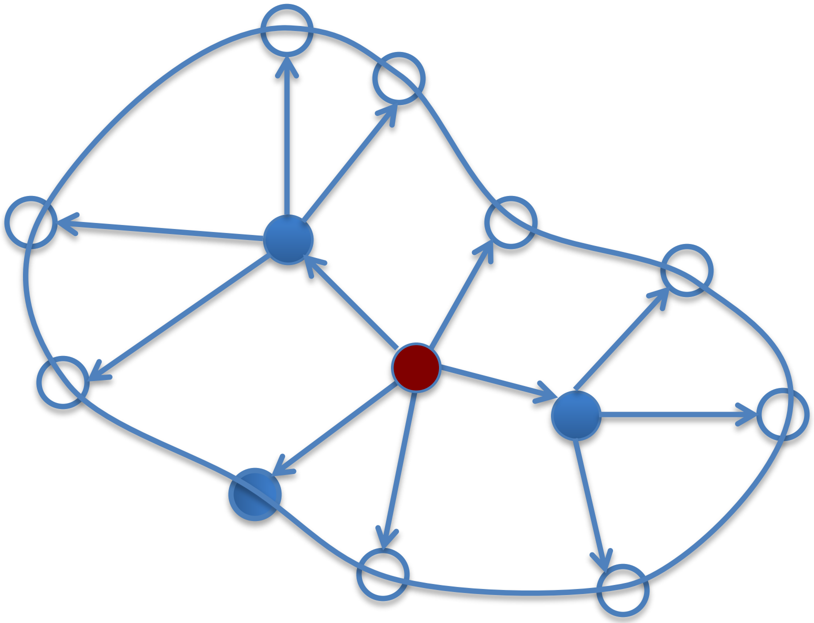

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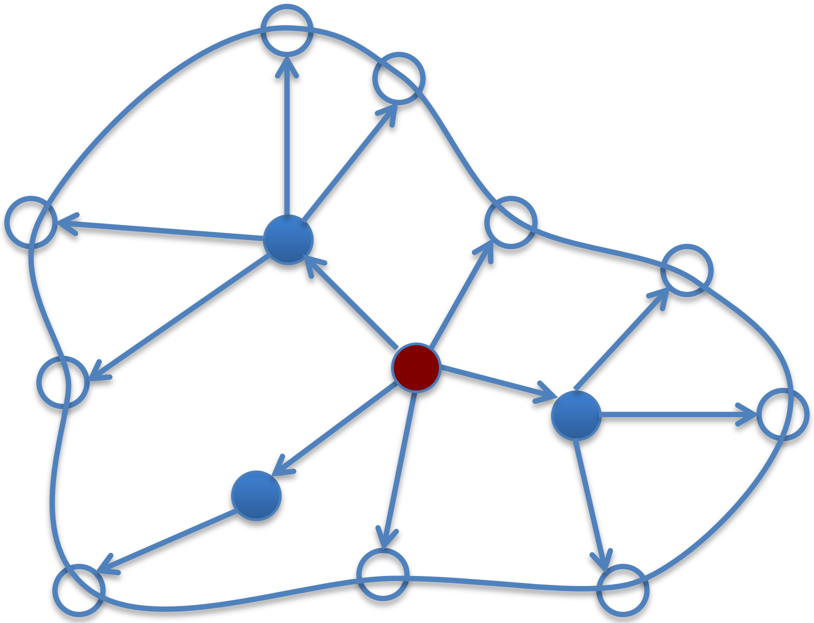

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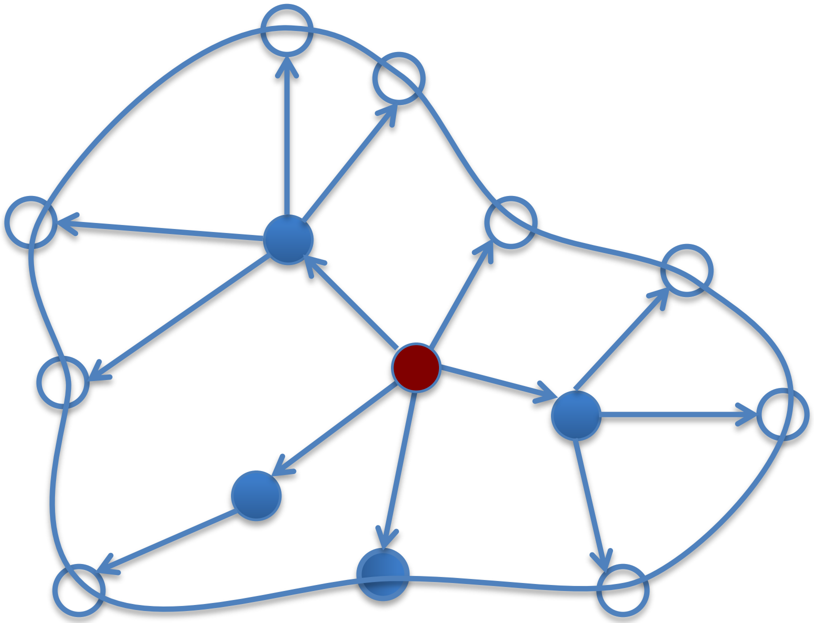

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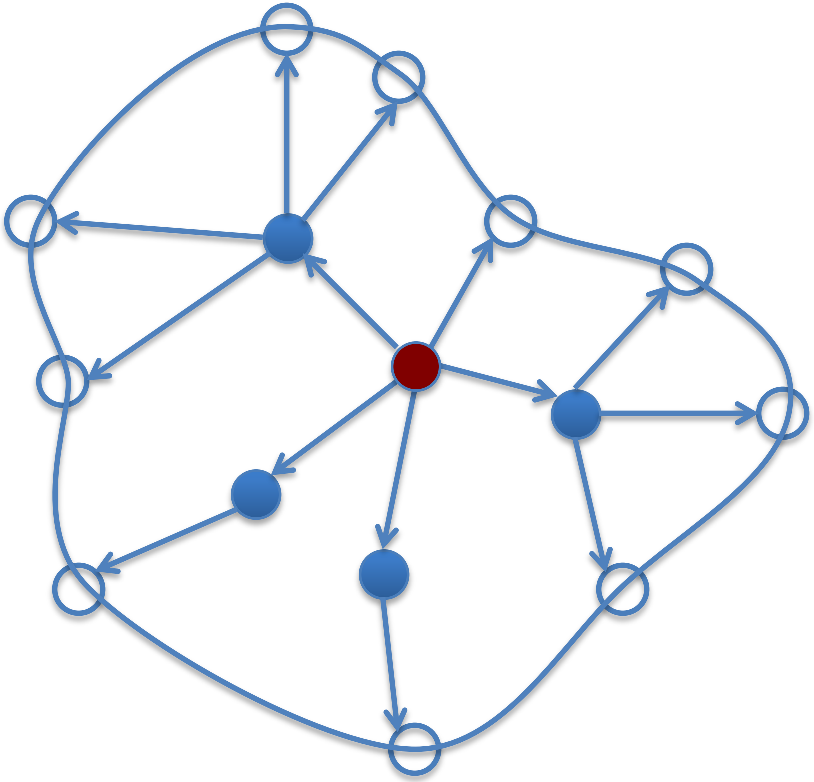

