# Problem Solving and Search

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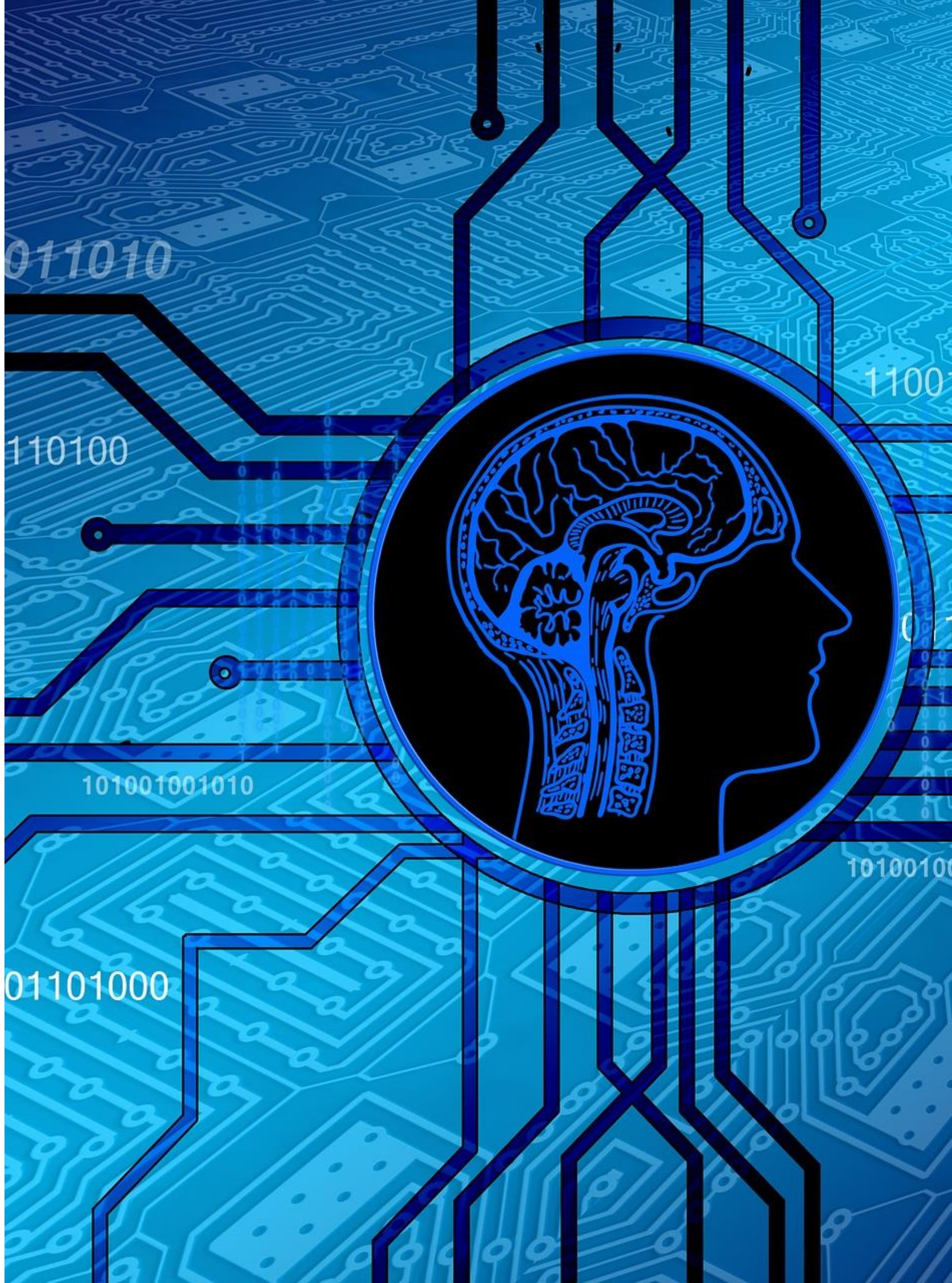
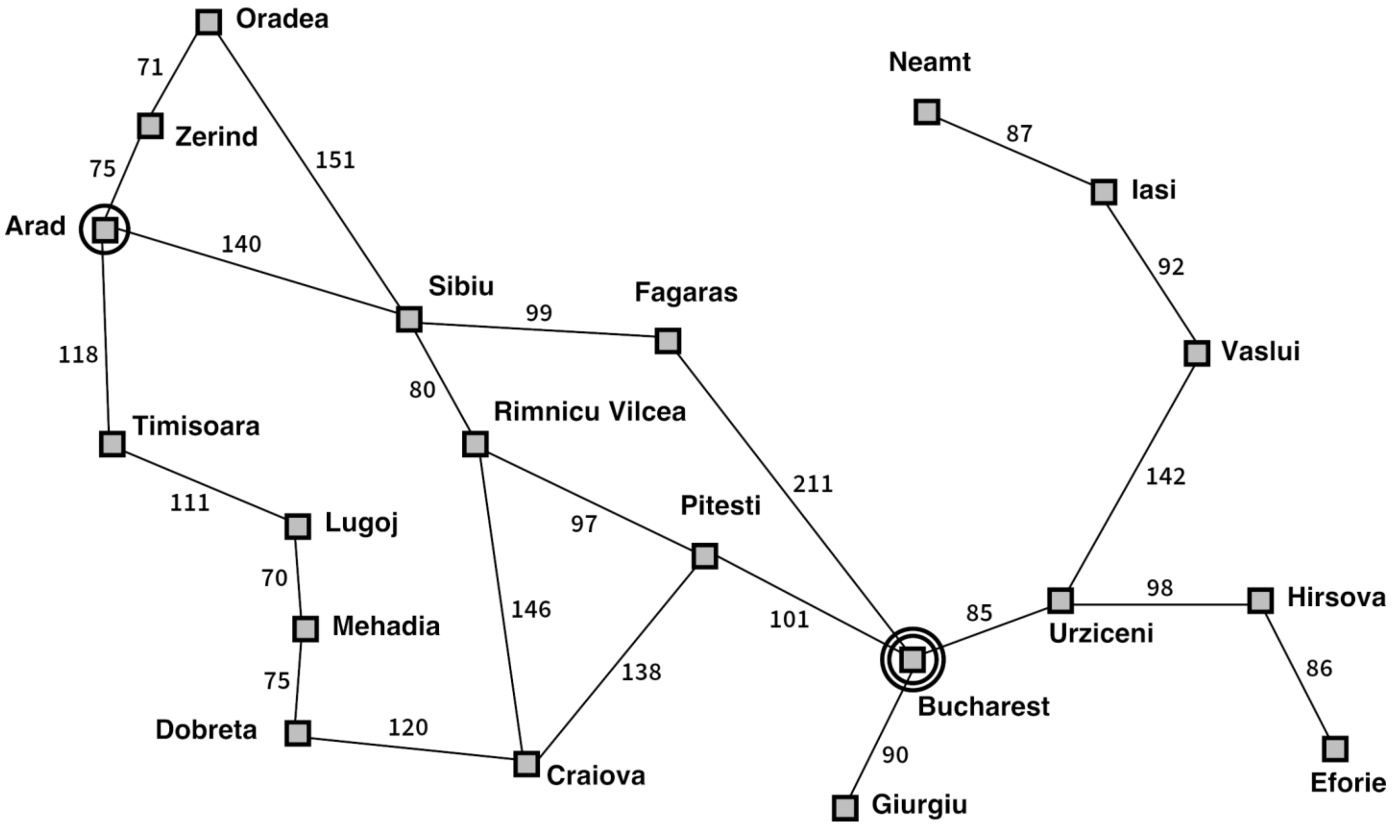
Informatics 2D: Reasoning and Agents
**Lecture 2**



# Problem-solving Agents

# 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
```




# Example: Romania

On holiday in Romania.

