

COMP338: Artificial Intelligence

Search Agents



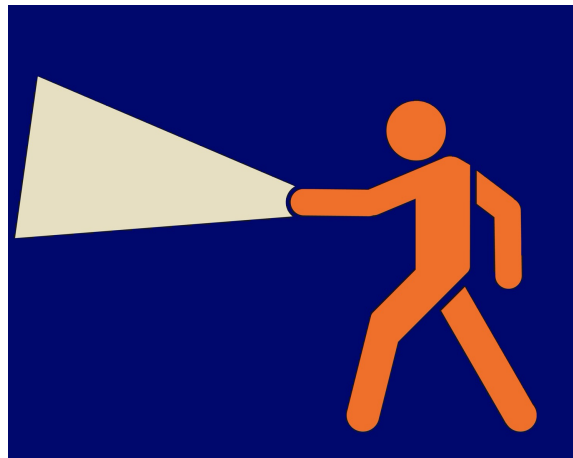
Note: these slides are borrowed from the slides in Russell and Norvig's website

Goal-based agents

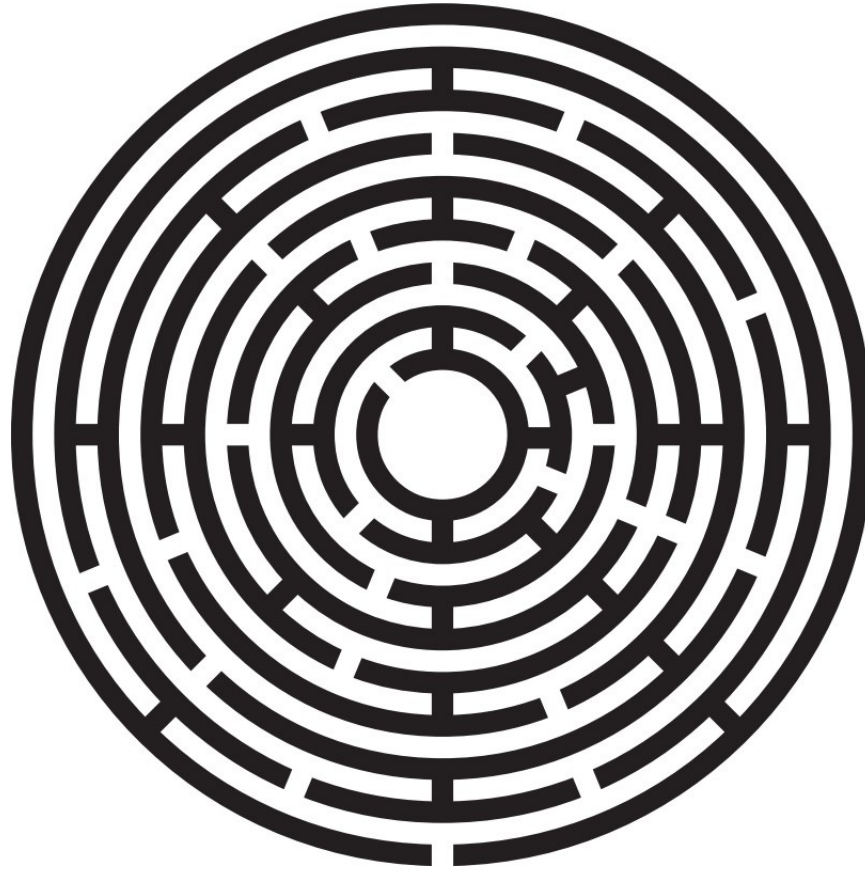
- Reflex agents: use a mapping from states to actions.
- Goal-based agents: problem solving agents or planning agents.

