Solving problems by searching

This Lecture

Chapters 3.1 to 3.4

Next Lecture

Chapter 3.5 to 3.7

(Please read lecture topic material before and after each lecture on that topic)

Complete architectures for intelligence?

- Search?
  - Solve the problem of what to do.
- Learning?
  - Learn what to do.
- Logic and inference?
  - Reason about what to do.
  - Encoded knowledge/"expert" systems?
    - Know what to do.
- Modern view: It's complex & multi-faceted.

Search?
Solve the problem of what to do.

- Formulate "What to do?" as a search problem.
  - Solution to the problem tells agent what to do.
- If no solution in the current search space?
  - Formulate and solve the problem of finding a search space that does contain a solution.
  - Solve original problem in the new search space.
- Many powerful extensions to these ideas.
  - Constraint satisfaction; means-ends analysis; planning; game playing; etc.
- Human problem-solving often looks like search.

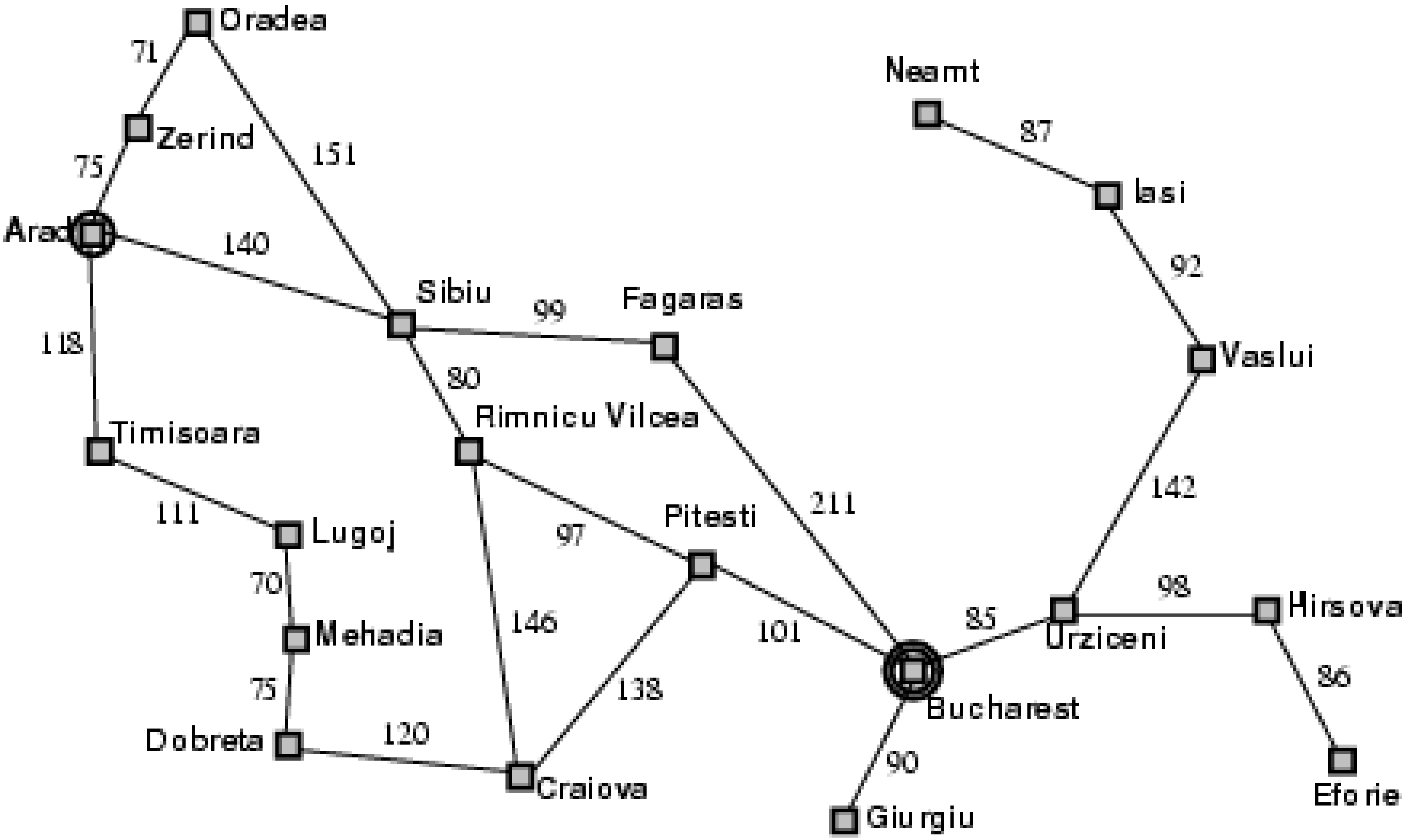
Why Search?

- To achieve goals or to maximize our utility we need to predict what the result of our actions in the future will be.
- There are many sequences of actions, each with their own utility.
- We want to find, or search for, the best one.

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 or choose next city
- Find solution:
  - sequence of cities, e.g., Arad, Sibiu, Fagaras, Bucharest

Example: Romania



Environments Types

- Static / Dynamic

  Previous problem was static: no attention to changes in environment

- Observable / Partially Observable / Unobservable

  Previous problem was observable: it knew initial state.