Currently in **Arad**.

Flight leaves tomorrow from **Bucharest**.

# 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

# Problem types

Deterministic, fully observable → single-state problem

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

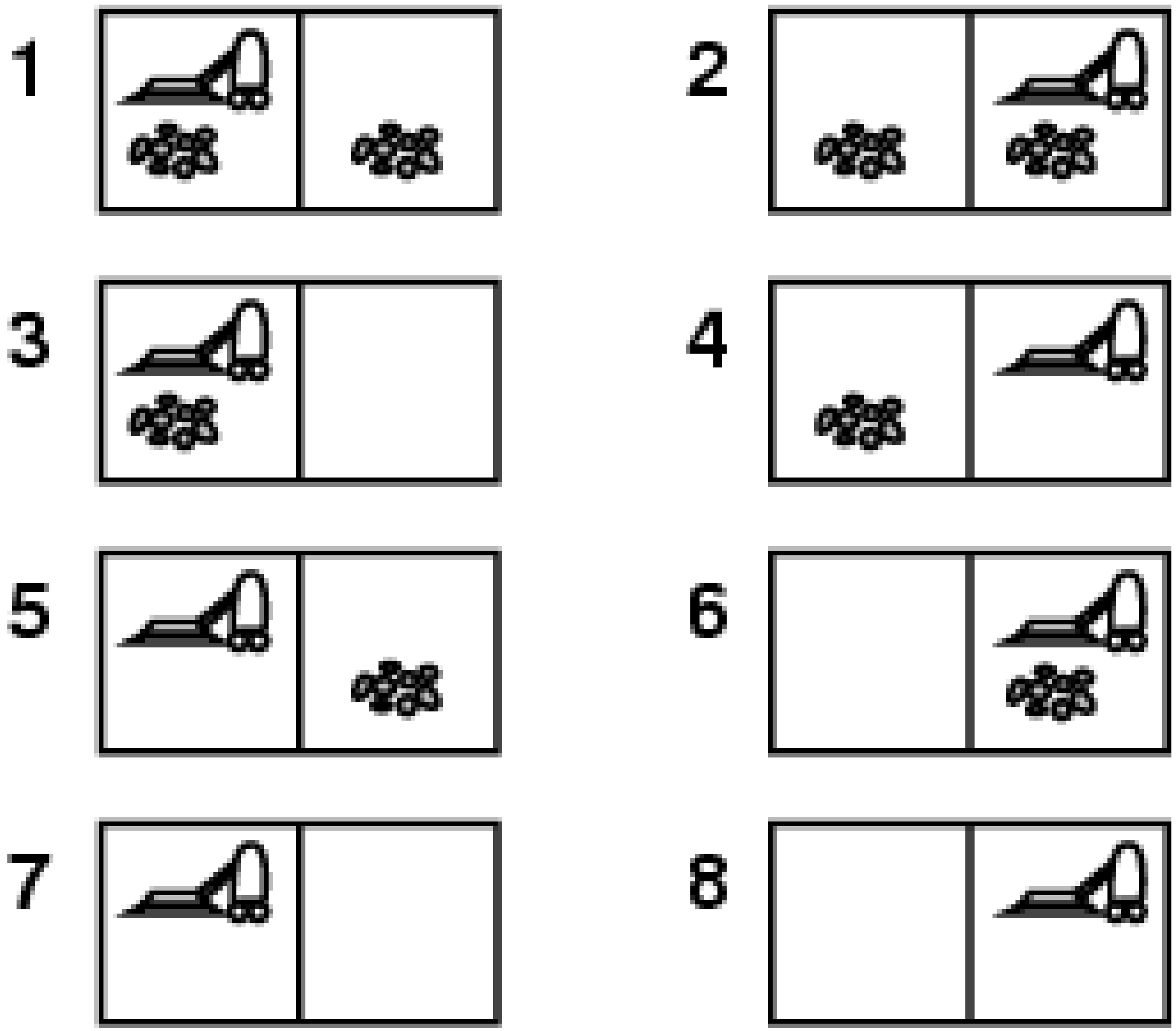