Goal-based agents

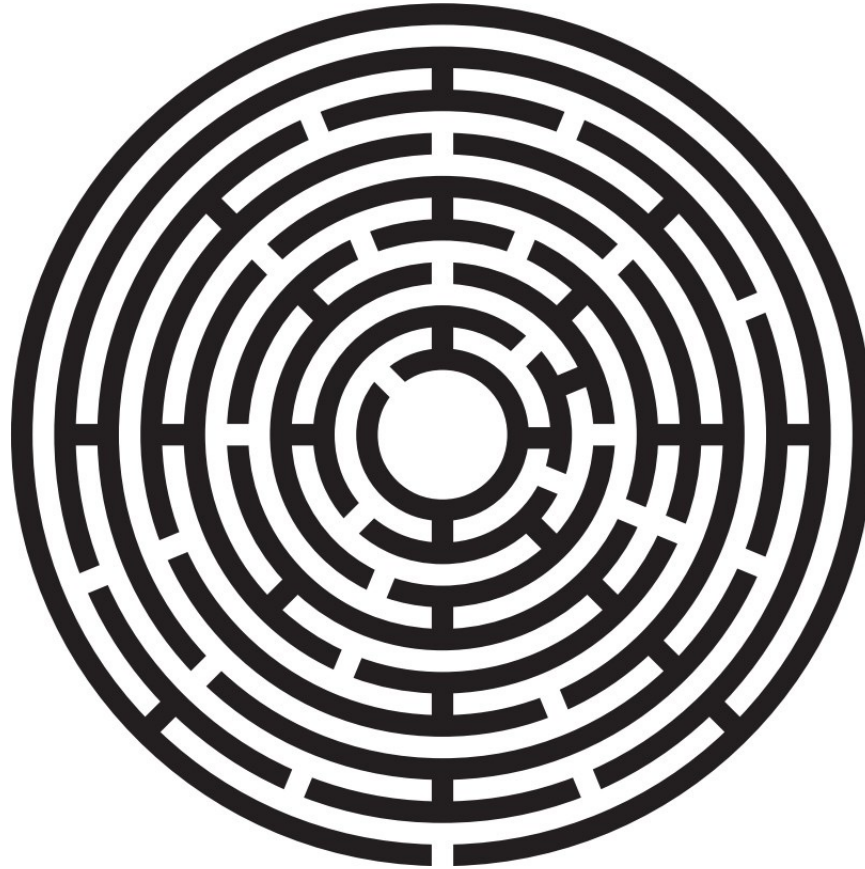
- Agents that work towards a **goal**.
- Agents consider the impact of **actions** on future **states**.
- Agent's job is to identify the action or series of actions that lead to the goal.
- Formalized as a **search** through possible **solutions**.



