



Problem Solving by Searching

R&N: §3.1-3.3

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Problem-solving agents

```

function SIMPLE-PROBLEM-SOLVING-AGENT(percept) returns an action
  persistent: seq, an action sequence, initially empty
               state, some description of the current world state
               goal, a goal, initially null
               problem, a problem formulation
  state ← UPDATE-STATE(state, percept)
  if seq is empty then do
    goal ← FORMULATE-GOAL(state)
    problem ← FORMULATE-PROBLEM(state, goal)
    seq ← SEARCH(problem)
    if seq = failure then return a null action
  action ← FIRST(seq)
  seq ← REST(seq)
  return action

```

Agent has a "Formulate, Search, Execute" design

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Outline

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

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Example: Romania

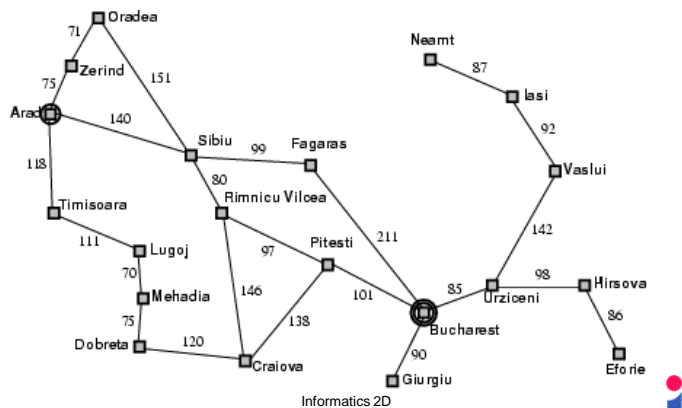
- On holiday in Romania; currently in Arad.
- Flight leaves tomorrow from Bucharest
- **Formulate goal:**
 - be in Bucharest
- **Formulate problem:**
 - states: various cities
 - actions: drive between cities
- **Find solution:**
 - sequence of cities, e.g., Arad, Sibiu, Fagaras, Bucharest

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Example: Romania



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Problem types

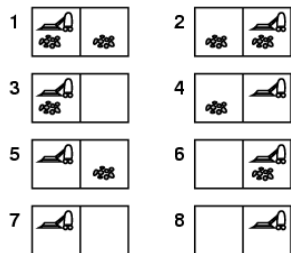
- **Deterministic, fully observable** → single-state problem
 - Agent knows exactly which state it will be in; solution is a sequence
- **Non-observable** → sensorless problem (conformant problem)
 - Agent may have no idea where it is; solution is a sequence
- **Nondeterministic and/or partially observable** → contingency problem
 - percepts provide new information about current state
 - often interleave search, execution
- **Unknown state space** → exploration problem

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Example: vacuum world

- **Single-state**, start in #5.
Solution?

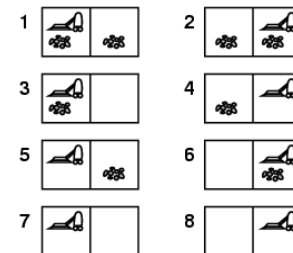


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Example: vacuum world

- **Single-state**, start in #5.
Solution? [*Right, Suck*]
- **Sensorless**, start in {1,2,3,4,5,6,7,8} e.g., *Right* goes to {2,4,6,8}



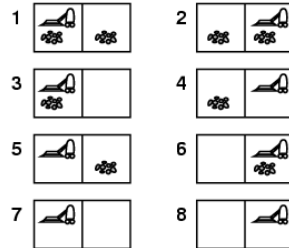
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Example: vacuum world

- **Sensorless**, start in {1,2,3,4,5,6,7,8} e.g., *Right* goes to {2,4,6,8} Solution? [*Right,Suck,Left,Suck*]



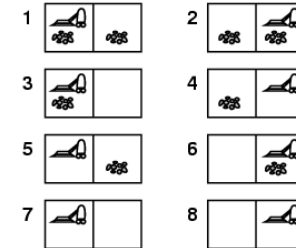
- **Contingency**
 - Nondeterministic: *Suck* may dirty a clean carpet
 - Partially observable: location, dirt at current location.
 - Percept: [*L, Clean*], i.e., start in #5 or #7 Solution?

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Example: vacuum world

- **Sensorless**, start in {1,2,3,4,5,6,7,8} e.g., *Right* goes to {2,4,6,8} Solution? [*Right,Suck,Left,Suck*]



- **Contingency**
 - Nondeterministic: *Suck* may dirty a clean carpet
 - Partially observable: location, dirt at current location.
 - Percept: [*L, Clean*], i.e., start in #5 or #7 Solution? [*Right, if dirt then Suck*]

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Single-state problem formulation

A problem is defined by four items:

1. initial state e.g., "in Arad"
 2. actions or successor function $S(x)$ = set of action–state pairs
 - e.g., $S(\text{Arad}) = \langle \text{Arad} \rightarrow \text{Zerind}, \text{Zerind} \rangle, \dots$
 3. goal test, can be
 - explicit, e.g., $x = \text{"in Bucharest"}$
 - implicit, e.g., $\text{Checkmate}(x)$
 4. path cost (additive)
 - e.g., sum of distances, number of actions executed, etc.
 - $c(x,a,y)$ is the **step cost** of taking action a in state x to reach state y , assumed to be ≥ 0
- A solution is a sequence of actions leading from the initial state to a goal state

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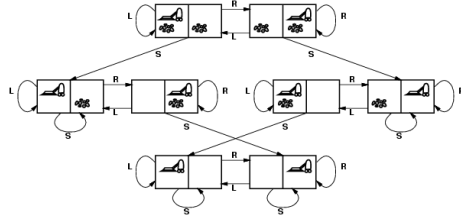
Selecting a state space

- Real world is absurdly complex
 - state space must be abstracted for problem solving
- (Abstract) state = set of real states
- (Abstract) action = complex combination of real actions
 - e.g., "Arad \rightarrow 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

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Vacuum world state space graph

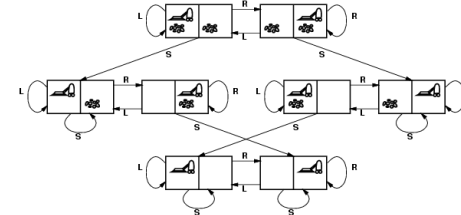


- states?
- actions?
- goal test?
- path cost?