Non-observable → sensorless problem (conformant problem)

- 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

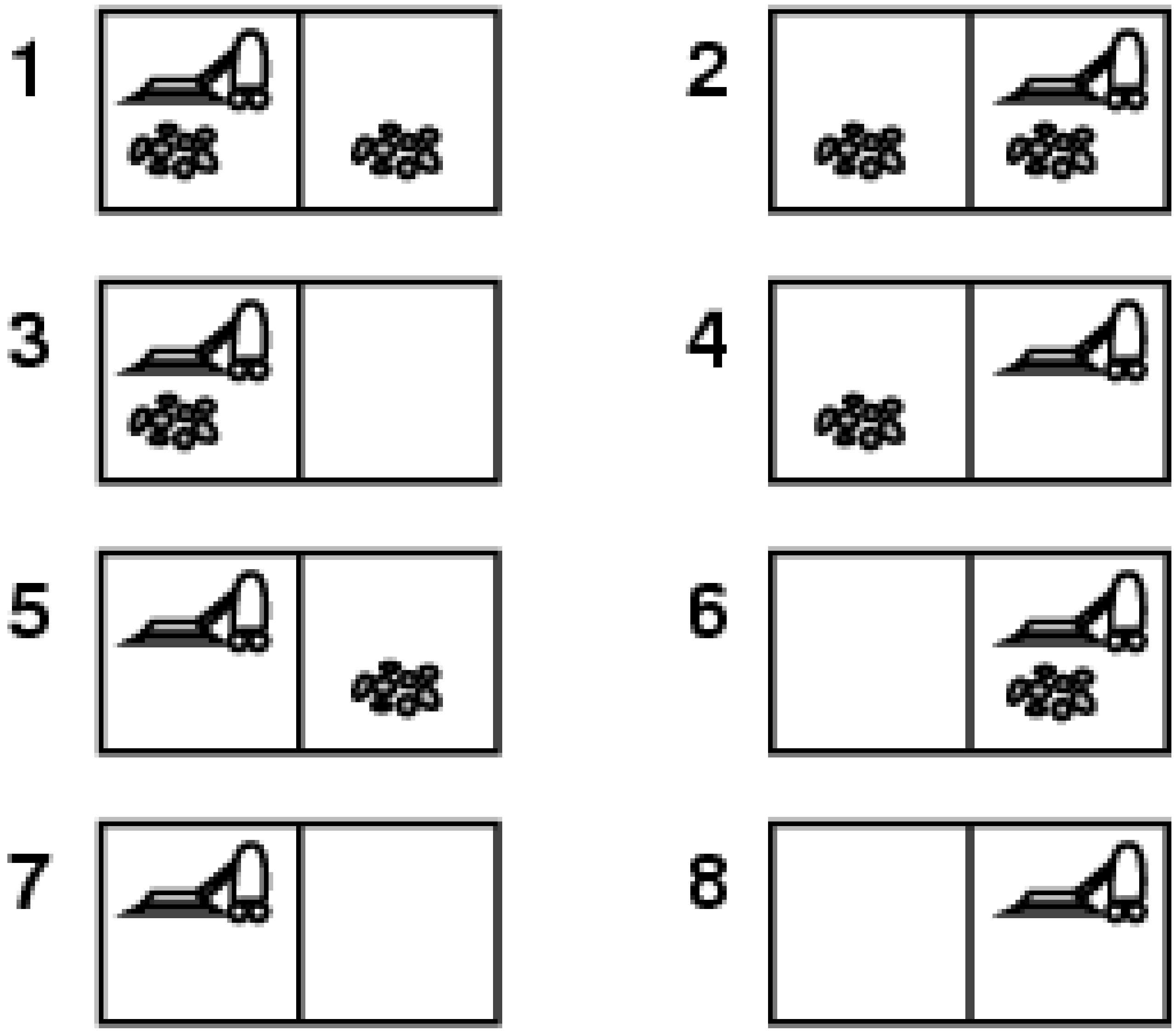



# Example: vacuum world

Single-state:

Start in 5

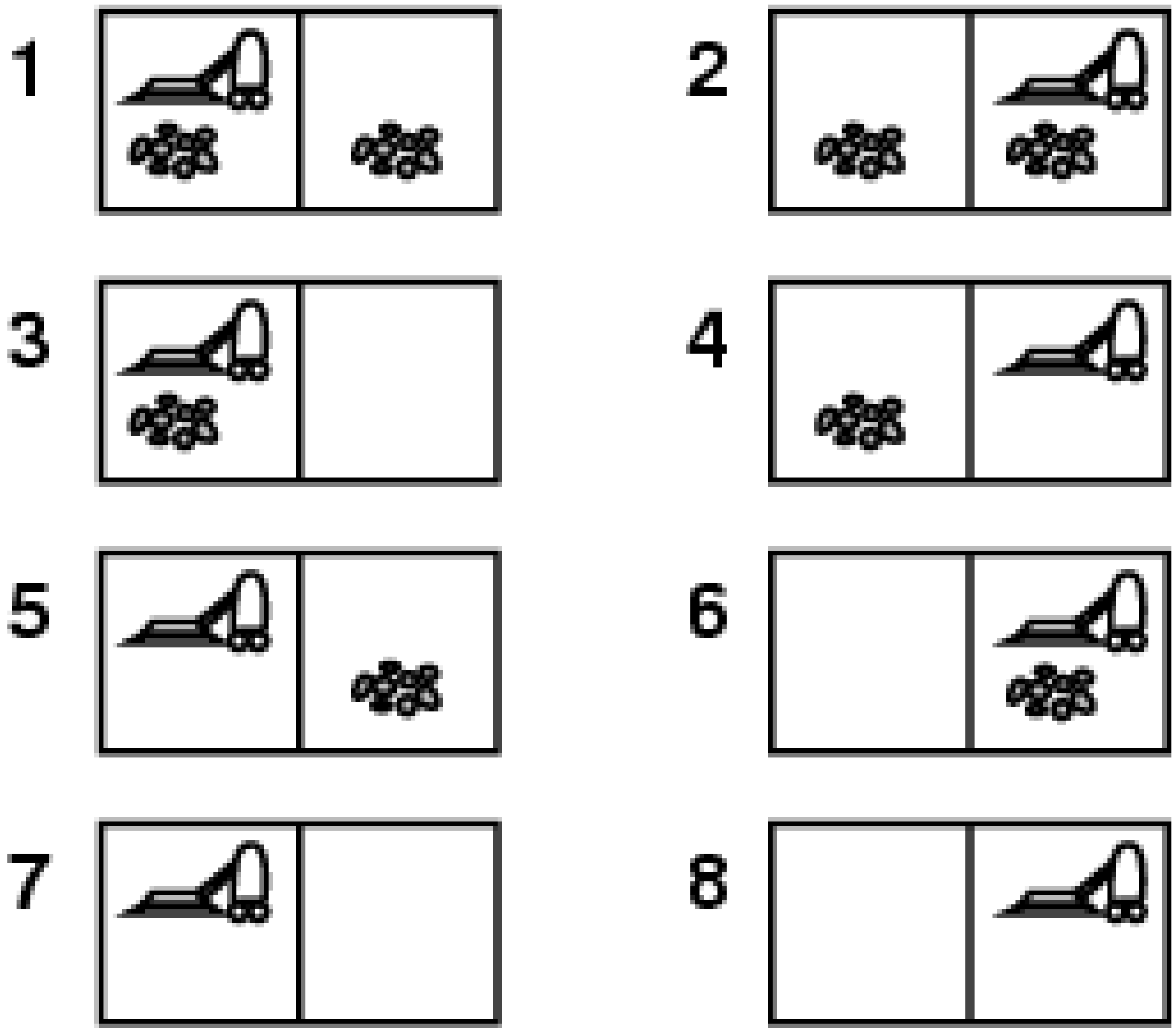
Solution?