Examples

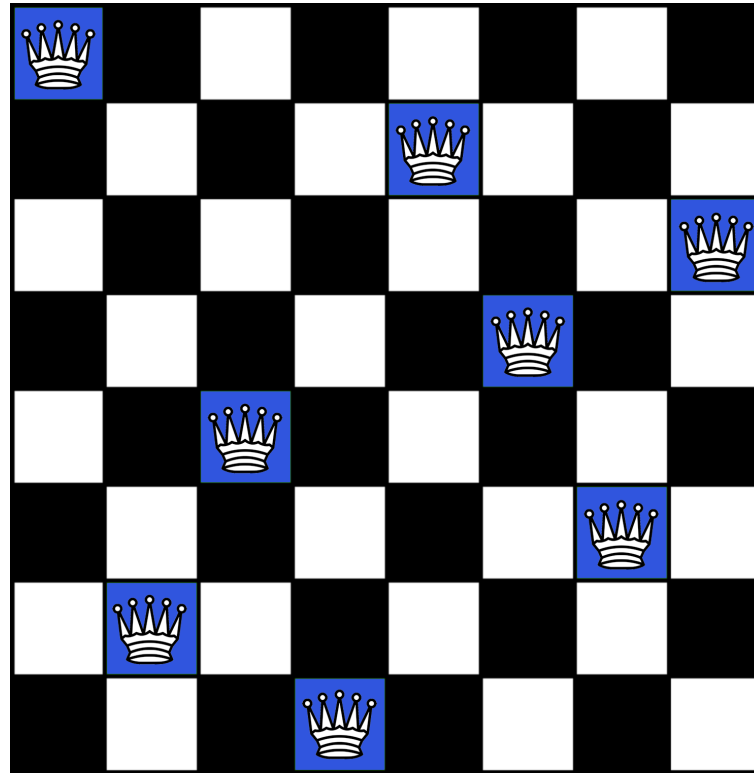


Examples



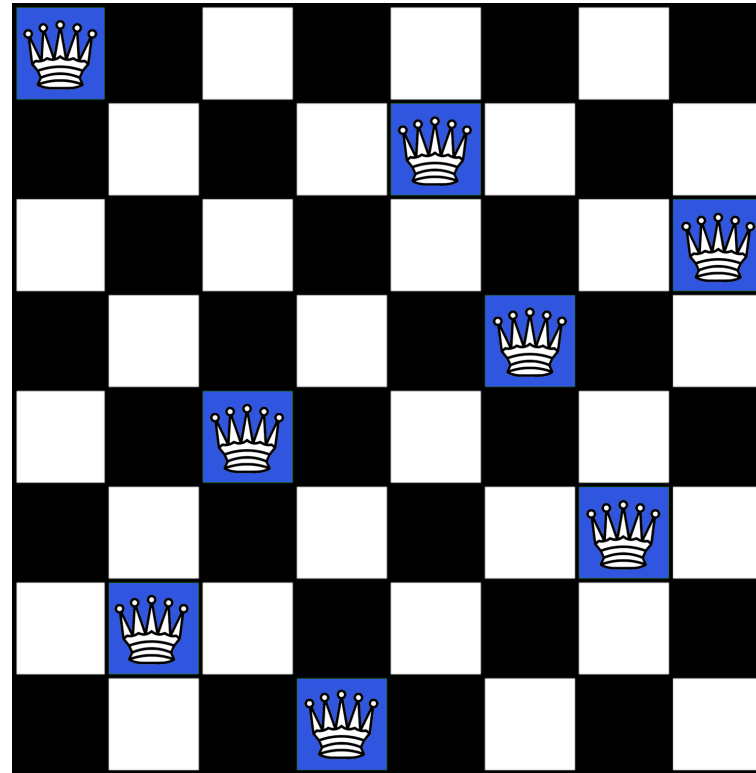
EXPLORE!

Examples



The 8-queen problem: on a chess board, place 8 queens so that no queen is attacking any other horizontally, vertically or diagonally.

Examples



Number of possible sequences to investigate:

$$64 * 63 * 62 * \dots * 57 = 1.8 \times 10^{14}$$

Eventually there are 92 solutions

Problem solving as search

A goal and a set of means for achieving the goal is called a **problem**, and the process of exploring what the means can do is called **search**.

1. Define the problem through:

(a) Goal formulation

(b) Problem formulation

2. Solving the problem as a 2-stage process:

(a) Search: exploring of several possibilities

(b) Execute the solution found

Problem formulation

- **Initial state:** the state in which the agent starts

Problem formulation

- **Initial state:** the state in which the agent starts
- **States:** All states reachable from the initial state by any sequence of actions (**State space**)

Problem formulation

- **Initial state:** the state in which the agent starts
- **States:** All states reachable from the initial state by any sequence of actions (**State space**)
- **Actions:** possible actions available to the agent. At a state s , $Actions(s)$ returns the set of actions that can be executed in state s . (**Action space**)

Problem formulation

- **Initial state:** the state in which the agent starts
- **States:** All states reachable from the initial state by any sequence of actions (**State space**)
- **Actions:** possible actions available to the agent. At a state s , $Actions(s)$ returns the set of actions that can be executed in state s . (**Action space**)
- **Transition model:** A description of what each action does
 $Results(s, a)$

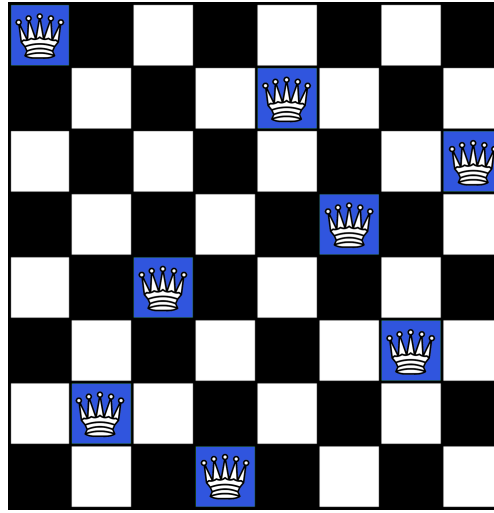
Problem formulation

- **Initial state:** the state in which the agent starts
- **States:** All states reachable from the initial state by any sequence of actions (**State space**)
- **Actions:** possible actions available to the agent. At a state s , $Actions(s)$ returns the set of actions that can be executed in state s . (**Action space**)
- **Transition model:** A description of what each action does
 $Results(s, a)$
- **Goal test:** determines if a given state is a goal state