- Deterministic / Stochastic

  Previous problem was deterministic: no new percepts were necessary, we can predict the future perfectly given our actions

- Discrete / continuous

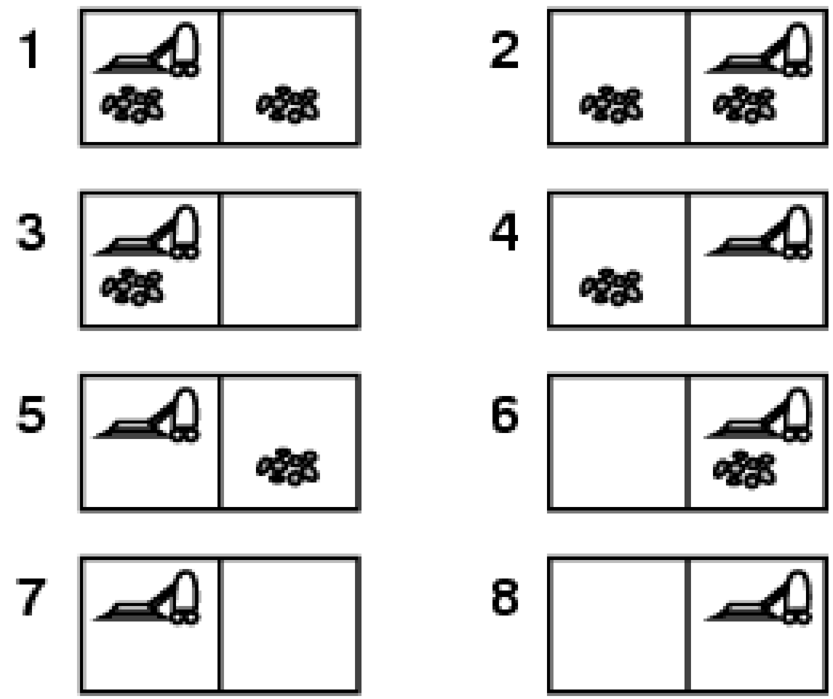
  Previous problem was discrete: we can enumerate all possibilities

Why not Dijkstra's Algorithm?

- Dijkstra's algorithm inputs the entire graph.
  - We want to search in unknown spaces.
  - Essentially, we combine search with exploration.
- D's algorithm takes connections as given.
  - We want to search based on agent's actions.
  - The agent may not know the result of an action in a state before trying it.
- D's algorithm won't work on infinite spaces.
  - We want to search in infinite spaces.
  - E.g., the logical reasoning space is infinite.

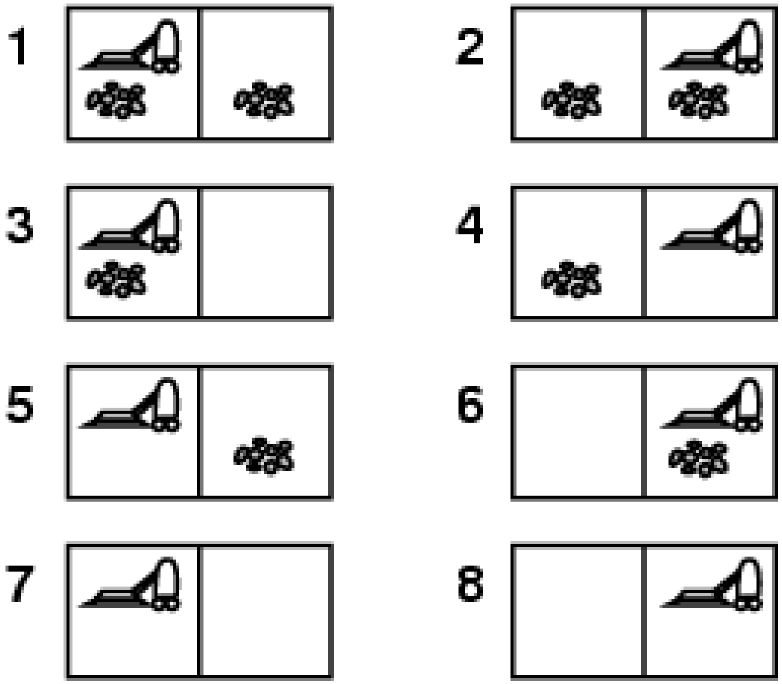
Example: vacuum world

- Observable, start in #5.
  Solution?



