Search – Chapter 3

- Problem-solving agents
- Problem types
- Problem formulation
- Example problems
- Basic search algorithms

Moving beyond reflex agents, first example of how to string together a series of actions
Uninformed search
Map of Area

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Goal Oriented Search – Ex: 1

On holiday in Romania; currently in Arad. 
Flight leaves tomorrow from Bucharest

Formulate goal:
be in Bucharest

Formulate problem:

states: various cities
operators: drive between cities

Find solution:
sequence of cities, e.g., Arad, Sibiu, Fagaras, Bucharest
Four Step Process

• Goal formulation, problem formulation, search, execute
• What does this tell you about the environment?
• How are the percepts for t>1 used?
Problem Types

Deterministic, fully observable $\implies$ single-state problem
Agent knows exactly which state it will be in; solution is a sequence

Non-observable $\implies$ conformant problem
Agent may have no idea where it is; solution (if any) is a sequence

Nondeterministic and/or partially observable $\implies$ contingency problem
percepts provide new information about current state
solution is a tree or policy
often interleave search, execution

Unknown state space $\implies$ exploration problem (“online”)
Single State Problem Definition

A problem is defined by four items:

**initial state** e.g., “at Arad”

**operators (or successor function S(x))**

  e.g., Arad → Zerind   Arad → Sibiu   etc.

**goal test**, can be

  *explicit*, e.g., \( x = \text{“at Bucharest”} \)

  *implicit*, e.g., \( \text{NoDirt}(x) \)

**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
State Space Definition

Real world is absurdly complex
⇒ state space must be abstracted for problem solving

(Abstract) state = set of real states

(Abstract) operator = complex combination of real actions
e.g., “Arad → Zerind” represents a complex set
of possible routes, detours, rest stops, etc.
For guaranteed realizability, any real state “in Arad”
must get to some real state “in Zerind”

(Abstract) solution =
set of real paths that are solutions in the real world

Each abstract action should be “easier” than the original problem!
Eight State Puzzle

Start State

Goal State

*states??
operators??
goal test??
path cost??
Eight State Puzzle

states??: integer locations of tiles (ignore intermediate positions)
actions??: move blank left, right, up, down (ignore unjamming etc.)
goal test??: = goal state (given)
path cost??: 1 per move

[Note: optimal solution of $n$-Puzzle family is NP-hard]
Converting the Problem to a Graph
Basic Uninformed Search

Basic idea:

offline, simulated exploration of state space
by generating successors of already-explored states
(a.k.a. expanding states)

function GENERAL-SEARCH(problem, strategy) returns a solution, or failure
initialize the search tree using the initial state of problem
loop do
    if there are no candidates for expansion then return failure
    choose a leaf node for expansion according to strategy
    if the node contains a goal state then return the corresponding solution
    else expand the node and add the resulting nodes to the search tree
end
What is a State and a Node?

A state is a (representation of) a physical configuration
A node is a data structure constituting part of a search tree
   includes parent, children, depth, path cost $g(x)$
States do not have parents, children, depth, or path cost! Why?

The Expand function creates new nodes, filling in the various fields and using the Operators (or SuccessorFn) of the problem to create the corresponding states.
Search Strategies and Effectiveness

A 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?
- time complexity—number of nodes generated/expanded
- space complexity—maximum number of nodes in memory
- optimality—does it always find a least-cost solution?

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 depth of the state space (may be $\infty$)
Basic Search Algorithm

```
function TREE-SEARCH(problem, fringe) returns a solution, or failure
fringe ← INSERT(MAKE-NODE(INITIAL-STATE[problem]), fringe)
loop do
  if fringe is empty then return failure
  node ← REMOVE-FRONT(fringe)
  if GOAL-TEST[problem] applied to STATE(node) succeeds return node
  fringe ← INSERTALL EXPAND(node, problem, fringe)
```

```
function EXPAND(node, problem) returns a set of nodes
successors ← the empty set
for each action, result in SUCCESSOR-FN[problem](STATE[node]) do
  s ← a new NODE
  PARENT-NODE[s] ← node; ACTION[s] ← action; STATE[s] ← result
  PATH-COST[s] ← PATH-COST[node] + STEP-COST(node, action, s)
  DEPTH[s] ← DEPTH[node] + 1
  add s to successors
return successors
```
Uninformed Search

*Uninformed* strategies use only the information available in the problem definition

Breadth-first search

Uniform-cost search

Depth-first search

Depth-limited search

Iterative deepening search
Breadth First Search

Expand shallowest unexpanded node

Implementation:

What queue type should the fringe be?

Complete?
Time?
Space?
Optimal?

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Uniform Search

Expand least-cost unexpanded node

Implementation:

Fringe queue order?

Equivalent to breadth-first if step costs all equal

Complete?
Time?
Space?
Optimal?
Depth First and Depth Limited

Expand **deepest unexpanded node**

**Implementation:**

Fringe queue order?

Complete? Time? Space? Optimal?
Iterative Deepening and Bi-directional Search

Limit = 1

Limit = 2

Complete?
Time?
Space?
Optimal?