Solving problems by searching

Chapter 3
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.
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?
• **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: ~10 trillion states
    • 24-puzzle: ~10^{25} states

• Actions
  – Move blank left, right, up, down

• Path cost
  – 1 per move

• 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
• 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
Search: Basic idea
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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 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 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

1. Initialize the **frontier** using the **starting state**
2. 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
Tree search example

Start: Arad
Goal: Bucharest
Tree search example

Start: Arad
Goal: Bucharest
Tree search example

Start: Arad
Goal: Bucharest
Tree search example

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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

Start: Arad
Goal: Bucharest
Search without repeated states

Start: Arad
Goal: Bucharest
Search without repeated states

Start: Arad
Goal: Bucharest
Search without repeated states

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