Example: vacuum world

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



Vacuum world state space graph

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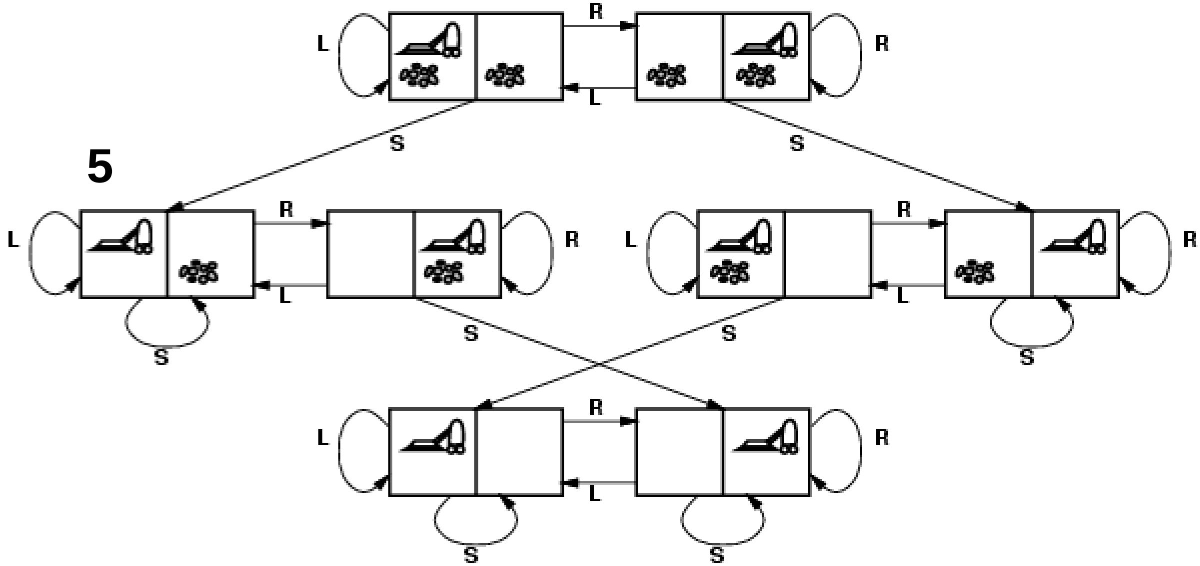
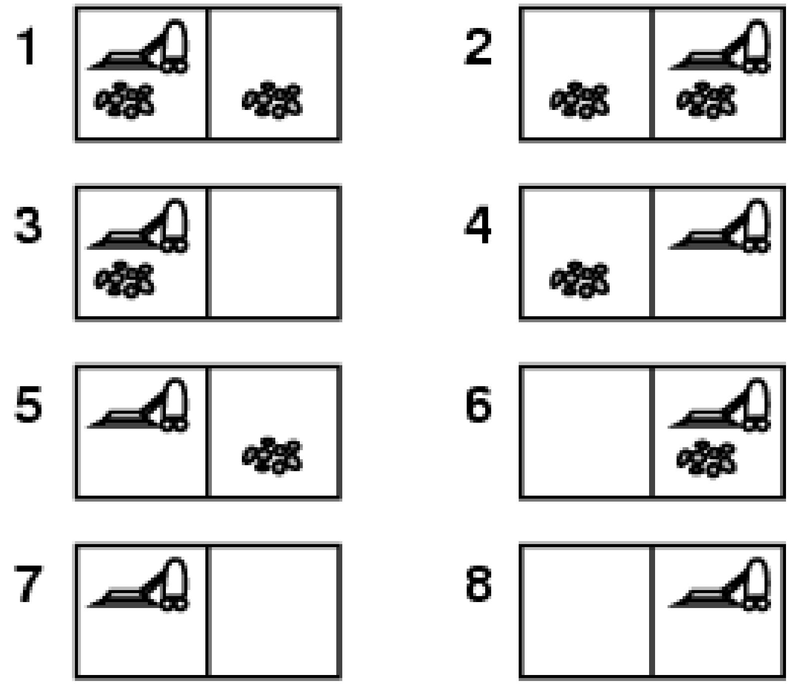


Example: vacuum world

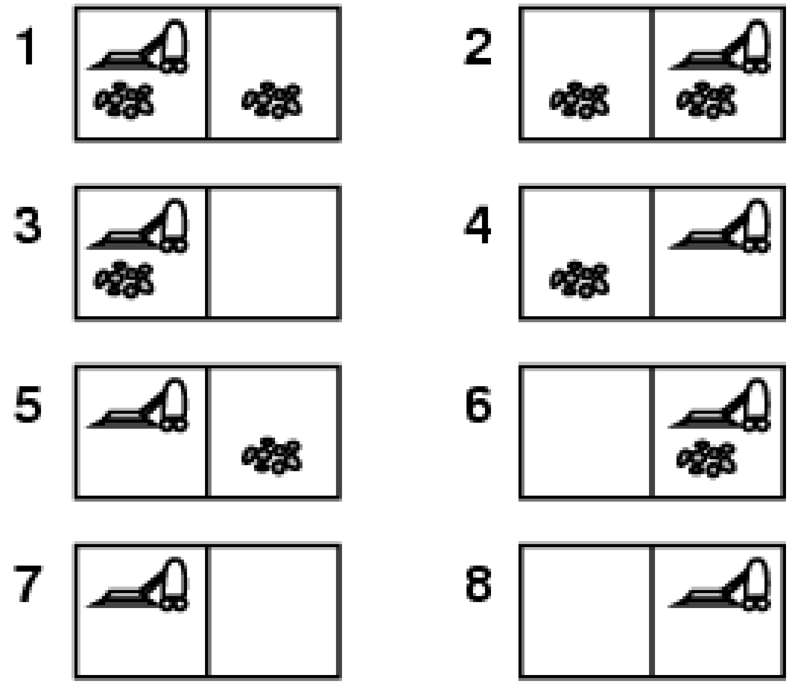
- Observable, start in #5.
  Solution? *[Right, Suck]*

