Title: Solving Problems by Searching
AIMA: Chapter 3 (Sections 3.1, 3.2 and 3.3)

Introduction to Artificial Intelligence
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Summary

Intelligent Agents

- Designing intelligent agents: PAES
- Types of Intelligent Agents
  1. Self Reflex
  2. ?
  3. ?
  4. ?
- Types of environments: observable (fully or partially), deterministic or stochastic, episodic or sequential, static vs. dynamic, discrete vs. continuous, single agent vs. multiagent
Outline

- Problem-solving agents
- Formulating problems
  - Problem components
  - Importance of modeling
- Search
  - basic elements/components
  - Uninformed search (Section 3.4)
  - Informed (heuristic) search (Section 3.5)
Simple reflex agent unable to plan ahead
- actions limited by current percepts
- no knowledge of what actions do
- no knowledge of what they are trying to achieve

Problem-solving agent: goal-based agent

Given:
- a problem formulation: a set of states and a set of actions
- a goal to reach/accomplish

Find:
- a sequence of actions leading to goal
Example: Holiday in Romania

On holiday in Romania, currently in Arad, want to go to Bucharest
**Example:** On holiday in Romania, currently in Arad, want to go to Bucharest

**Formulate goal:**
be in Bucharest

**Formulate problem:**

*states:* various cities

*actions:* (operators, successor function) drive between cities

**Find solution:**
sequence of cities, *e.g.* Arad, Sibiu, Fagaras, Bucharest
Drive to Bucharest... how many roads out of Arad?

Use map to consider hypothetical journeys through each road until reaching Bucharest
Looking for a sequence of actions $\rightarrow$ search
Sequence of actions to goal $\rightarrow$ solution
Carrying out actions $\rightarrow$ execution phase

Formulate, search, execute
Formulate, search, execute

```plaintext
function SIMPLE-PROBLEM-SOLVING-AGENT(p) returns an action
inputs: p, a percept
static: s, an action sequence, initially empty
state, some description of the current world state
g, a goal, initially null
problem, a problem formulation

state ← UPDATE-STATE(state, p)
if s is empty then
    g ← FORMULATE-GOAL(state)
    problem ← FORMULATE-PROBLEM(state, g)
    s ← SEARCH(problem)
action ← RECOMMENDATION(s, state)
s ← REMAINDER(s, state)
return action
```

× Update-State       × Formulate-goal
✓ Formulate-Problem  ✓ Search

Recommendation = first, and Remainder = rest

Assumptions for environment: observable, static, discrete, deterministic sequential, single-agent
Problem formulation

A problem is defined by the following items:

1. initial state: $In(Arad)$

2. successor function $S(x)$ (operators, actions)
   Example, $S(In(Arad)) = \{\langle Go(Sibiu), In(Sibiu)\rangle,
   \langle Go(Timisoara), In(Timisoara)\rangle, \langle Go(Zerind), In(Zerind)\rangle\}$

3. goal test, can be explicit, e.g., $x = In(Bucharest)$
   or a property $NoDirt(x)$

4. step cost: assumed non-negative

5. path cost (additive)
   e.g., sum of distances, number of operators executed, etc.

A solution is a sequence of operators leading from the initial state to a goal state.
Solution quality, optimal solutions.
Importance of modeling (for problem formulation)

Real art of problem solving is modeling,

deciding what’s in \( \{ \) state description

action description

choosing the right level of abstraction

State abstraction: road maps, weather forecast, traveling companions, scenery, radio programs, ...

Action abstraction: generate pollution, slowing down/speeding up, time duration, turning on the radio, ..

Combinatorial explosion. Abstraction by removing irrelevant detail make the task easier to handle
State space vs. state set
Example problems

Toy Problems:

→ intended to illustrate or exercise \{ concepts

✓ can be given concise, exact description

✓ researchers can compare performance of algorithms

× yield methods that rarely scale-up

× may reflect reality inaccurately (or not at all)

Real-world Problems:

→ more difficult but whose solutions people actually care about

✓ more credible, useful for practical settings

× difficult to model, rarely agreed-upon descriptions
Toy problem: vacuum

Single state case

States:
Initial State:
Successor function:
Goal test:
Path cost:

With 2 locations: $2.2^2$ states. With $n$ locations: $n.2^n$ states
**Toy problem: 8-puzzle**

**States:**

**Initial state:**

**Successor function:**

**Goal test:**

**Path cost:**

→ instance of sliding-block puzzles, known to be **NP-complete**

→ Optimal solution of *n*-puzzle **NP-hard**

→ so far, nothing better than search

→ 8-puzzle, 15-puzzle traditionally used to test search algorithms
**Toy problem: n-Queens**