# Example: vacuum world

Single-state:
Start in 5
Solution?
[*Right*, *Suck*]

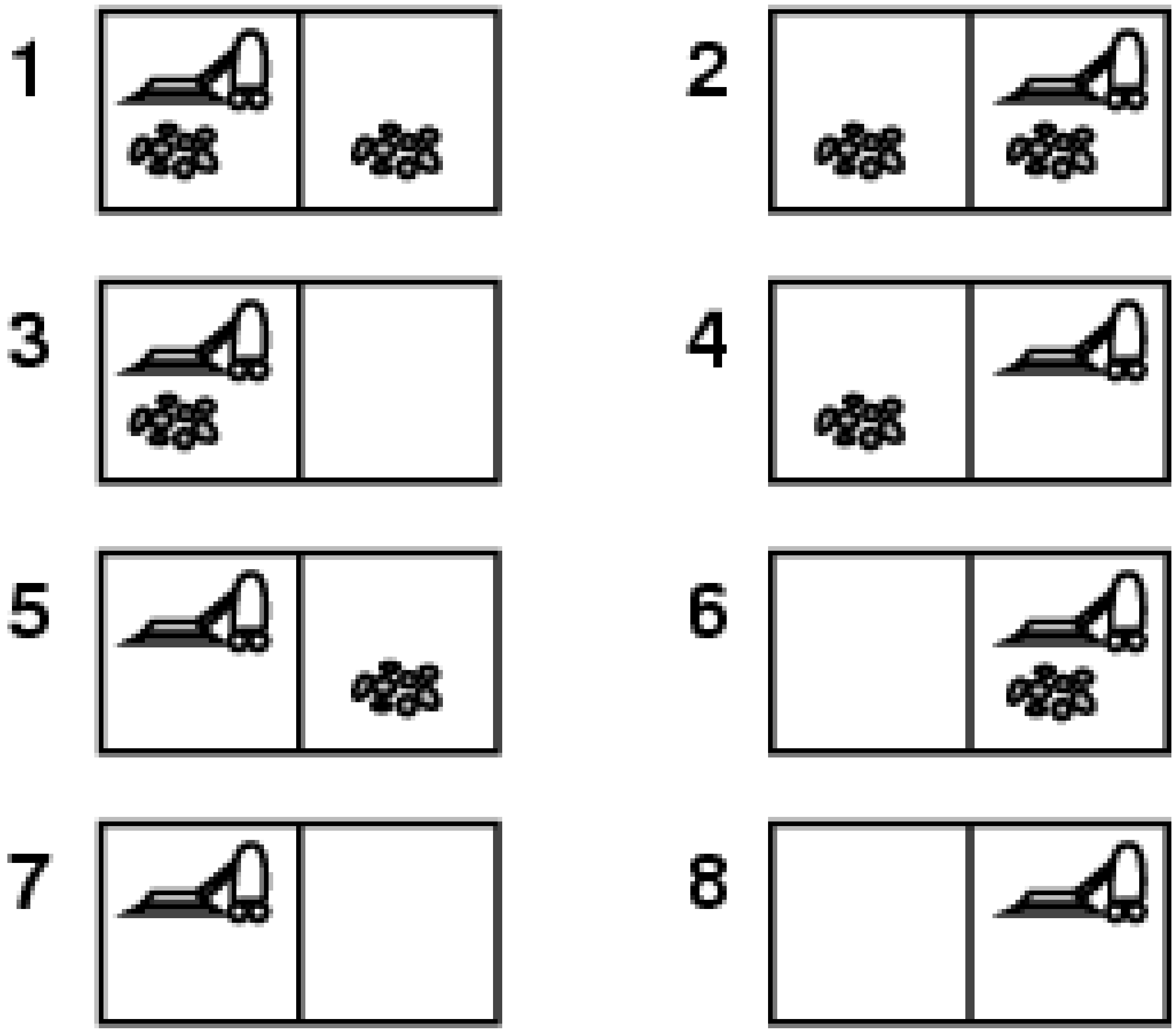
Sensorless:
Start in {*1,2,3,4,5,6,7,8*}
e.g. *Right* goes to {*2,4,6,8*}
Solution?




# Example: vacuum world

Single-state:
Start in 5
Solution?