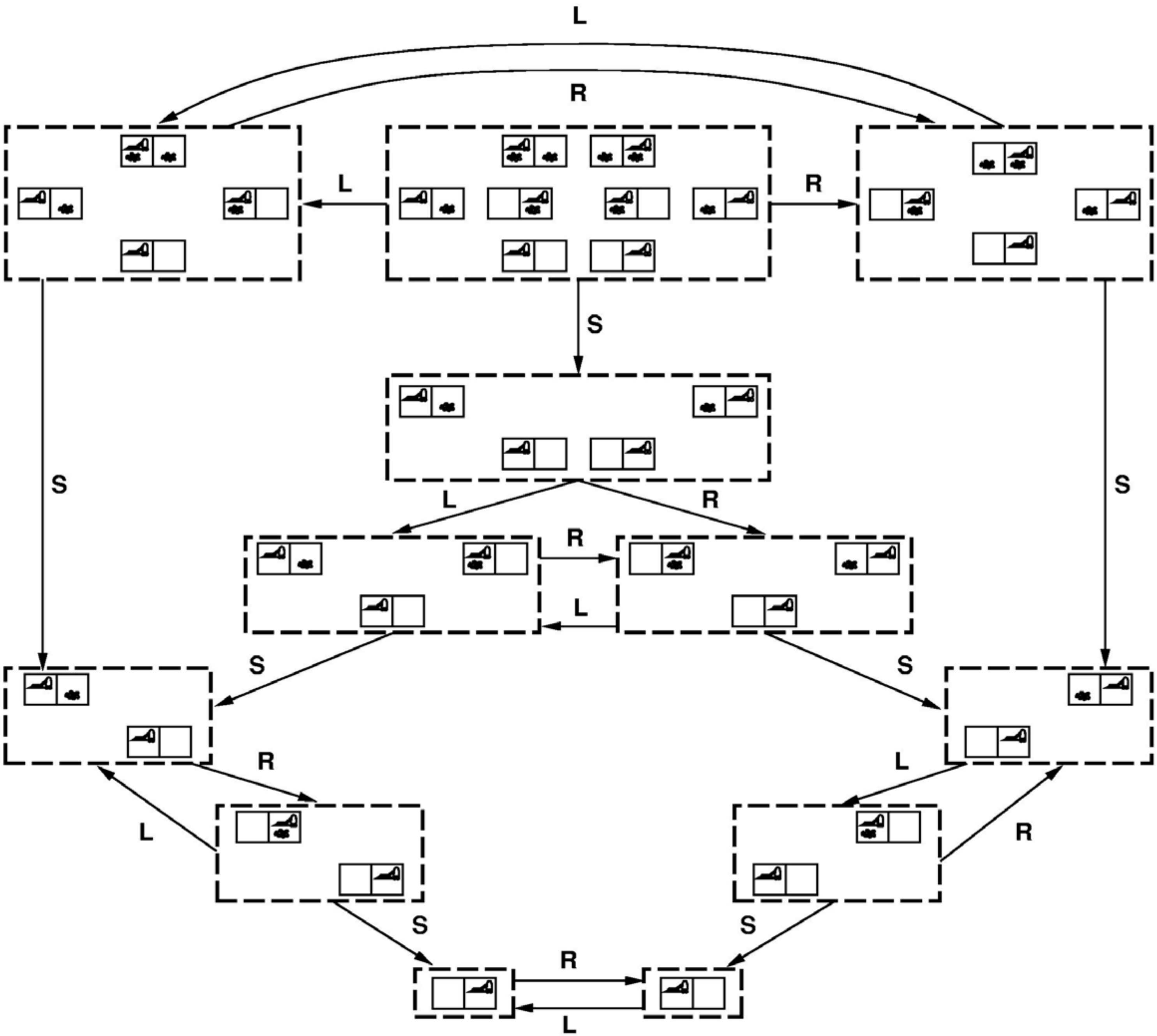
- Unobservable, start in {*1,2,3,4,5,6,7,8*} e.g.,
  Solution?



Example: vacuum world

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

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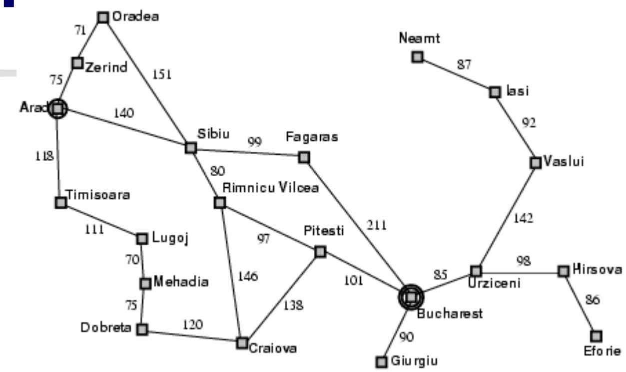
Problem Formulation



A problem is defined by five items:

initial state e.g., "at Arad“

actions Actions(s) = set of actions available in state s

transition model Result(s,a) = state that results from action a in state s

(alternative: successor function) *S(x)* = set of action–state pairs

- e.g., *S(Arad) = { <Arad → Zerind, Sibiu, Timisoara>, … }*

goal test, e.g., *x* = "at Bucharest”, *Checkmate(x)*

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

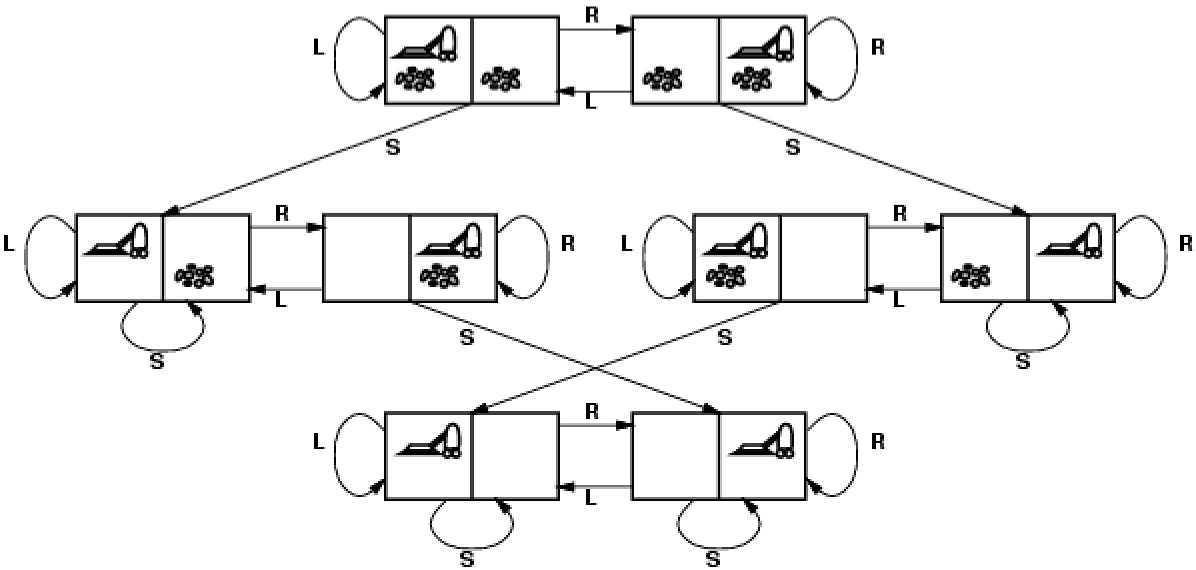
- *c(x,a,y)* is the step cost, assumed to be ≥ 0