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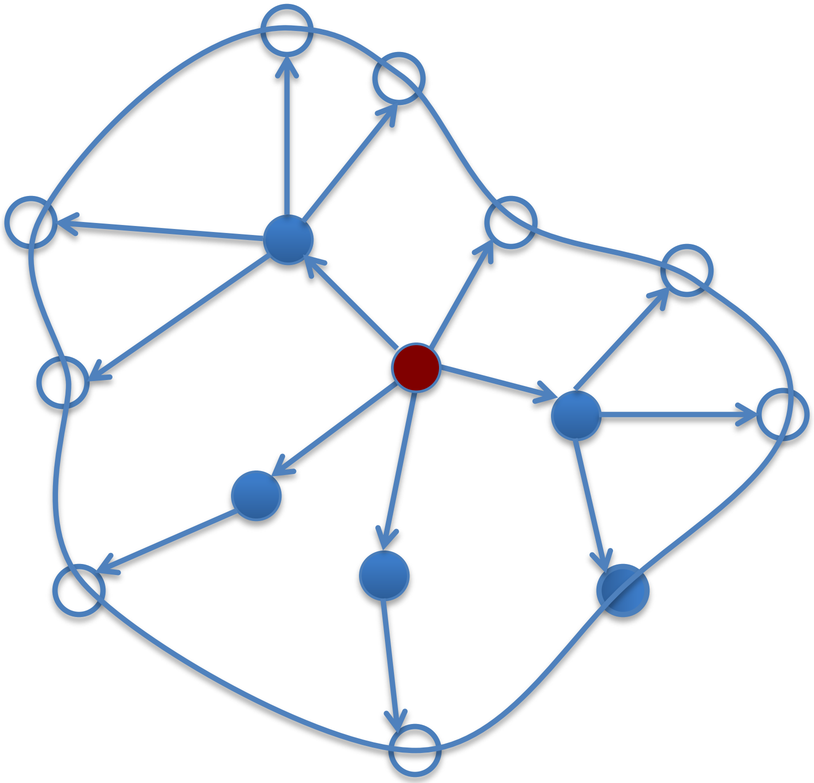

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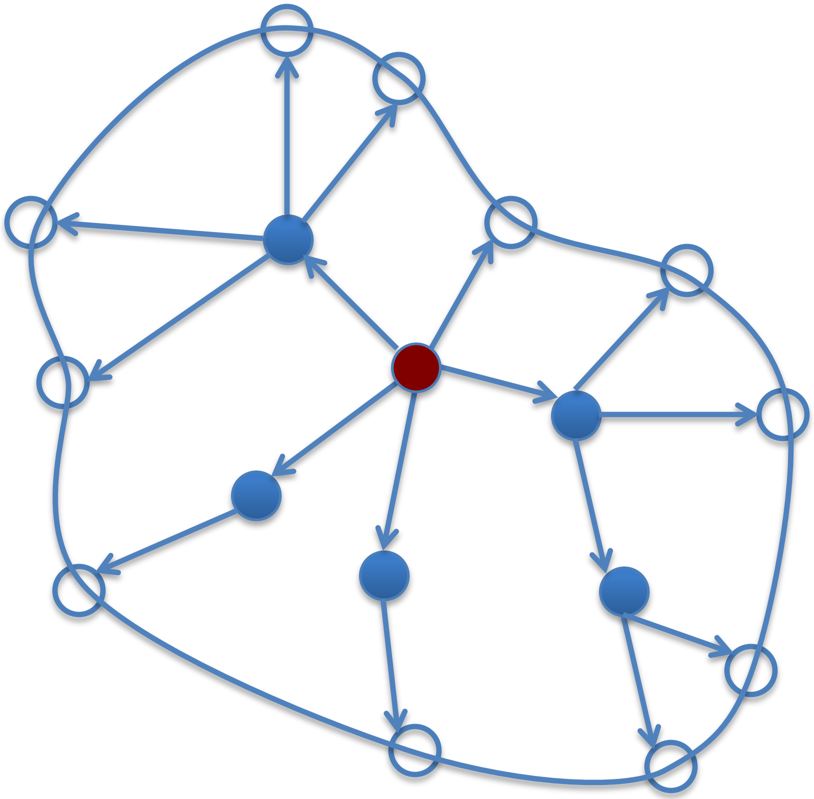
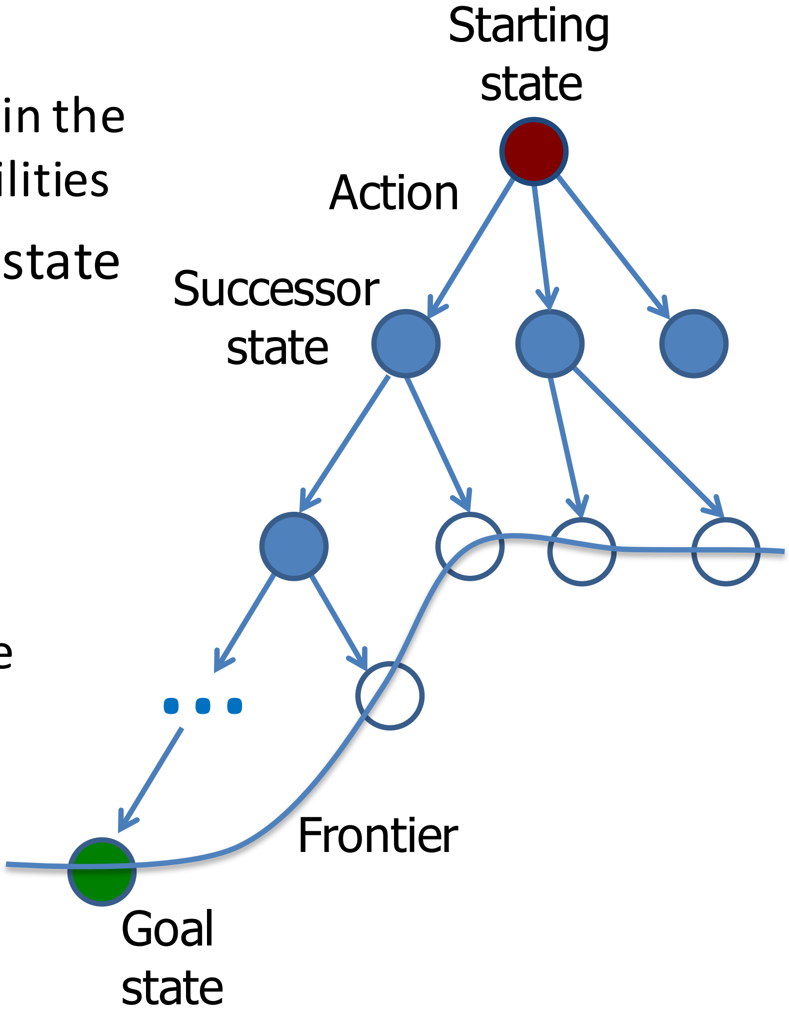