[*Right*, *Suck*]

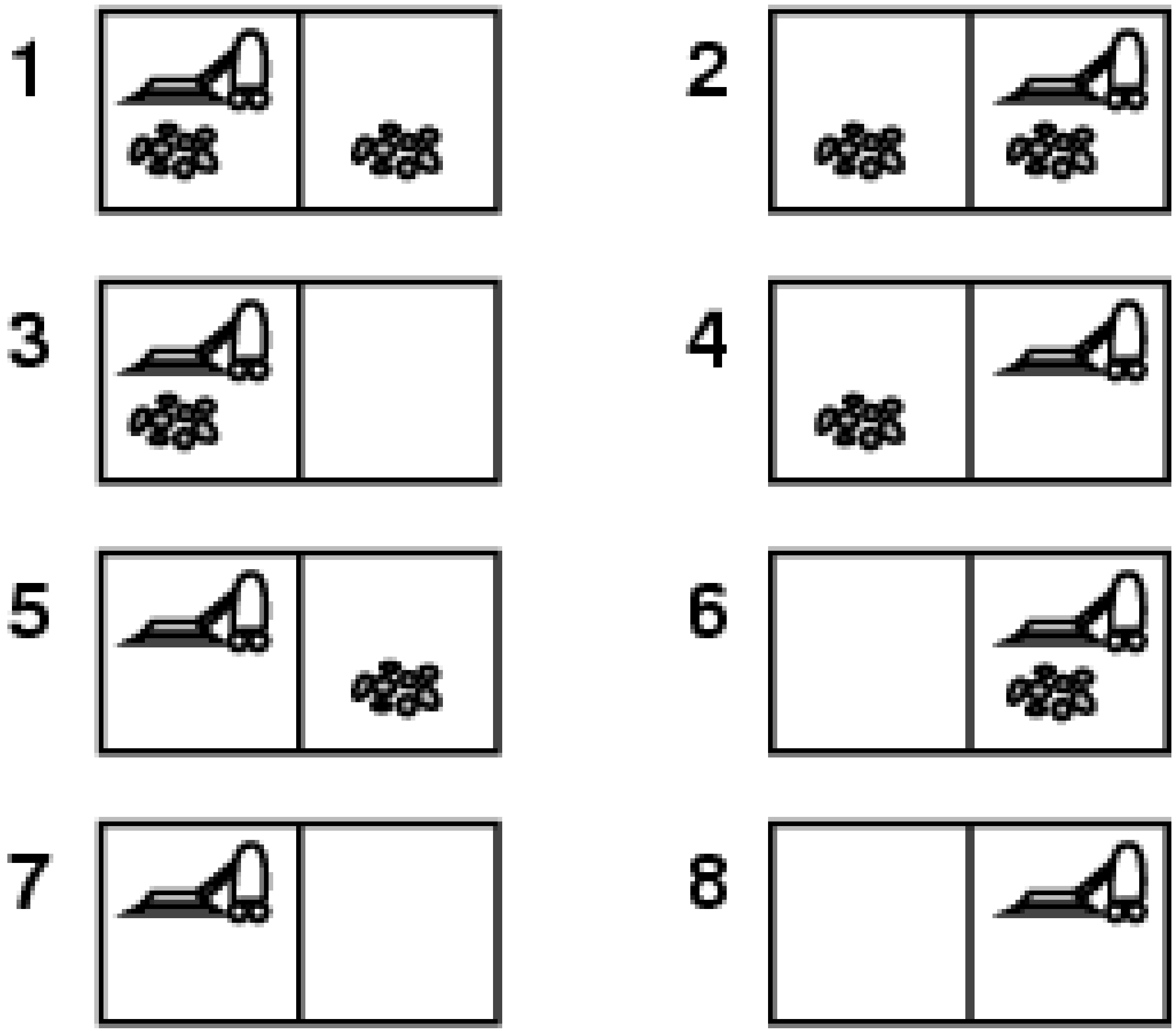
Sensorless:
Start in {*1,2,3,4,5,6,7,8*}
e.g. *Right* goes to {*2,4,6,8*}
Solution?
[*Right*, *Suck*, *Left*, *Suck*]




# Example: vacuum world

Contingency:

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




# Example: vacuum world

Contingency:

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

# Problem Formulation

# Single-state problem formulation

## Initial State

- e.g. "in Arad"

## Actions or Successor function

- *S*(x) = set of action-state pairs
- e.g. *S*(Arad) = {<Arad → Zerind, Zerind>, … }

## Goal test

- explicit e.g. *x* = "in Bucharest"
- implicit e.g. *Checkmate(x)*

## 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 $\geq 0$

# Single-state problem formulation

## Initial State

- e.g. "in Arad"

## Actions or Successor function

- $S(x)$ = set of action-state pairs
- e.g. $S$(Arad) = {<Arad → Zerind, Zerind>, … }

A ***solution*** is a sequence of actions leading from the initial state to a goal state, i.e. a state that succeeds the goal test.