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

Selecting a state space

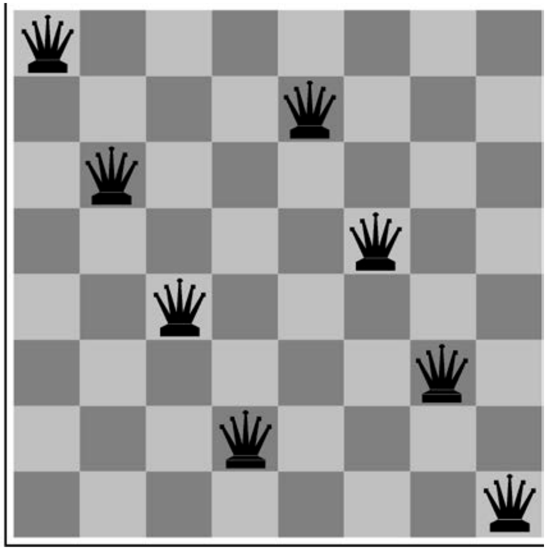
- Real world is absurdly complex
  - state space must be abstracted for problem solving
- (Abstract) state ← set of real states
- (Abstract) action ← complex combination of real actions
  - e.g., "Arad → Zerind" represents a complex set of possible routes, detours, rest stops, etc.
- For guaranteed realizability, 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

Vacuum world state space graph



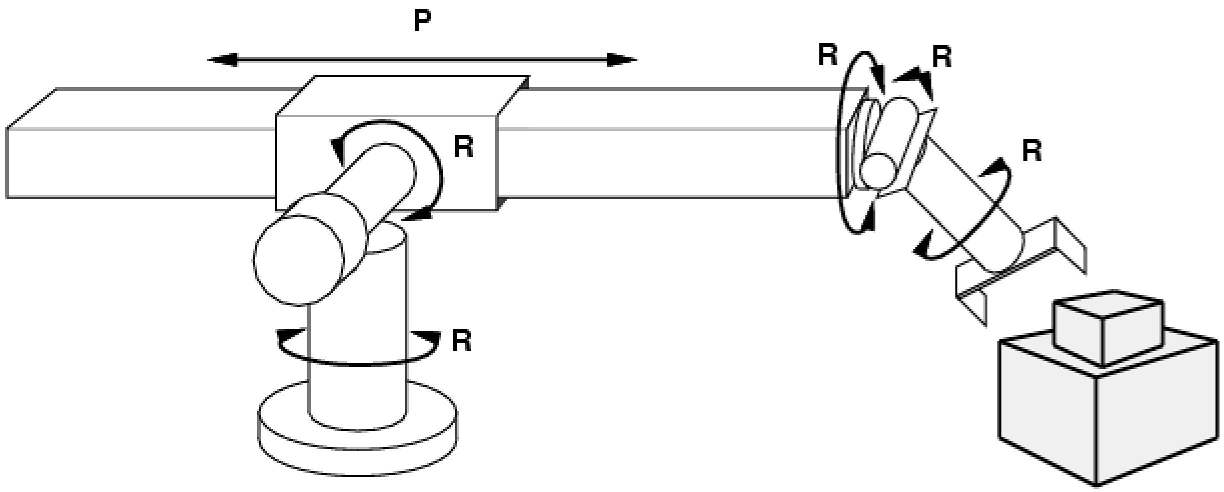
- states? discrete: dirt and robot location
- initial state? any
- actions? *Left*, *Right*, *Suck*
- goal test? no dirt at all locations
- path cost? 1 per action

Example: 8-Queens



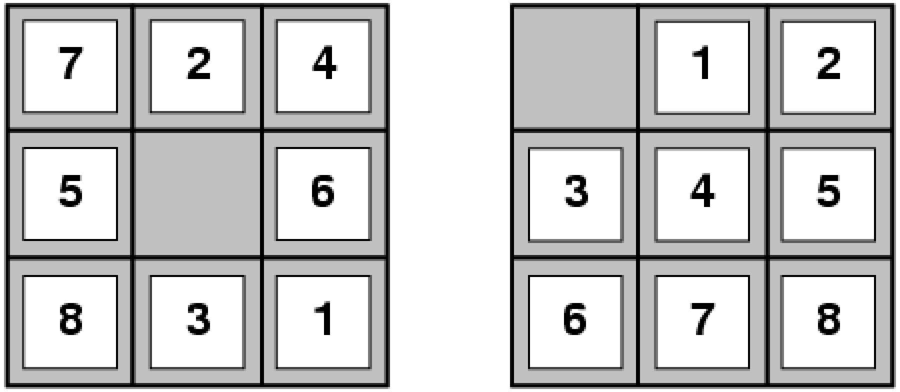
- <u>states?</u> -any arrangement of n<=8 queens
  -*or* arrangements of n<=8 queens in leftmost n columns, 1 per column, such that no queen attacks any other.
- <u>initial state?</u> no queens on the board
- <u>actions?</u> -add queen to any empty square
  -*or* add queen to leftmost empty square such that it is not attacked by other queens.
- <u>goal test?</u> 8 queens on the board, none attacked.
- <u>path cost?</u> 1 per move

Example: robotic assembly



- states?: real-valued coordinates of robot joint angles parts of the object to be assembled
- initial state?: rest configuration
- actions?: continuous motions of robot joints
- goal test?: complete assembly
- path cost?: time to execute+energy used