Search tree

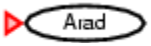
- "What if" tree of sequences of actions and outcomes
  - When we are searching, we are not acting in the world, merely "thinking" about the possibilities
- The root node corresponds to the starting state
- The children of a node are generated by a successor function
- A path through the tree corresponds to a sequence of actions
  - A solution is a path ending in the goal state
- Nodes vs. states
  - A state is a representation of the world, while a node is a data structure that is part of the search tree
    - Node has to keep pointer to parent, path cost, possibly other info

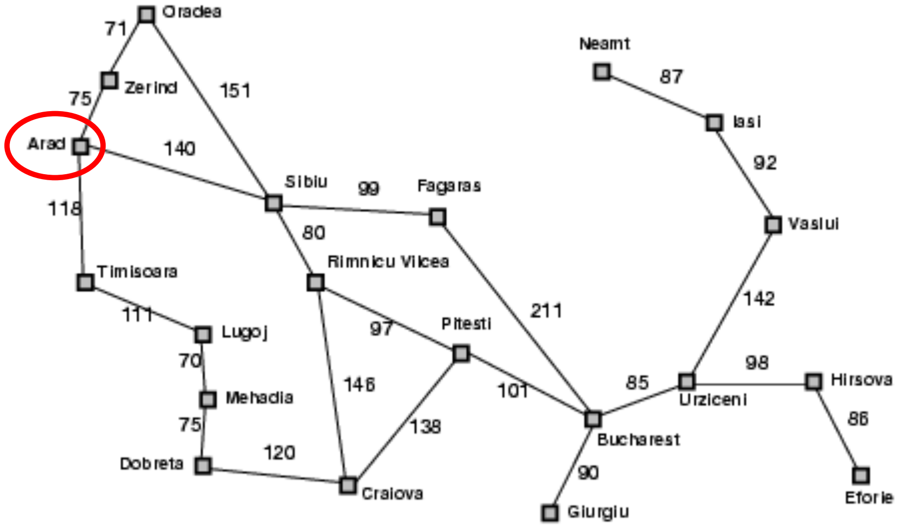


Tree Search Algorithm Outline

- Initialize the **frontier** using the **starting state**
- While the frontier is not empty
  - Choose a frontier node according to **search strategy** and take it off the frontier
  - If the node contains the **goal state**, return solution
  - Else **expand** the node by applying the **successor function** and add its children to the frontier