Problem formulation

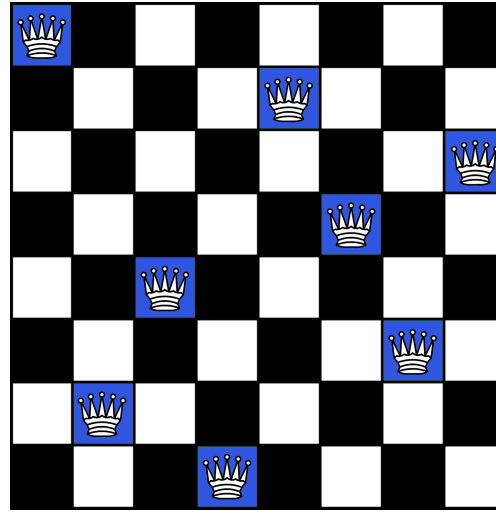
- **Initial state:** the state in which the agent starts
- **States:** All states reachable from the initial state by any sequence of actions (**State space**)
- **Actions:** possible actions available to the agent. At a state s , $Actions(s)$ returns the set of actions that can be executed in state s . (**Action space**)
- **Transition model:** A description of what each action does
 $Results(s, a)$
- **Goal test:** determines if a given state is a goal state
- **Path cost:** function that assigns a numeric cost to a path w.r.t. performance measure

Examples



- **States:**
- **Initial state:**
- **Actions:**
- **Transition model:**
- **Goal test:**

Examples



- **States:** all arrangements of 0 to 8 queens on the board.
- **Initial state:** No queen on the board
- **Actions:** Add a queen to any empty square
- **Transition model:** updated board
- **Goal test:** 8 queens on the board with none attacked

Examples

	0	6
7	1	2
5	3	4

8 puzzles

Examples

	0	6
7	1	2
5	3	4



	0	1
2	3	4
5	6	7

Examples

	0	6
7	1	2
5	3	4

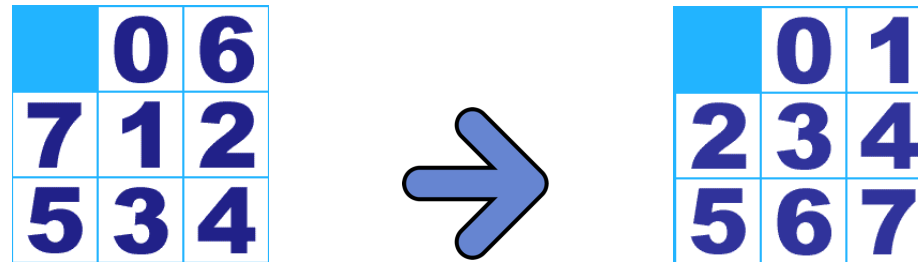
Start State



	0	1
2	3	4
5	6	7

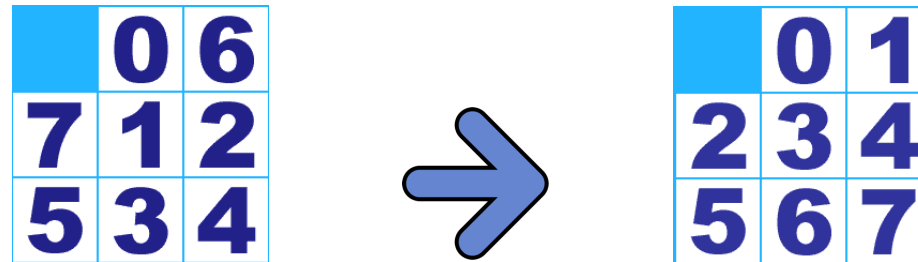
Goal State

Examples



- **States:**
- **Initial state:**
- **Actions:**
- **Transition model:**
- **Goal test:**
- **Path cost:**

Examples



- **States:** Location of each of the 8 tiles in the 3x3 grid
- **Initial state:** Any state
- **Actions:** Move Left, Right, Up or Down
- **Transition model:** Given a state and an action, returns resulting state
- **Goal test:** state matches the goal state?
- **Path cost:** total moves, each move costs 1.