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Vacuum world state space graph

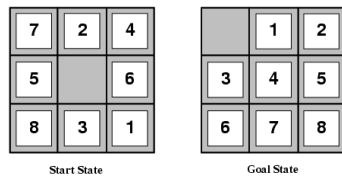


- states? Pair of dirt and robot locations
- actions? *Left, Right, Suck*
- goal test? no dirt at any location
- path cost? 1 per action

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Example: The 8-puzzle

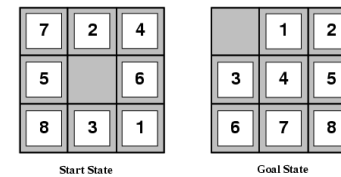


- states?
- actions?
- goal test?
- path cost?

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Example: The 8-puzzle



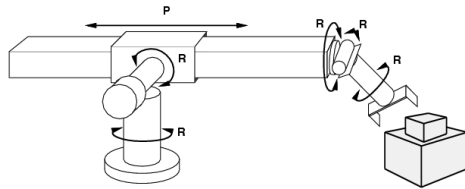
- states? locations of tiles
- actions? move blank left, right, up, down
- goal test? = goal state (given)
- path cost? 1 per move

[Note: optimal solution of n -Puzzle family is NP-hard]

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Example: robotic assembly



- **states?**: real-valued coordinates of robot joint angles & parts of the object to be assembled
- **actions?**: continuous motions of robot joints
- **goal test?**: complete assembly
- **path cost?**: time to execute

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Tree search algorithms



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

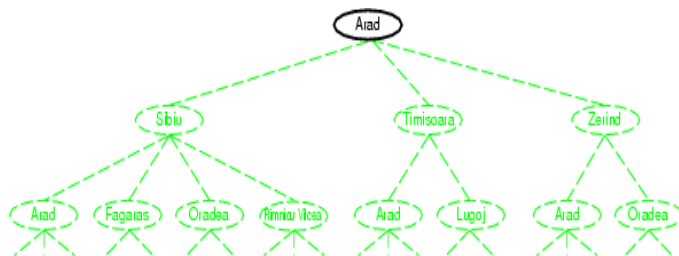
```

function TREE-SEARCH(problem) returns a solution, or failure
  initialize the frontier using the initial state of problem
  loop do
    if the frontier is empty then return failure
    choose a leaf node and remove it from the frontier
    if the node contains a goal state then return the corresponding solution
    expand the chosen node, adding the resulting nodes to the frontier
    
```

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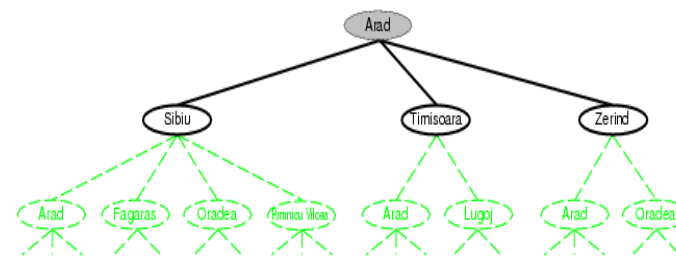
Tree search example



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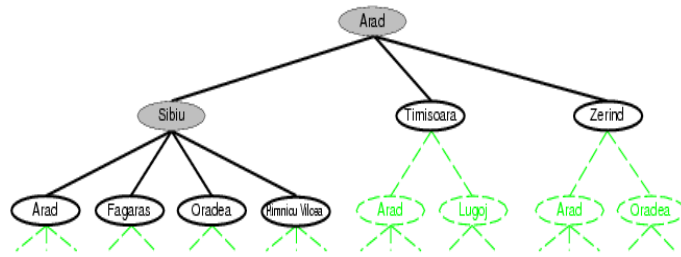
Tree search example



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Tree search example



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Implementation: general tree search



```

function TREE-SEARCH(problem) returns a solution, or failure
  initialize the frontier using the initial state of problem
  loop do
    if the frontier is empty then return failure
    choose a leaf node and remove it from the frontier
    if the node contains a goal state then return the corresponding solution
    expand the chosen node, adding the resulting nodes to the frontier
  
```

```

function CHILD-NODE(problem, parent, action) returns a node
  return a node with
    STATE = problem.RESULT(parent.STATE, action),
    PARENT = parent, ACTION = action,
    PATH-COST = parent.PATH-COST + problem.STEP-COST(parent.STATE, action)
  
```

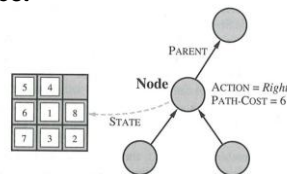
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Implementation: states vs. nodes



- A state is a (representation of) a physical configuration
- A node is a book-keeping data structure constituting part of a **search tree** includes *state*, *parent node*, *action*, *path cost*



- Using these it is easy to compute the components for a child node. (The CHILD-NODE function)

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Summary



- Problem formulation usually requires abstracting away real-world details to define a state space that can feasibly be explored.

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