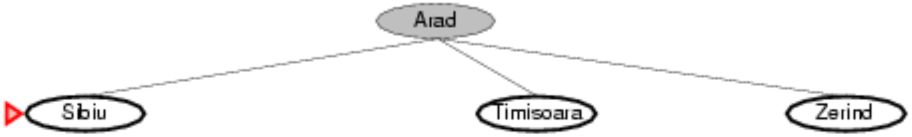
Tree search example

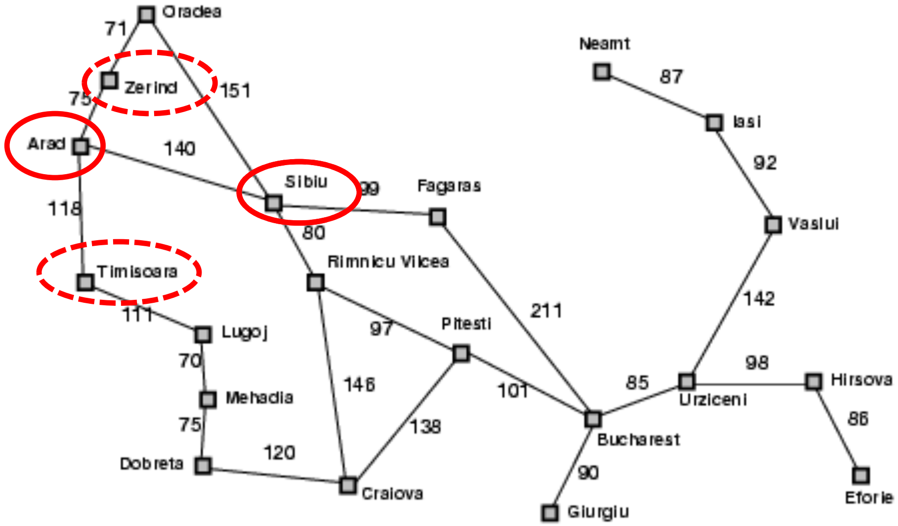




Start: Arad
Goal: Bucharest

Tree search example





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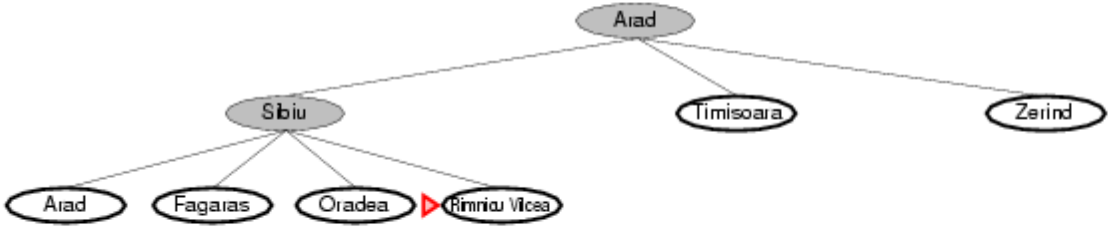
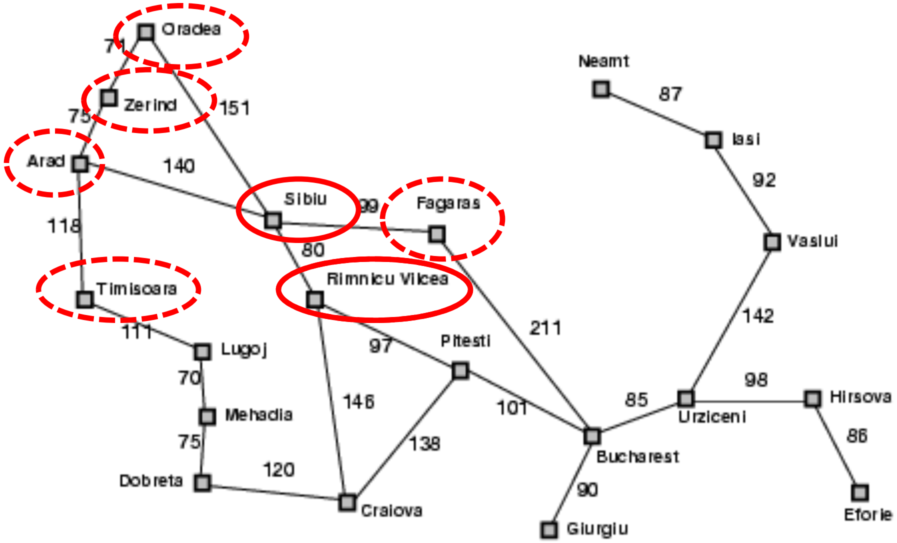
Tree search example





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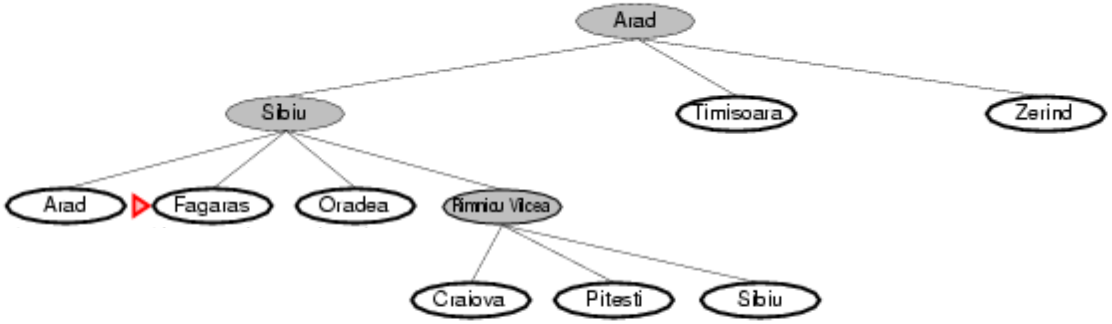
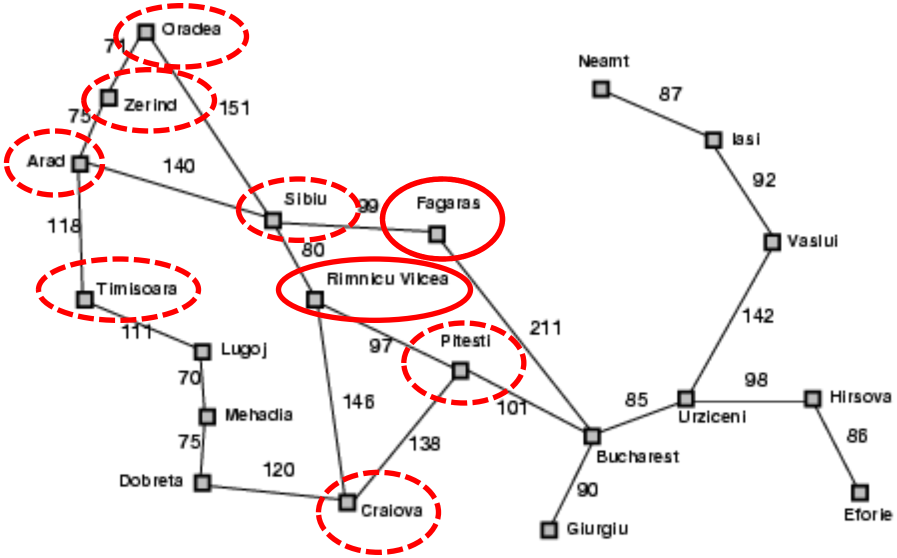
Goal: Bucharest