→ Formulation: incremental vs. complete-state

**States:** Any arrangement of $x \leq 8$ queens on board

**Initial state:**

**Successor function:** add a queen (alt., move a queen)

**Goal test:** 8 queens not attacking one another

**Path cost:** irrelevant (only final state matters)

→ $64^8$ possible states, but $\exists$ other more effective formulations
Toy problems: requiring search

✓ 8 puzzles
✓ $n$-queens
✓ vacuum

Others: Missionaries & cannibals, farmer’s dilemma, etc.
Real-world problems: requiring search

- Route finding: state = locations, actions = transitions
  routing computer networks, travel advisory, etc.

- Touring: start in Bucharest, visit every city at least once
  Traveling salesperson problem (TSP) (exactly once, shortest tour)

- VLSI layout: cell layout, channel layout
  minimize area and connection lengths to maximize speed

- Robot navigation (continuous space, 2D, 3D, ldots)

- Assembly by robot-arm
  States: robot joint angles, robot and parts coordinates
  Successor function: continuous motions of the robot joins
  goal test: complete assembly
  path cost: time to execute

- + protein design, internet search, etc. (check AIMA)
Problem solving performance

Measures for **effectiveness** of search:

1. Does it find a solution? complete
2. Is it a good solution? path cost low
3. Search cost? time & space

**Total** cost = Search cost + Path cost

→ problem?

Example: Arad to Bucharest
Path cost: total mileage, fuel, tire wear \( f(\text{route}) \), etc.
Search cost: time, computer at hand, etc.
So far

- Problem-solving agents
  Formulate, Search, Execute

- Formulating problems
  - Problem components: States, Initial state, Successor function, Goal test, Step cost, Path cost
    Solution: sequence of actions from initial state to goal state
  - Importance of modeling

Now, search

- Terminology: tree, node, expansion, fringe, leaf, queue, strategy

- Implementation: data structures

- Four evaluation criteria.. ?
Search: generate action sequences

partial solution: sequence yielding a (non goal) intermediate state

\[
\text{Search} \begin{cases} 
\text{generate} \\
\text{maintain}
\end{cases} \text{ a set of sequences of partial solutions}
\]

Two aspects:

1. how to generate sequences

2. which data structures to keep track of them
**Search** generate action sequences

Basic idea:

- offline, simulated exploration of state space
- by generating successors of already-explored states
  → *expanding* states

Start from a state, test if it is a goal state

- If it is, we are done
- If it is not: *expand state*
  - Apply all operators applicable to current state to generate all possible sequences of future states
  - *now we have set of partial solutions*

...
Search tree, nodes

\{ root: initial state \\
leaves: states that can/should not be expanded \}
**Data structure**

A node $x$ has a parent, children, depth, path cost $g(x)$

A data structure for a search node:

\[
\begin{align*}
\text{State}[x] & \quad \text{state in state space} \\
\text{Parent} - \text{Node}[x] & \quad \text{parent node} \\
\text{Action}[x] & \quad \text{operator used to generate node} \\
\text{Path} - \text{Cost}[x] & \quad \text{path cost of parent} + \text{cost step, path cost } g(x) \\
\text{Depth}[x] & \quad \textbf{depth}: \ # \text{ nodes from root (path length)}
\end{align*}
\]

Nodes to be expanded:

- constitute a fringe (frontier)
- managed in a queue,
- order of node expansion determines search strategy.

*LHW Chapter 13*
Warning:

Do not confuse: **State** space and **Search** (tree) space

- What is a state?
- What is the state space?

Holiday in Romania:

- What is the size of state space?
- What is the size of search tree?

A node has a parent, children, depth, path cost \( g(x) \)
A state has no parent, children, depth, etc.
Types of Search

**Uninformed:** use only information available in problem definition

**Heuristic:** exploits some knowledge of the domain

**Uninformed search strategies:**
Breadth-first search, Uniform-cost search, Depth-first search, Depth-limited search, Iterative deepening search, Bidirectional search
Search strategies

Criteria for evaluating search:

1. Completeness: does it always find a solution if one exists?
2. Time complexity: number of nodes generated/expanded
3. Space complexity: maximum number of nodes in memory
4. Optimality: does it always find a least-cost solution?

Time/space complexity measured in terms of:

- $b$: maximum branching factor of the search tree
- $d$: depth of the least-cost solution
- $m$: maximum depth of the search space (may be $\infty$)