Solving Problems by Searching

AIMA Sections 3.1–3.3

Outline

- ◇ Problem-solving agents
- ◇ Problem types
- ◇ Problem formulation
- ◇ Example problems
- ◇ General search algorithm

Problem-solving agents

```
function SIMPLE-PROBLEM-SOLVING-AGENT( percept) returns an action
    static: 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
        goal ← FORMULATE-GOAL(state)
        problem ← FORMULATE-PROBLEM(state, goal)
        seq ← SEARCH( problem)
    action ← FIRST(seq)
    seq ← REST(seq)
    return action
```

Problem-solving agents

Restricted form of general agent: **Goal based agents**

- formulate a goal and a problem given the current state
- search for a solution
- execute the solution **ignoring** perceptions

Note: this is offline problem solving; solution executed "eyes closed."
Online problem solving involves acting without complete knowledge.

An example: Traveling in Romania

Example (Holidays in Romania)

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

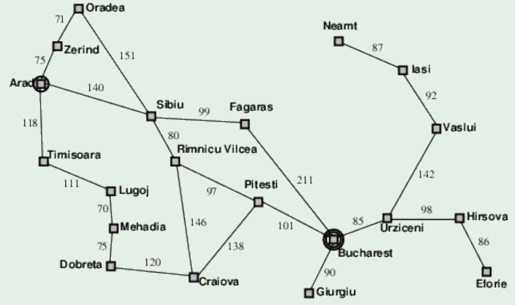
Formulate goal:
- be in Bucharest

Formulate problem:
- states: various cities
- actions: drive between cities

Find solution:
- sequence of cities, e.g., Arad, Sibiu, Fagaras, Bucharest

An example: Traveling in Romania

Example (Holidays in Romania)



Problem types

Deterministic, fully observable $\Longrightarrow$ single-state problem

Agent knows exactly which state it will be in; solution is a sequence

Non-observable $\Longrightarrow$ conformant problem

Agent may have no idea where it is; solution (if any) is a sequence

Nondeterministic and/or partially observable $\Longrightarrow$ contingency problem

percepts provide **new** information about current state

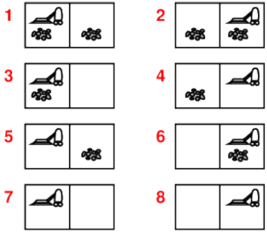
solution is a contingent plan or a policy

often **interleave** search, execution

Unknown state space $\Longrightarrow$ exploration problem ("online")

Example: vacuum world

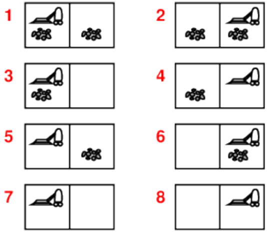
Single-state, start in #5. Solution??



Example: vacuum world

Single-state, start in #5. Solution??
[*Right*, *Suck*]

Conformant
start in {1, 2, 3, 4, 5, 6, 7, 8}
e.g., *Right* goes to {2, 4, 6, 8}.
Solution??



Example: vacuum world

Single-state, start in #5. Solution??
[*Right*, *Suck*]

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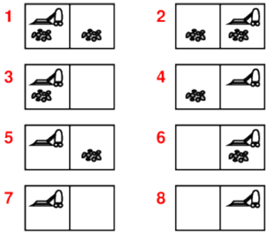
start in $\{1, 2, 3, 4, 5, 6, 7, 8\}$
e.g., *Right* goes to $\{2, 4, 6, 8\}$. Solution??
[*Right*, *Suck*, *Left*, *Suck*]

Contingency, start in #5
Murphy's Law: *Suck* can dirty a clean carpet
Local sensing: dirt, location only.
Solution??

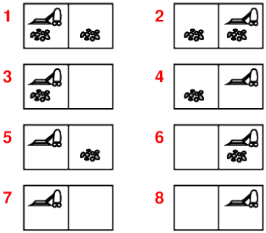


Example: vacuum world

Single-state, start in #5. Solution??
[*Right*, *Suck*]

Conformant
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, start in #5
Murphy's Law: *Suck* can dirty a clean carpet
Local sensing: dirt, location only.
Solution??
[*Right*, **if** *dirt* **then** *Suck*]



Single-state problem formulation

A problem is defined by four items:

initial state e.g., "at Arad"

successor function $S(x)$ = set of action–state pairs

e.g., $S(A) = \{< Arad \rightarrow Zerind, Zerind >, \ldots\}$

goal test, can be

explicit, e.g., x = "at Bucharest"

implicit, e.g., $NoDirt(x)$

path cost (additive)

e.g., sum of distances, number of actions executed, etc.