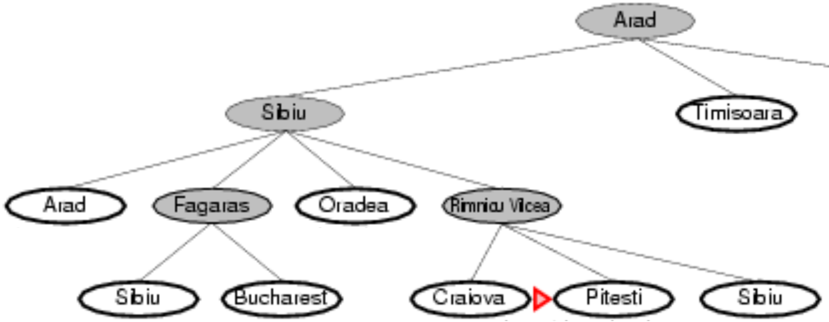
Tree search example

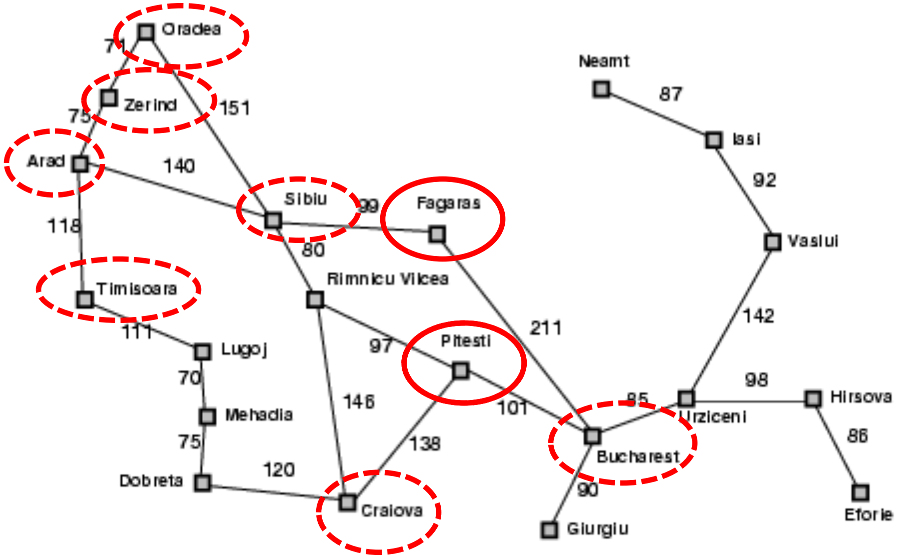


Start: Arad
Goal: Bucharest



Tree search example





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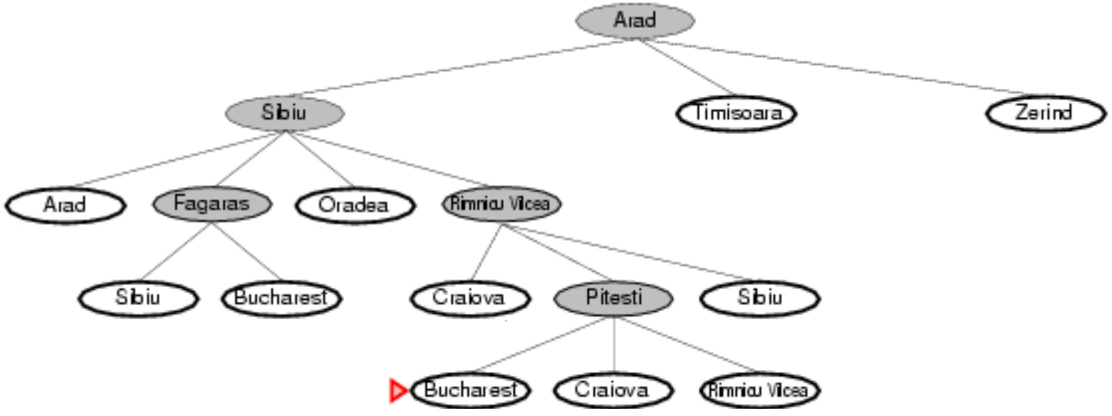

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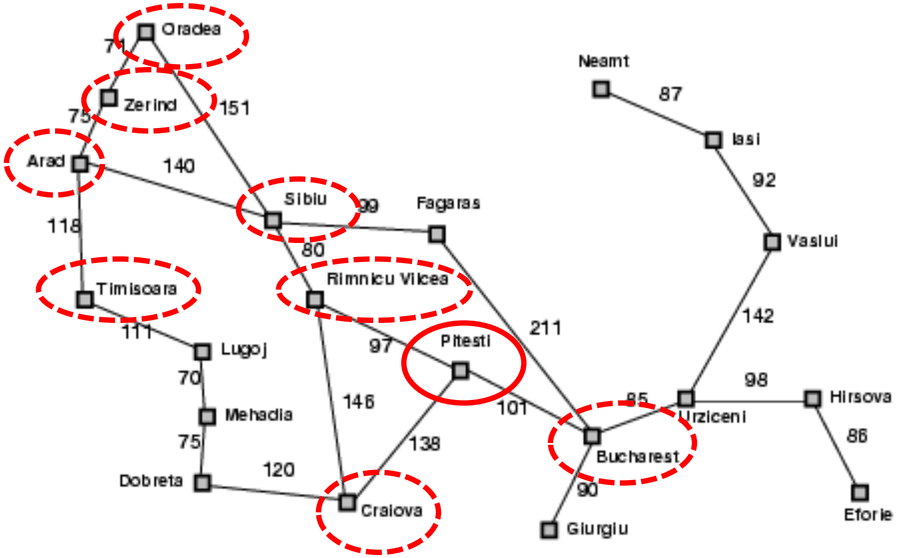

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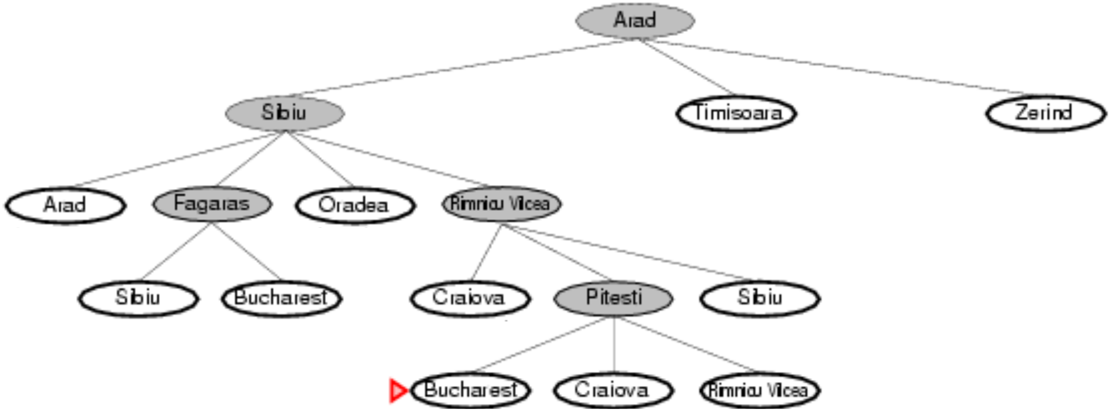
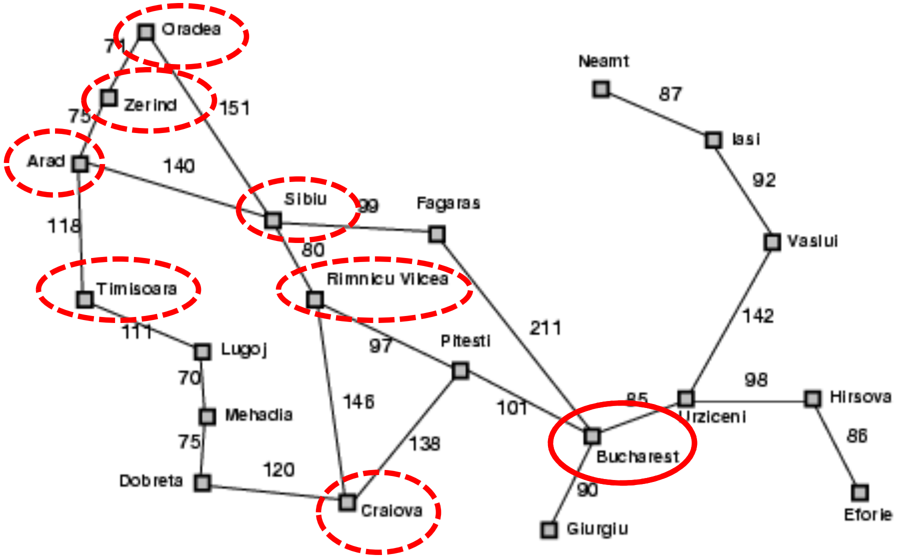