Examples

- **States:** In any City where $City \in Palestine$
- **Initial state:** In Hebron
- **Actions:** Go Bethlehem, etc.
- **Transition model:** In(Jerusalem)
- **Goal test:** In(Haifa)
- **Path cost:** path length in kilometers



Real-world examples

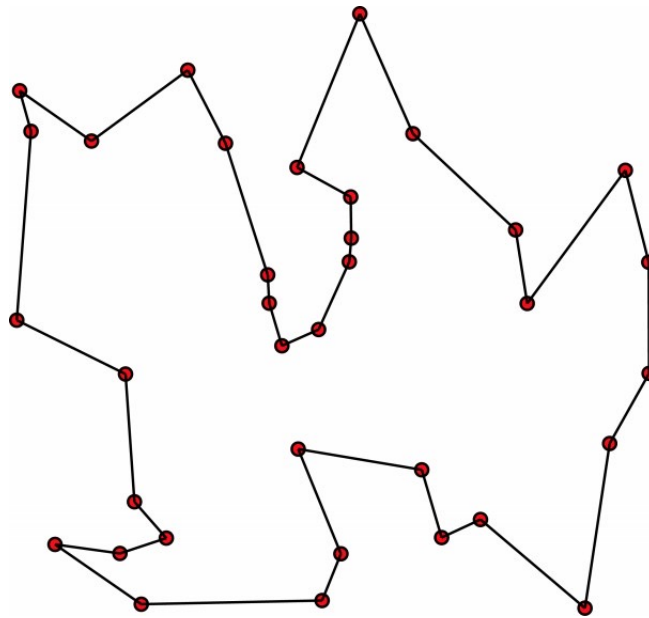
- **Route finding problem:** typically our example of map search, where we need to go from location to location using links or transitions. Example of applications include tools for driving directions in websites, in-car systems, etc.



Real-world examples

- **Traveling salesperson problem:**

Find the shortest tour to visit each city exactly once.



Real-world examples

- **Robot navigation:** Special case of route finding for robots with no specific routes or connections. The robot navigates in 2D or 3D space or more where the state space and action space are potentially infinite.



Real-world examples

- **Automatic assembly sequencing:** find an order in which to assemble parts of an object which is in general a difficult and expensive geometric search.



State space vs. search space

- **State space:** a *physical* configuration
- **Search space:** an *abstract* configuration represented by a search tree or graph of possible solutions.
- **Search tree: models the sequence of actions**
 - Root: initial state
 - Branches: actions
 - Nodes: results from actions. A node has: parent, children, depth, path cost, associated state in the state space.
- **Expand:** A function that given a node, creates all children nodes

Search Space Regions

- The search space is divided into three regions:
 1. **Explored** (a.k.a. Closed List, Visited Set)
 2. **Frontier** (a.k.a. Open List, the Fringe)
 3. **Unexplored.**
- The essence of search is moving nodes from regions (3) to (2) to (1), and the essence of search strategy is deciding the order of such moves.
- In the following we adopt the following color coding: orange nodes are explored, grey nodes are the frontier, white nodes are unexplored, and black nodes are failures.

Tree search

function TREE-SEARCH(initialState, goalTest)

returns **SUCCESS** or **FAILURE** :

initialize frontier **with** initialState

while not frontier.isEmpty():

 state = frontier.remove()

if goalTest(state):