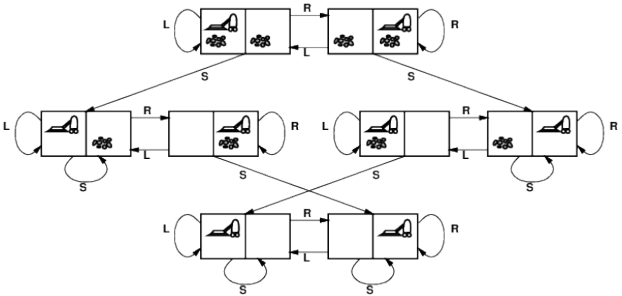
$c(x, a, y)$ is the step cost, assumed to be ≥ 0

A solution is a sequence of actions
leading from the initial state to a goal state

Selecting a state space

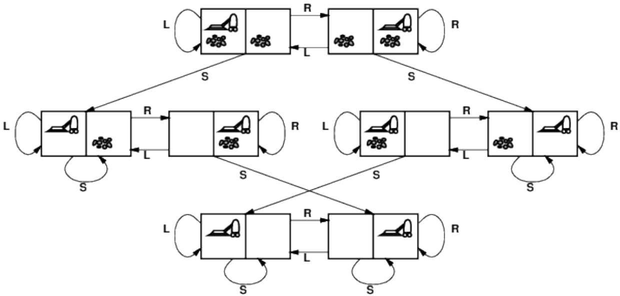
Real world is absurdly complex
$\Rightarrow$ state space must be **abstracted** for problem solving
(Abstract) state = set of real states
(Abstract) action = complex combination of real actions
e.g., "Arad $\rightarrow$ Zerind" represents a complex set
of possible routes, detours, rest stops, etc.
For 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!

Example: vacuum world state space graph



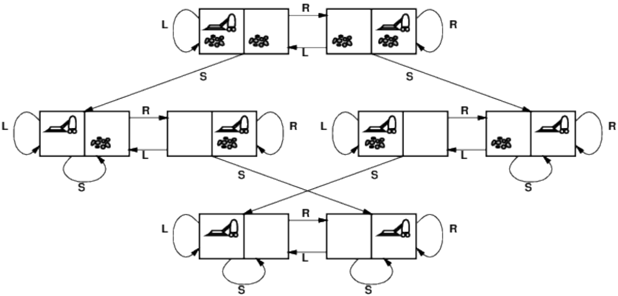
states??:
actions??:
goal test??:
path cost??:

Example: vacuum world state space graph



states??: discrete dirt and robot locations (ignore dirt amounts)
actions??:
goal test??:
path cost??:

Example: vacuum world state space graph



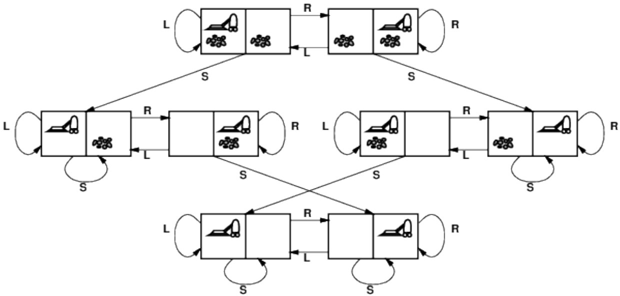
states??: discrete dirt and robot locations (ignore dirt amounts)

actions??: *Left*, *Right*, *Suck*, *NoOp*

goal test??:

path cost??:

Example: vacuum world state space graph



states??: discrete dirt and robot locations (ignore dirt amounts)
actions??: *Left*, *Right*, *Suck*, *NoOp*
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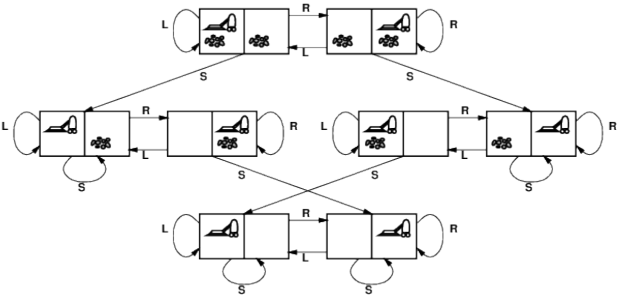
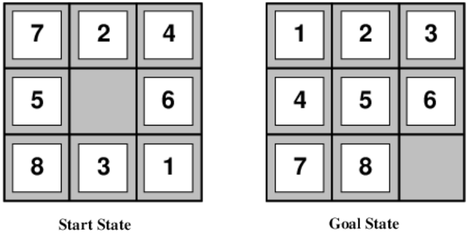
path cost??:

Example: vacuum world state space graph



states??: discrete dirt and robot locations (ignore dirt amounts)
actions??: *Left*, *Right*, *Suck*, *NoOp*
goal test??: no dirt
path cost??: 1 per action (0 for *NoOp*)

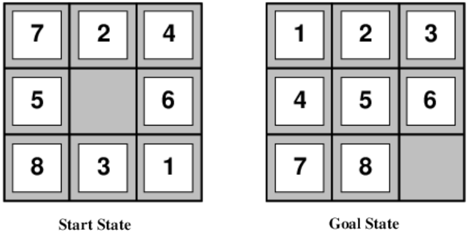
Example: The 8-puzzle



states??:

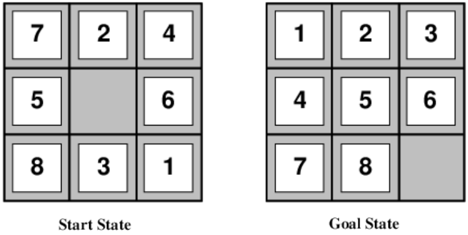
actions??:
goal test??:
path cost??:

Example: The 8-puzzle



states??: integer locations of tiles (ignore intermediate positions)
actions??:
goal test??:
path cost??:

Example: The 8-puzzle



states??: integer locations of tiles (ignore intermediate positions)
actions??: move blank left, right, up, down
goal test??:
path cost??:

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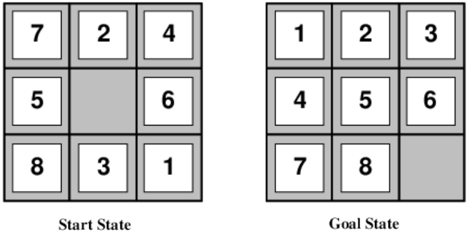

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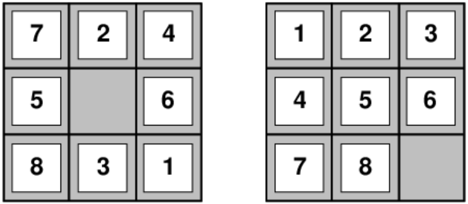
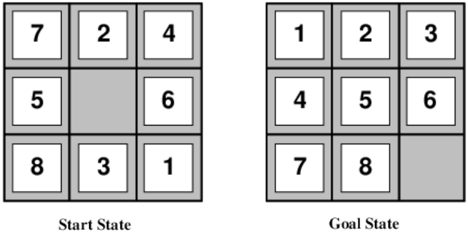


Start State   Goal State

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

Example: The 8-puzzle



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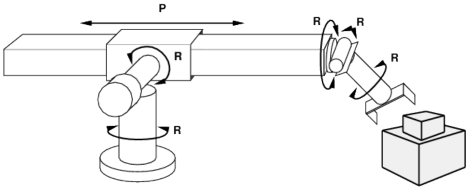
path cost??: 1 per move

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

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 **with no robot included!**

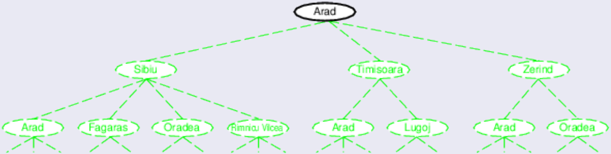
path cost??: time to execute

Tree search algorithm

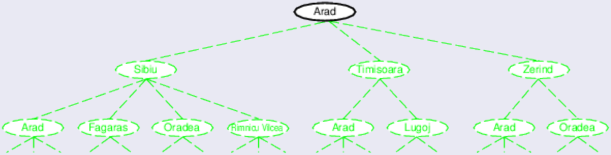
Basic idea:
offline, simulated exploration of state space
by generating successors of already-explored states
(a.k.a. expanding states)

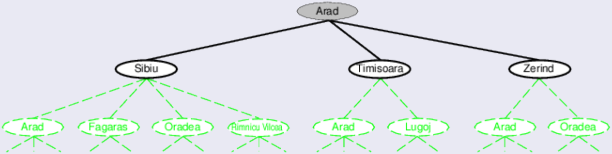
function Tree-Search(*problem, strategy*) **returns** a solution, or failure
initialize the search tree using the initial state of *problem*
loop do
if no candidates for expansion **then return** failure
choose a leaf node for expansion according to *strategy*
if node contains a goal state **then return** the solution
else add successor nodes to the search tree (expansion)
end