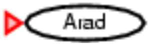
Start: Arad
Goal: Bucharest

Handling repeated states

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

- To handle repeated states:
  - Every time you expand a node, add that state to the **explored set**; do not put explored states on the frontier again
  - Every time you add a node to the frontier, check whether it already exists in the frontier with a higher path cost, and if yes, replace that node with the new one

Search without repeated states



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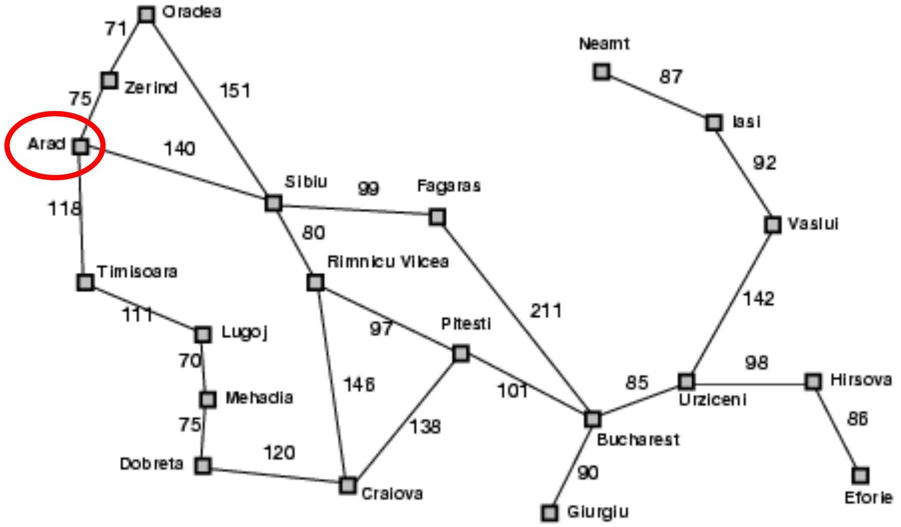
Goal: Bucharest



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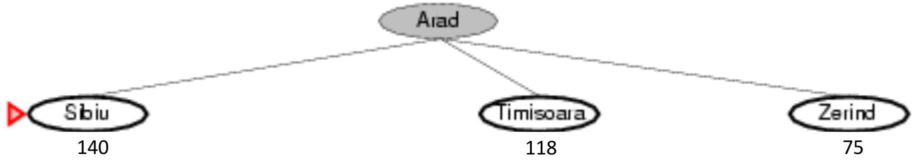

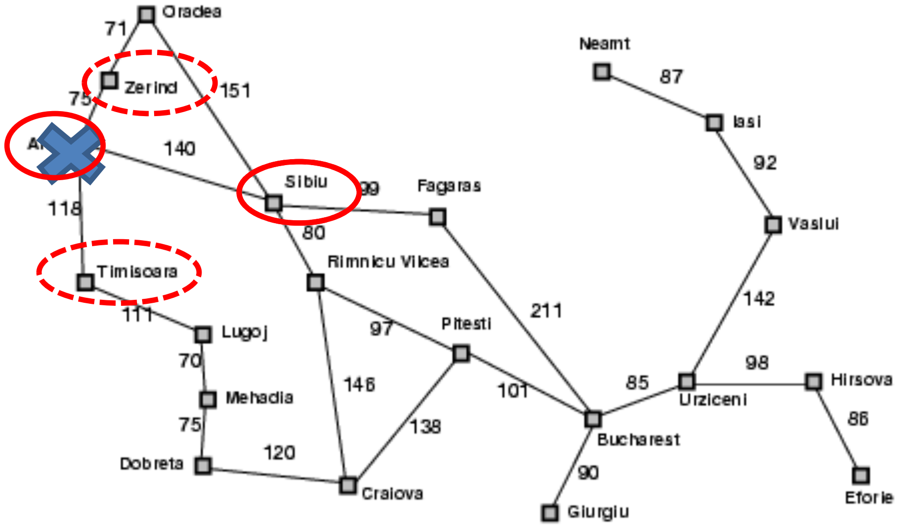

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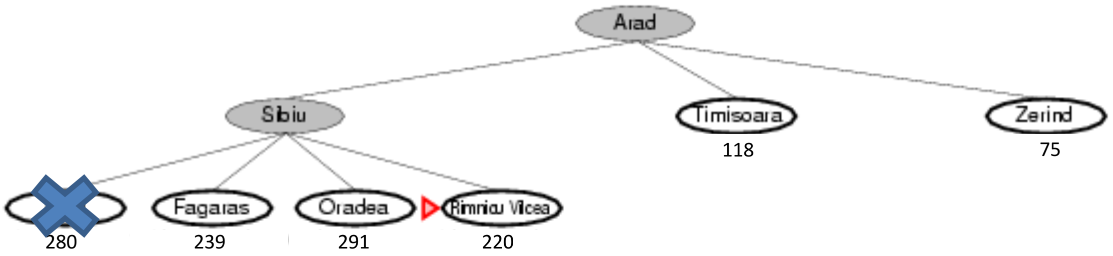