## Goal test

- explicit e.g. $x$ = "in Bucharest"
- implicit e.g. *Checkmate(x)*

## 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 $\geq 0$

# Selecting a state space

Real world is absurdly complex

→ state space must be abstracted for problem solving

(Abstract) state = set of real states

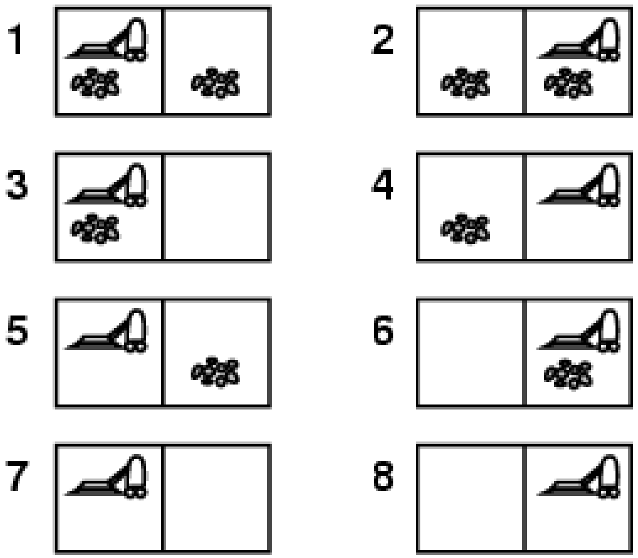
(Abstract) action = complex combination of real actions

- e.g., "Arad → 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*

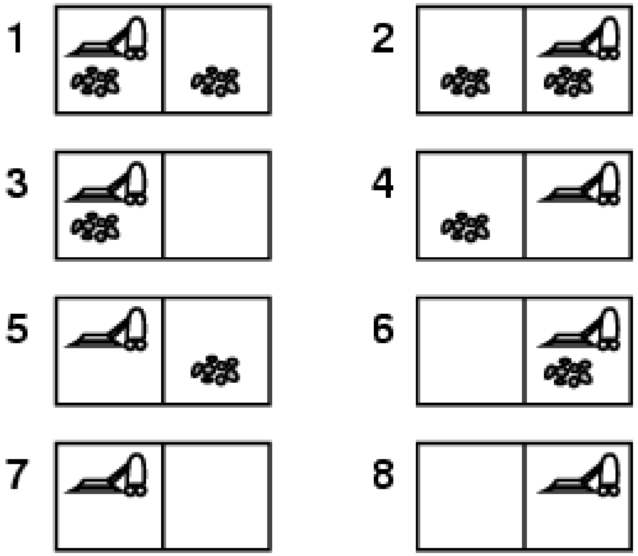
*Each abstract action should be "easier" than the original problem.*

# Example: Vacuum world




- States
- Actions
- Goal test
- Path cost (additive)

# Example: Vacuum world




## States

- Pair of dirt and robot locations

## Actions

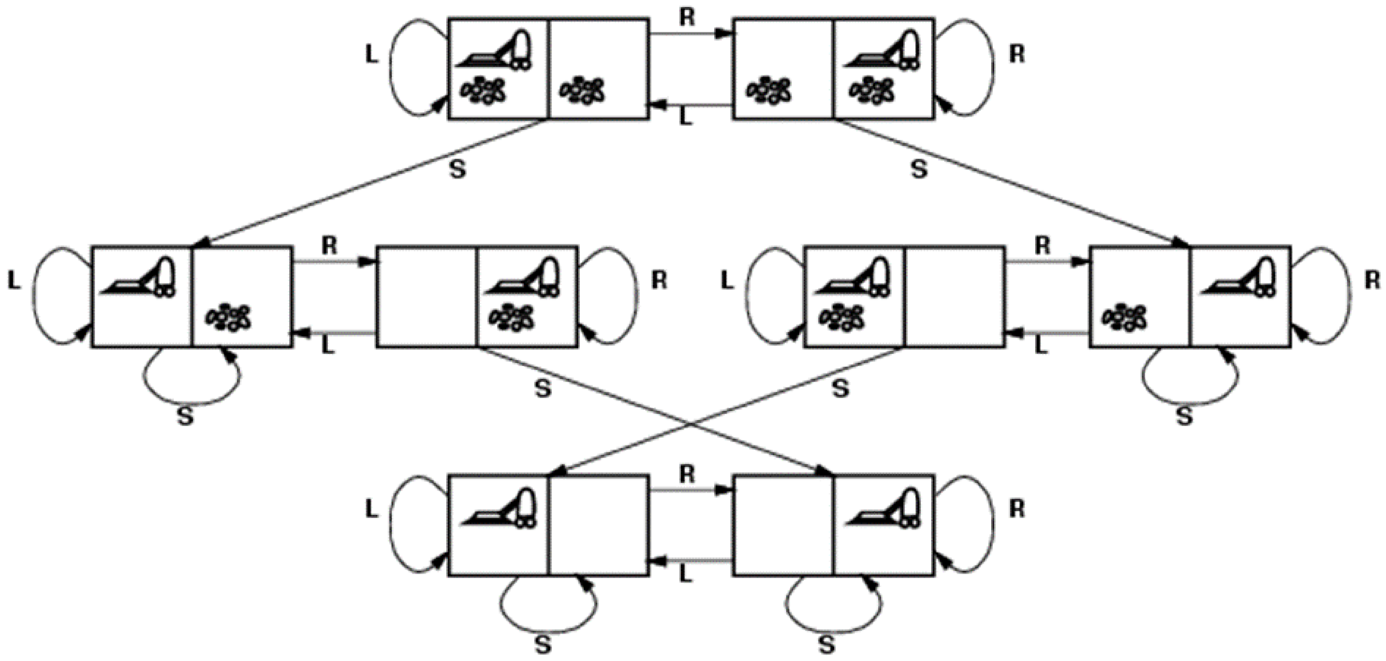
- *Left, Right, Suck*

## Goal test

- No dirt at any location

## Path cost (additive)

- 1 per action




# Example: Vacuum world

## States

- Pair of dirt and robot locations

## Actions

- *Left, Right, Suck*

## Goal test

- No dirt at any location