Example: The 8-puzzle

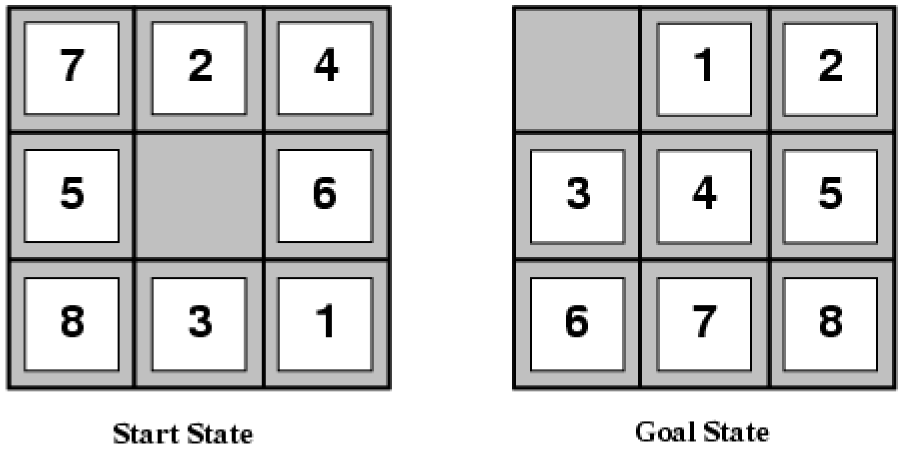


Start State   Goal State

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

Try yourselves

Example: The 8-puzzle



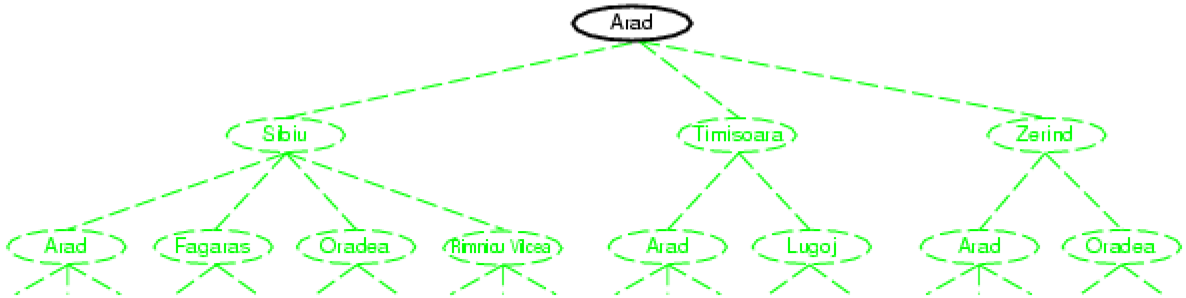
- states? locations of tiles
- initial state? given
- actions? move blank left, right, up, down
- goal test? goal state (given)
- path cost? 1 per move

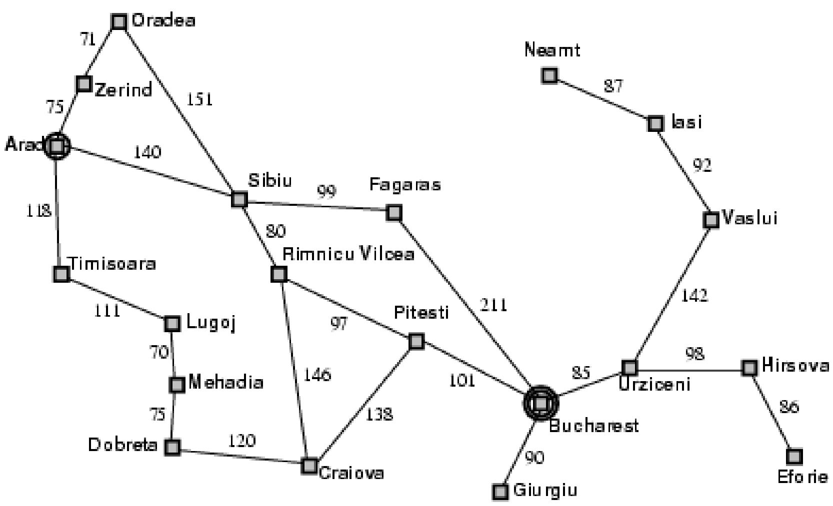
[Note: optimal solution of *n*-Puzzle family is NP-hard]

Tree search algorithms

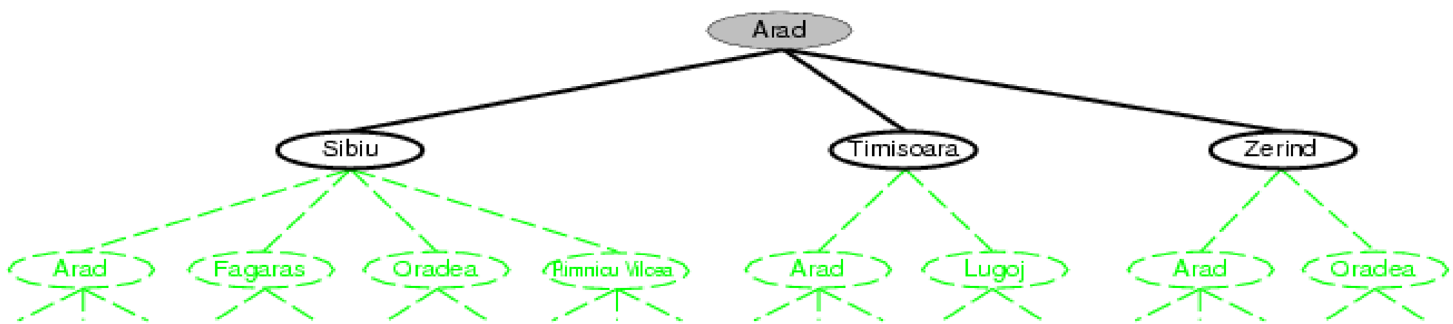
- Basic idea:
  - Exploration of state space by generating successors of already-explored states (a.k.a.~expanding states).
  - Every generated state is evaluated: *is it a goal state*?