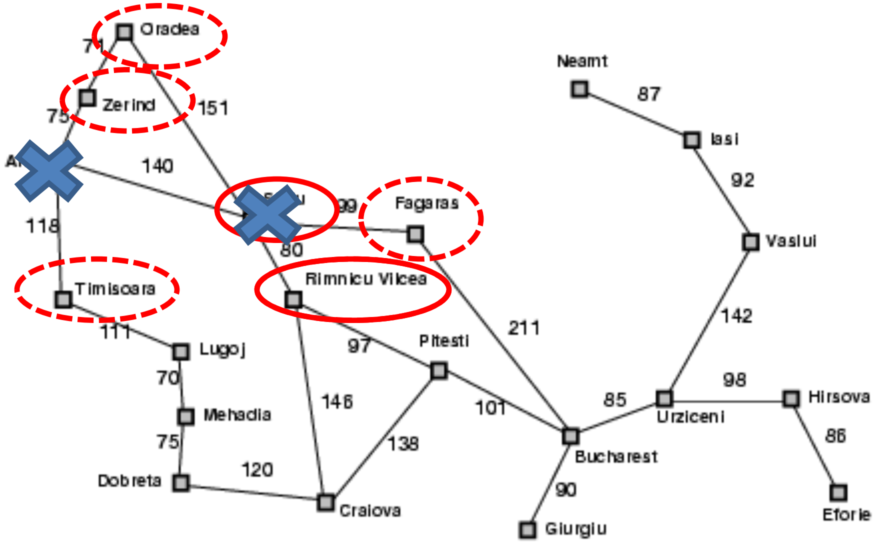

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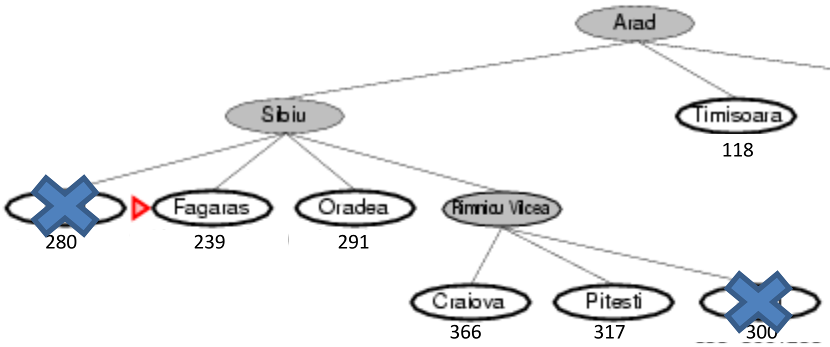
Search without repeated states



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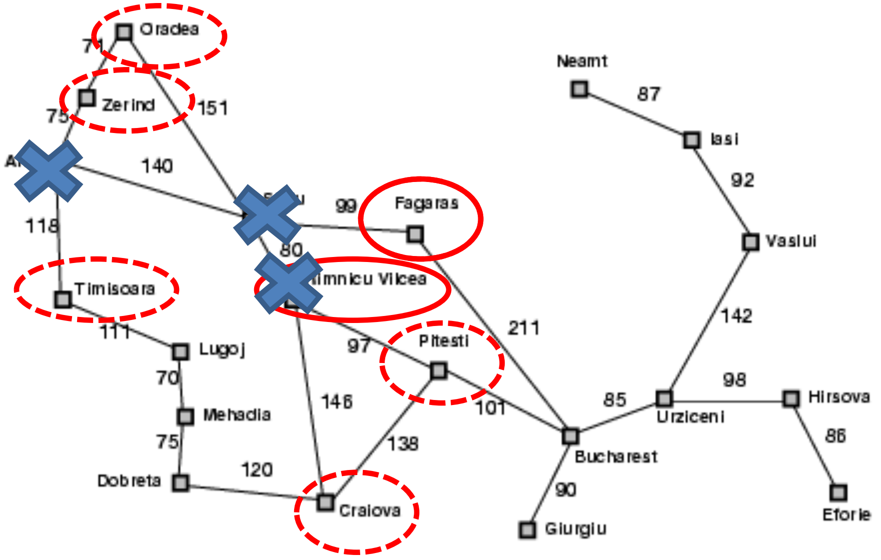

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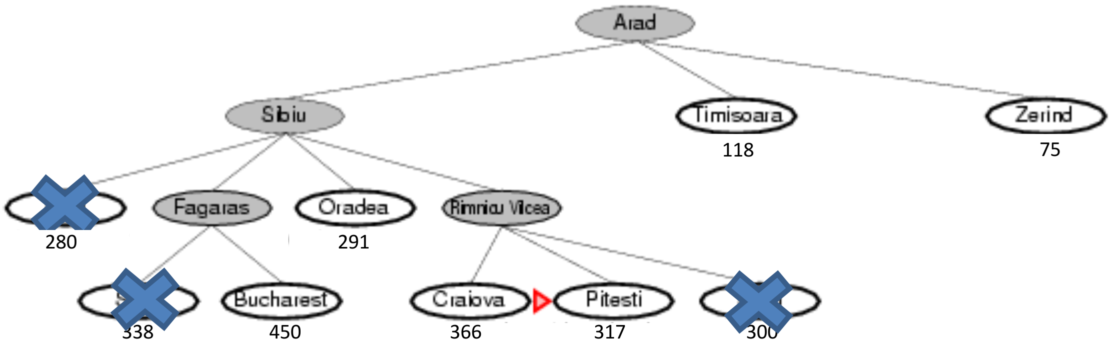

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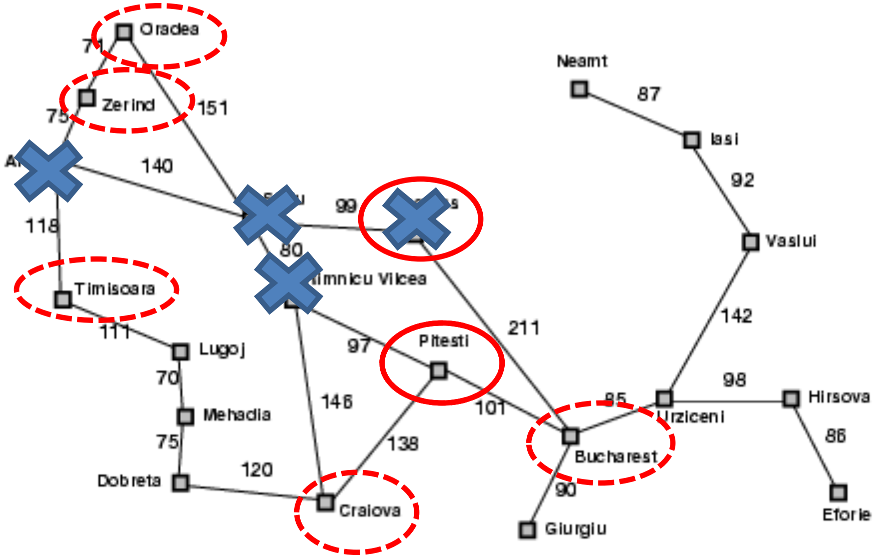