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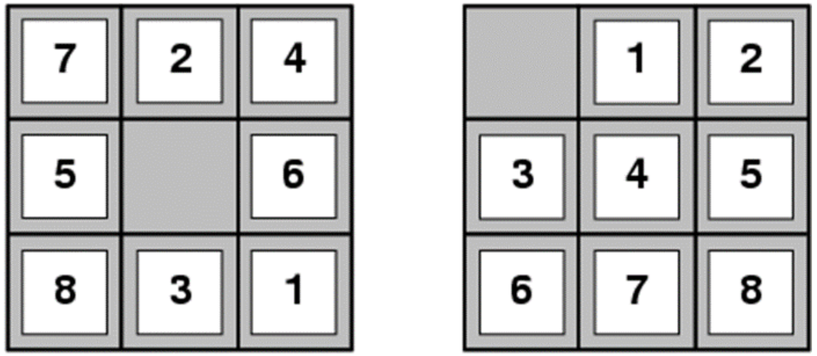
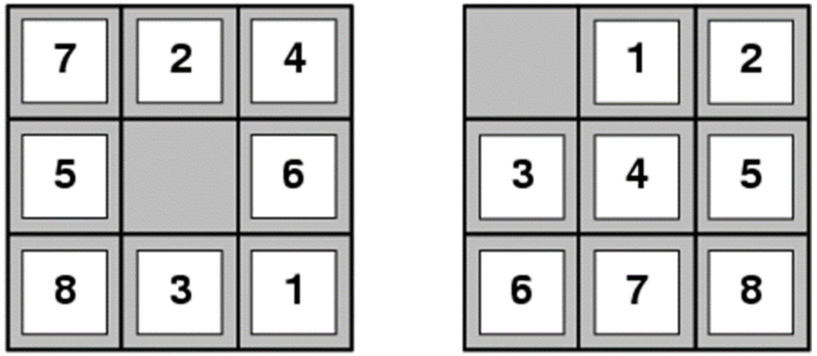
# Example: 8-puzzle




Start State Goal State

- States
- Actions
- Goal test
- Path cost (additive)

# Example: 8-puzzle




Start State Goal State

## States

- Integer location of tiles

## Actions

- Move blank *left, right, up, down*

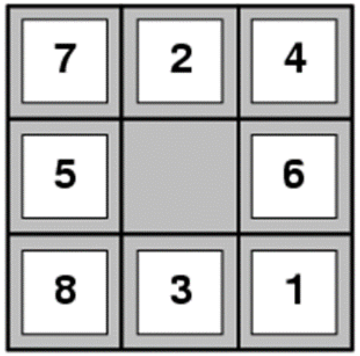
## Goal test

- = Goal state (given)

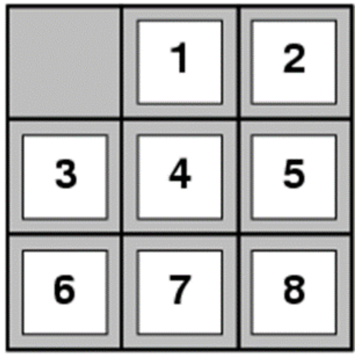
## Path cost (additive)

- 1 per move

# Example: 8-puzzle




Start State




Goal State

NP-Hard

## States

- Integer location of tiles

## Actions

- Move blank *left, right, up, down*

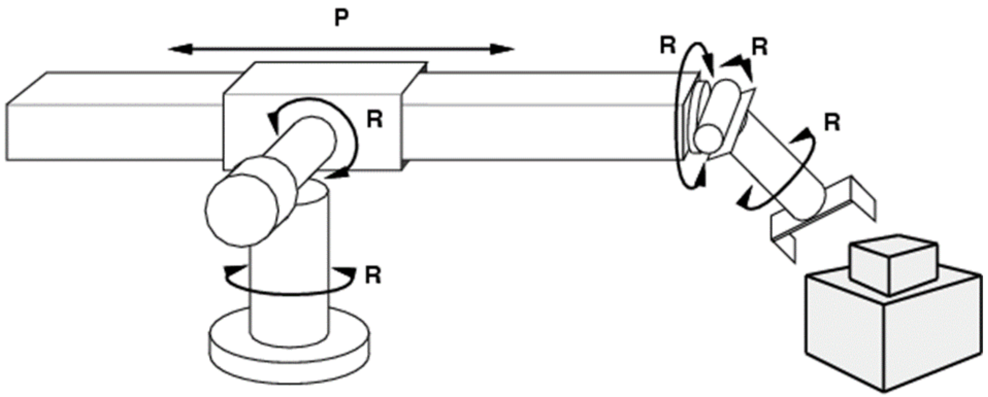
## Goal test

- = Goal state (given)

## Path cost (additive)

- 1 per move

# 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 (additive)

- Time to execute

# Searching for Solutions

# Tree search algorithms

**function** TREE-SEARCH(*problem*) **returns** a solution, or failure

  initialize the frontier using the initial state of *problem*

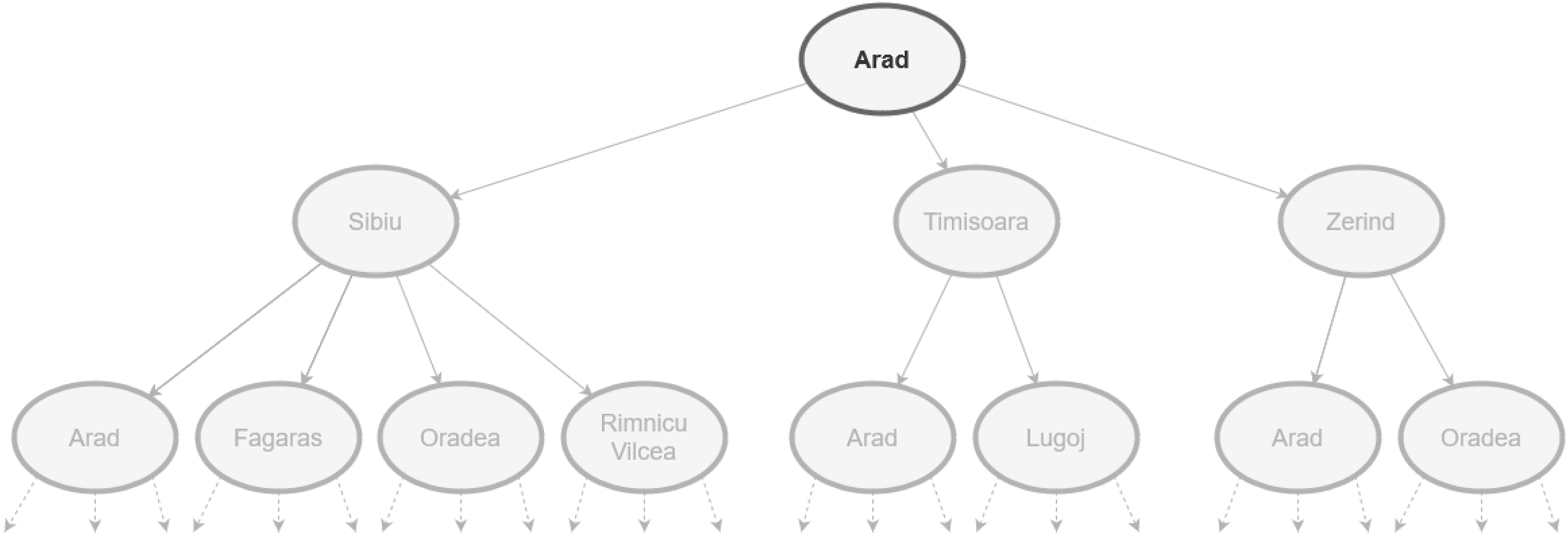