Tree search example

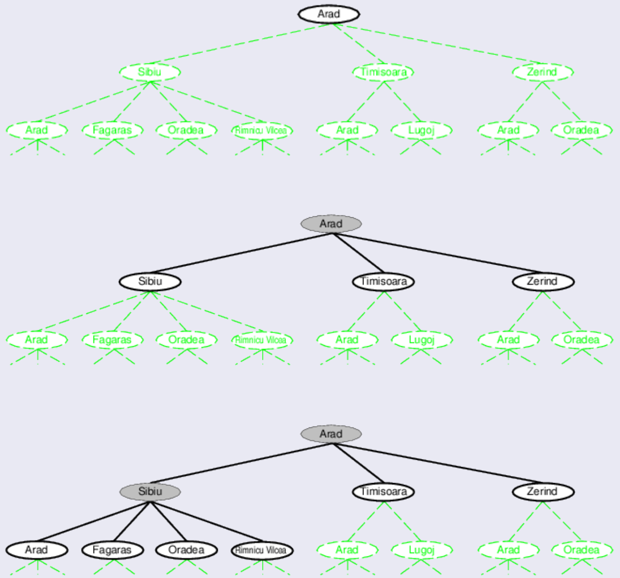


Tree search example





Tree search example



Implementation: states vs. nodes

A state is a (representation of) a physical configuration

A node is a data structure constituting part of a search tree
  includes parent, action, children, depth, path cost (i.e., $g(x)$)

States do not have parents, actions,children, depth, or path cost!

Implementation: states vs. nodes

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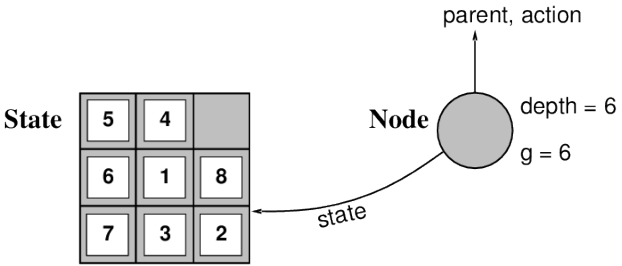


The Expand function creates new nodes, filling in the various fields and using the SuccessorFn of the problem to create the corresponding states.

Implementation: general tree search


```
function Tree-Search( problem, frontier) returns a solution, or failure
  frontier ← Insert(Make-Node(problem.Initial-State))
  loop do
    if frontier is empty then return failure
    node ← Pop(frontier)
    if problem.Goal-Test(node.State) then return node
    frontier ← InsertAll(Expand(node, problem))
  end loop
```

Implementation: expand nodes

```
function Expand( node, problem) returns a set of nodes
   successors ← the empty set
   for each action, result in Successor-Fn(problem, node.State)
    do
       s ← a new Node
       s.Parent-Node ← node;
       s.Action ← action;
       s.State ← result
       s.Path-Cost ← node.Path-Cost +
                     Step-Cost(node.State, action, result)
       s.Depth ← node.Depth + 1
       add s to successors
   return successors
```

Search strategies

A strategy is defined by picking the **order of node expansion**

Strategies are evaluated along the following dimensions:

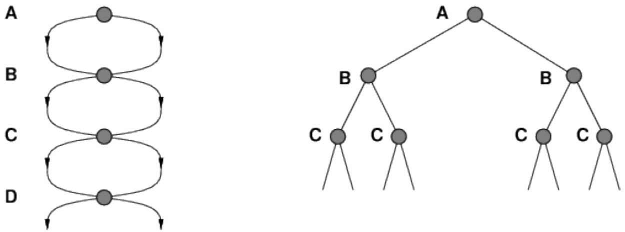
- completeness—does it always find a solution if one exists?
- time complexity—number of nodes generated/expanded
- space complexity—maximum number of nodes in memory
- optimality—does it always find a least-cost solution?

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 ∞)

Repeated states

Failure to detect repeated states can turn a linear problem into an exponential one!



Graph search


```
function Graph-Search( problem, frontier) returns a solution, or failure
  explored ← an empty set
  frontier ← Insert(Make-Node(problem.Initial-State))
  loop do
    if frontier is empty then return failure
    node ← Pop(frontier)
    if problem.Goal-Test(node.State) then return node
    if node.State is not in explored then
      add node.State to explored
      frontier ← InsertAll(Expand(node, problem))
    end if
  end loop
```