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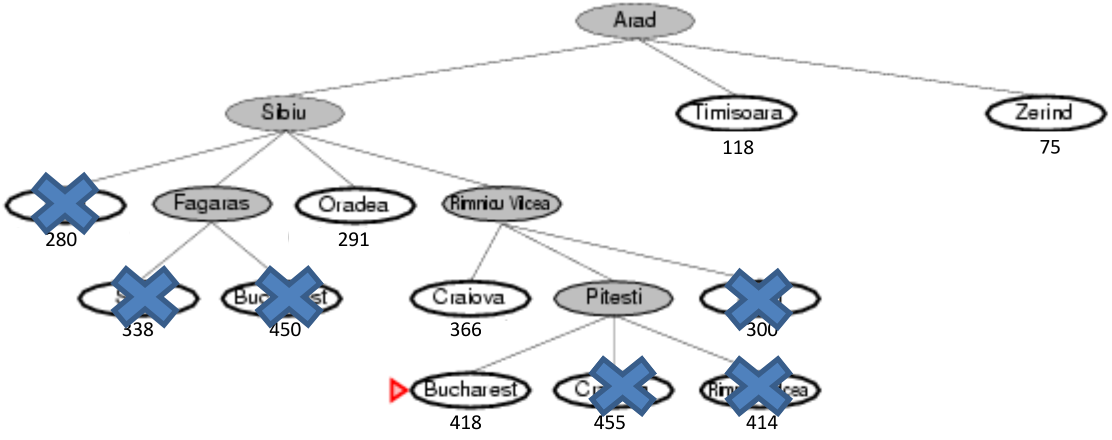

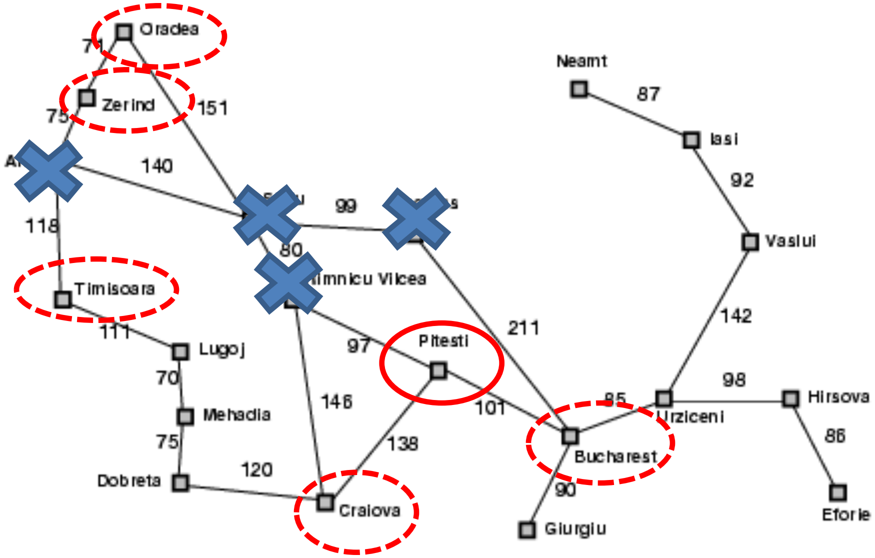

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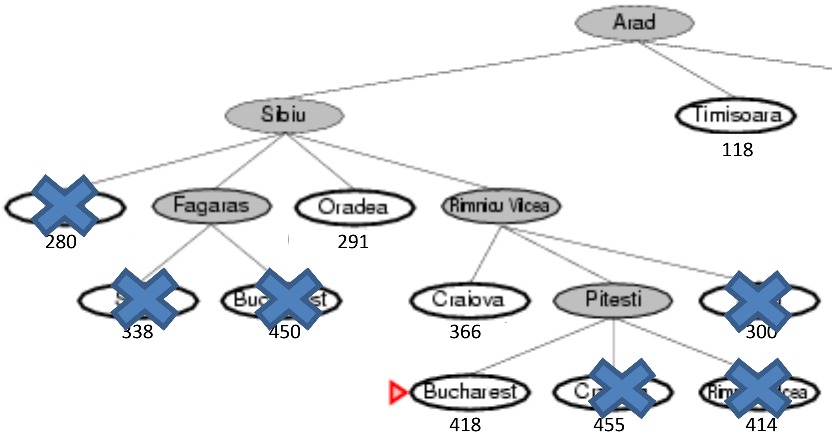
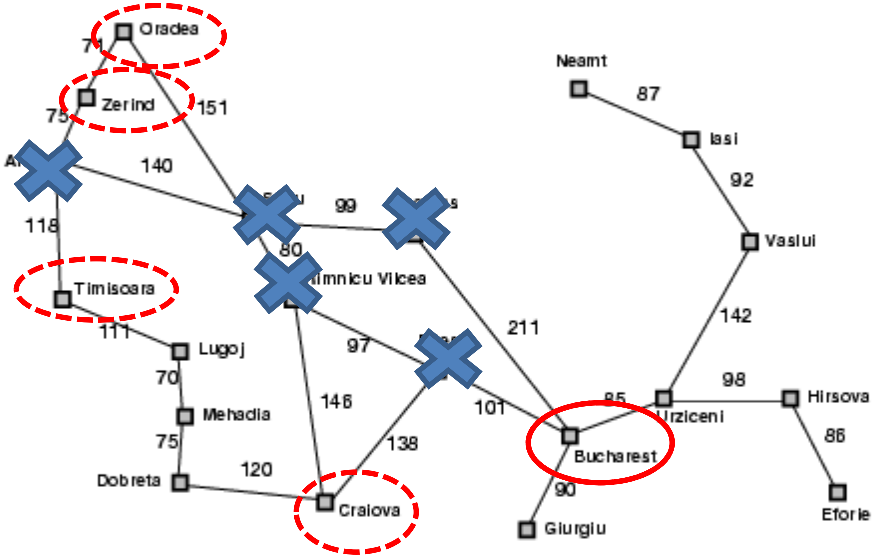
Search without repeated states





Start: Arad
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