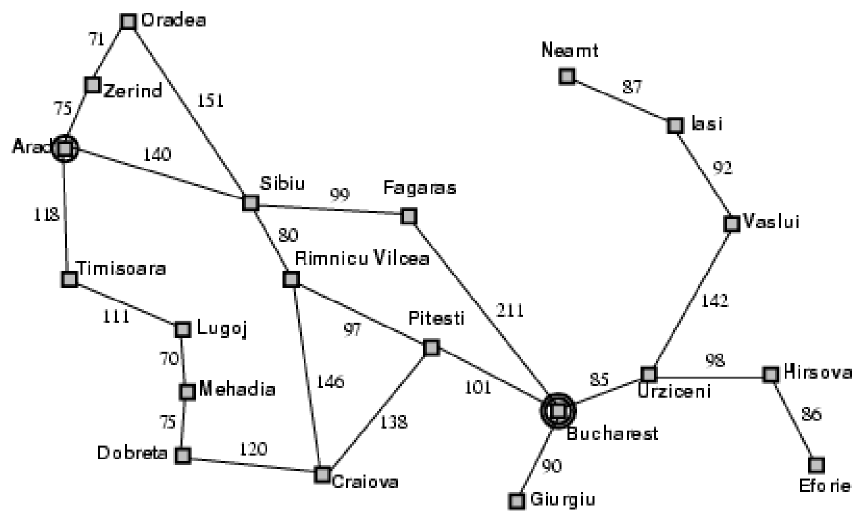
Tree search example



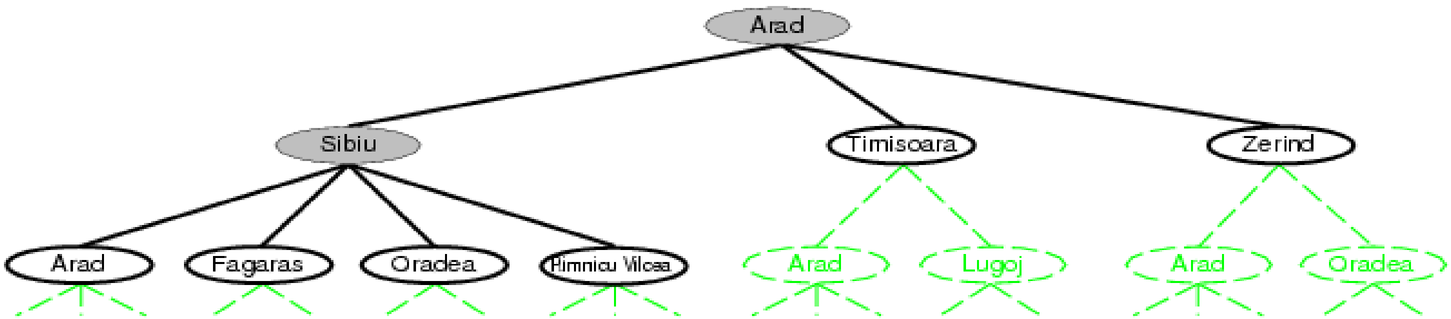


Tree search example





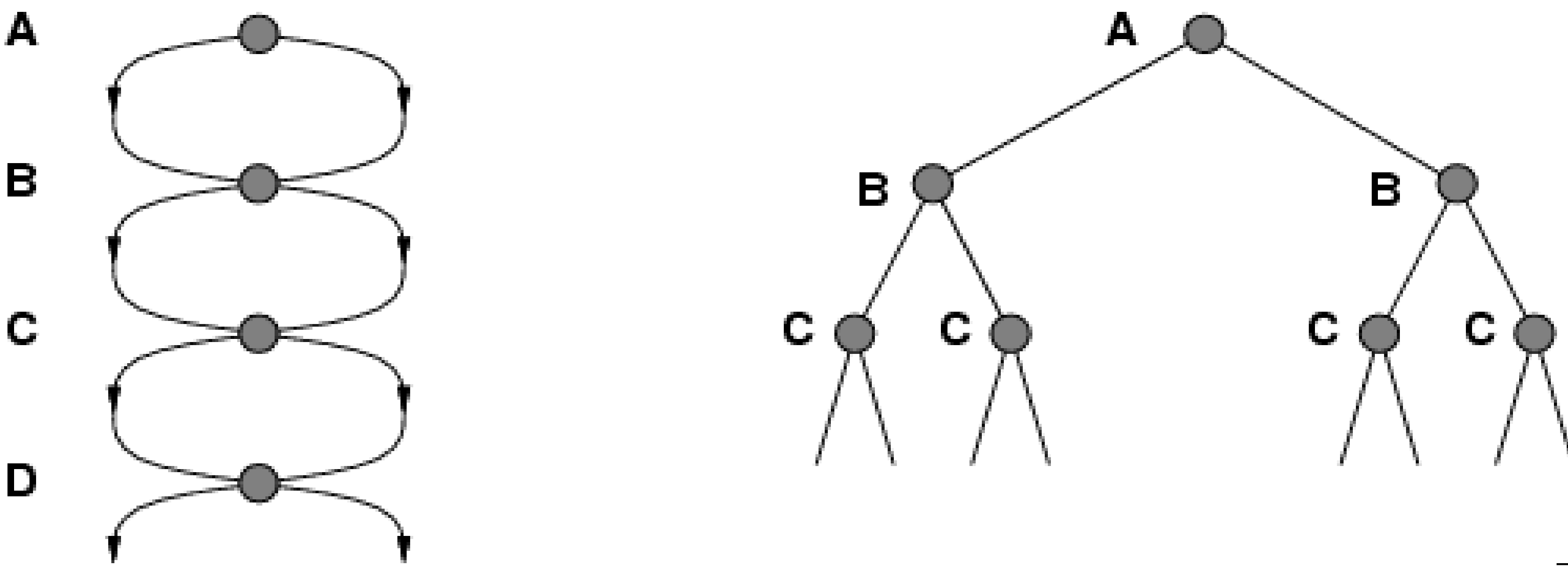
Tree search example



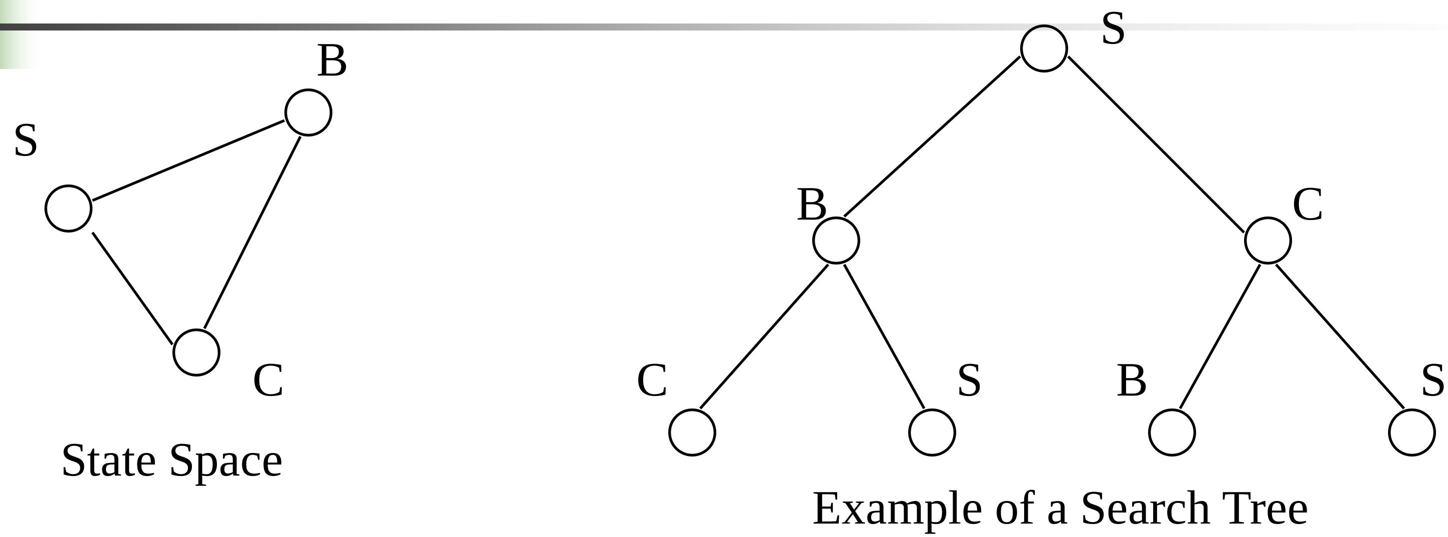

```
function TREE-SEARCH(problem, strategy) returns a solution, or failure
    initialize the search tree using the initial state of problem
    loop do
        if there are no candidates for expansion then return failure
        choose a leaf node for expansion according to strategy
        if the node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

Repeated states

- Failure to detect repeated states can turn a linear problem into an exponential one!
- Test is often implemented as a hash table.