  **loop do**

    **if** the frontier is empty **then return** failure

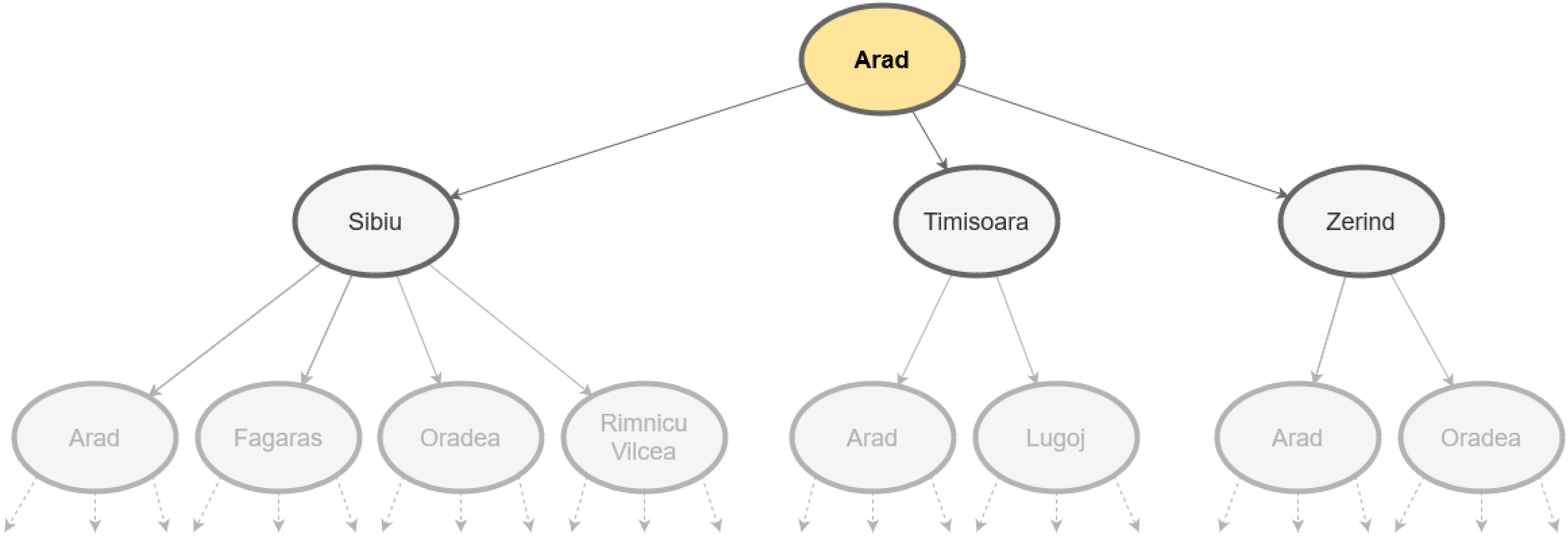
    choose a leaf node and remove it from the frontier

    **if** the node contains a goal state **then return** the corresponding solution

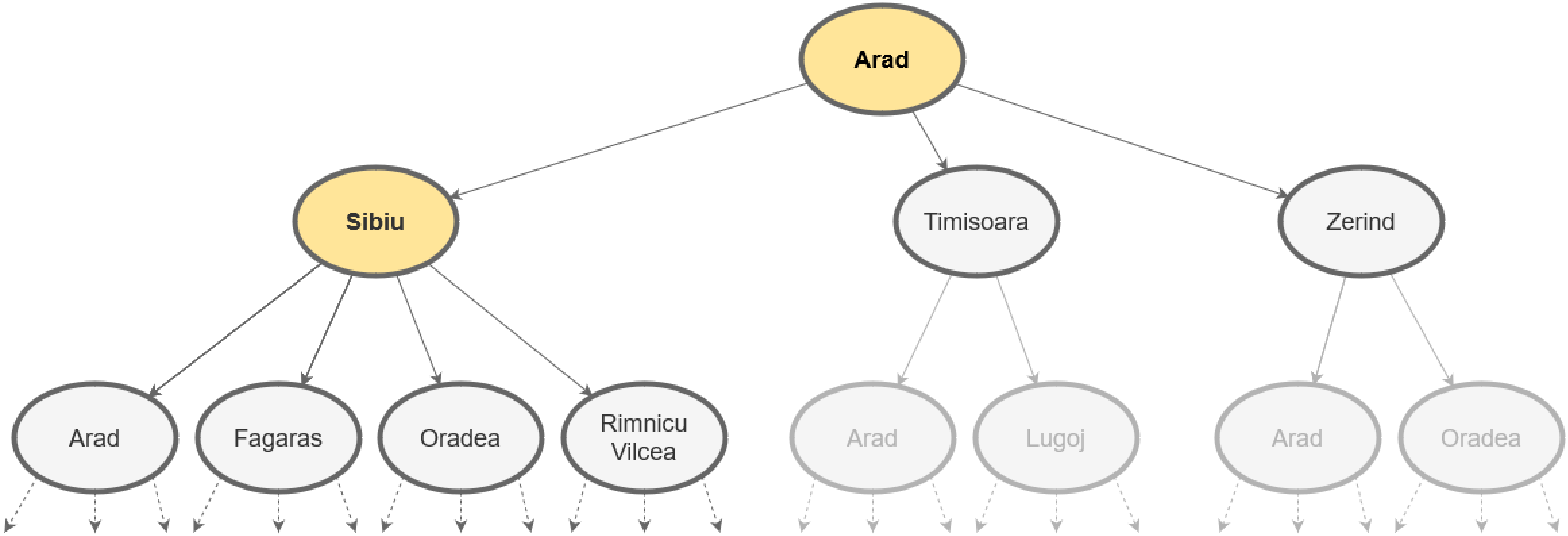
    expand the chosen node, adding the resulting nodes to the frontier



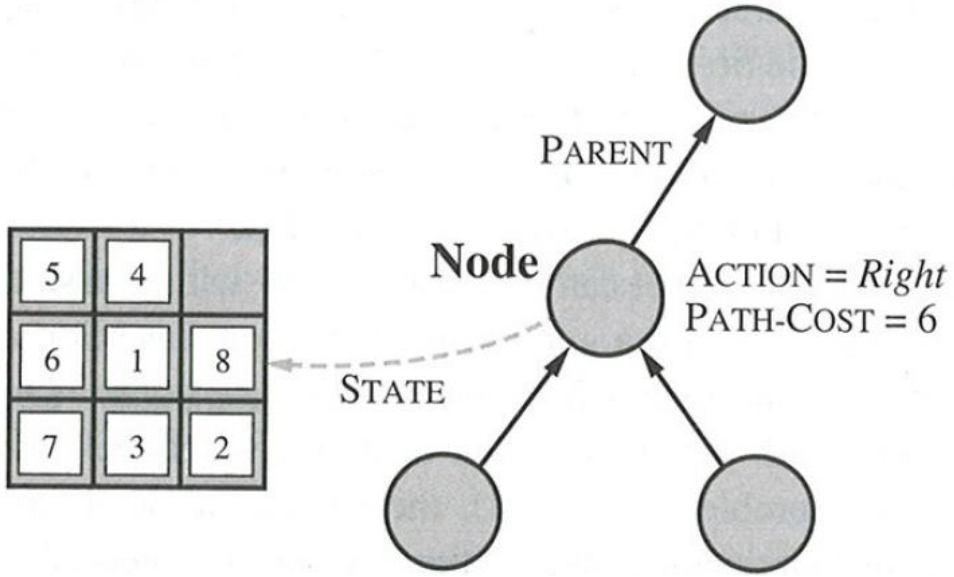

# Tree search example




# Tree search example




# Tree search example




# Implementation: states vs. nodes

A state is a (representation of) a physical configuration

A node is a 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)

# 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)
```

# Summary

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

# Why?

- Formulating problems in a way that a computer can understand.
- Breaking down the problem and its parameters.
- Clarifying the possible actions and assumptions about them.
- Creating structures where we can methodically and systematically search for solutions.