Solutions to Repeated States

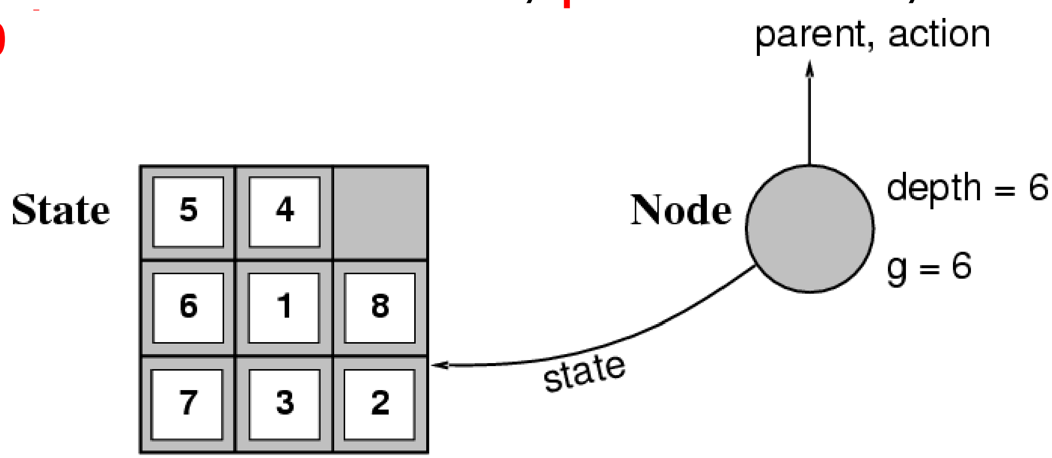


- Graph search ← optimal but memory inefficient
  - never generate a state generated before
    - must keep track of all possible states (uses a lot of memory)
    - e.g., 8-puzzle problem, we have 9! = 362,880 states
    - approximation for DFS/DLS: only avoid states in its (limited) memory: avoid looping paths.
    - Graph search optimal for BFS and UCS, not for DFS.

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 contains info such as: state, parent node, action, path cost *g(x)*, dep



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

Search strategies

- A search 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
  - 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 ∞)