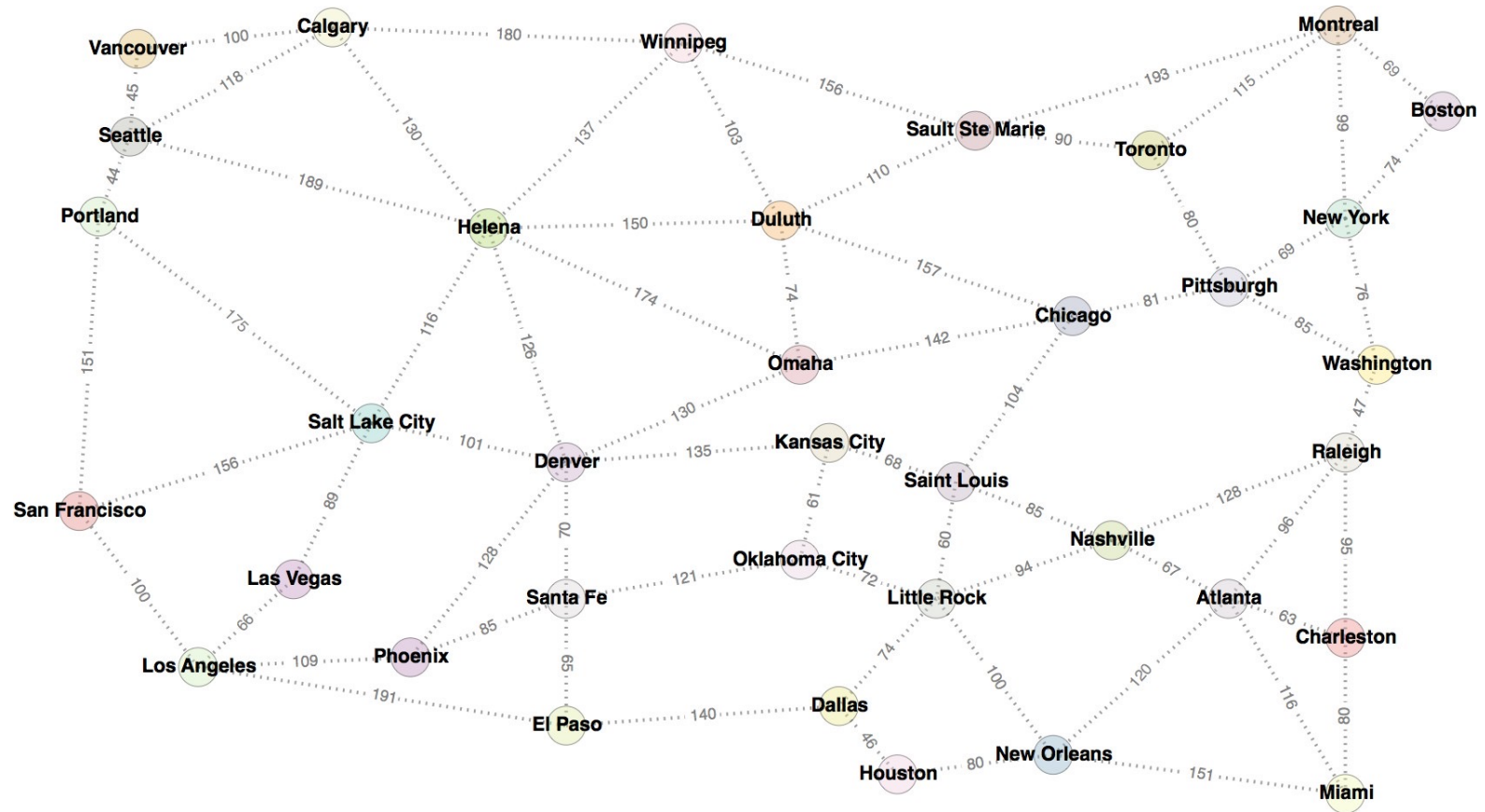
return **SUCCESS**(state)

for neighbor **in** state.neighbors():

 frontier.add(neighbor)

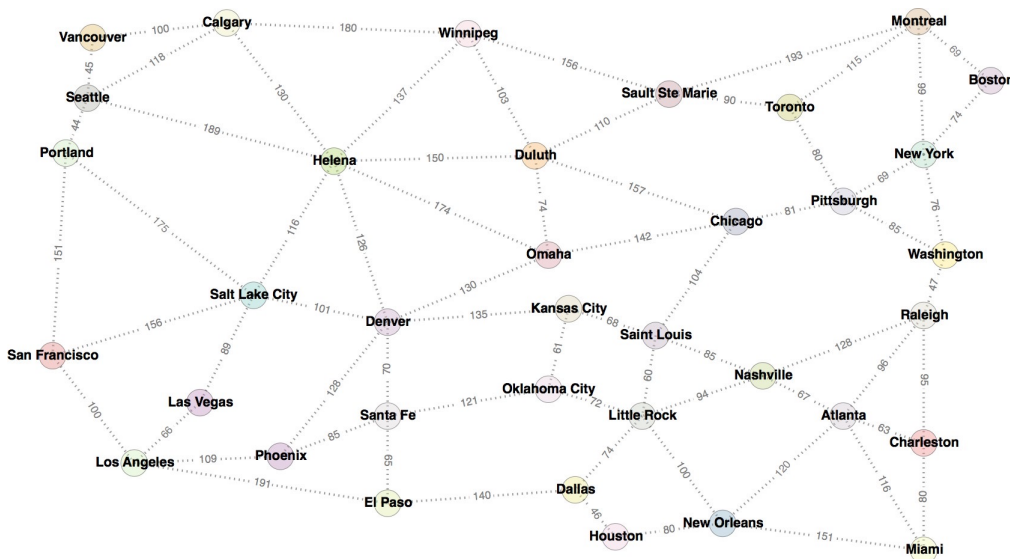
return **FAILURE**

Examples of search agents



Let's show the first steps in growing the search tree to find a route from San Francisco to another city

Examples of search agents



function TREE-SEARCH(initialState, goalTest)
returns **SUCCESS** or **FAILURE** :

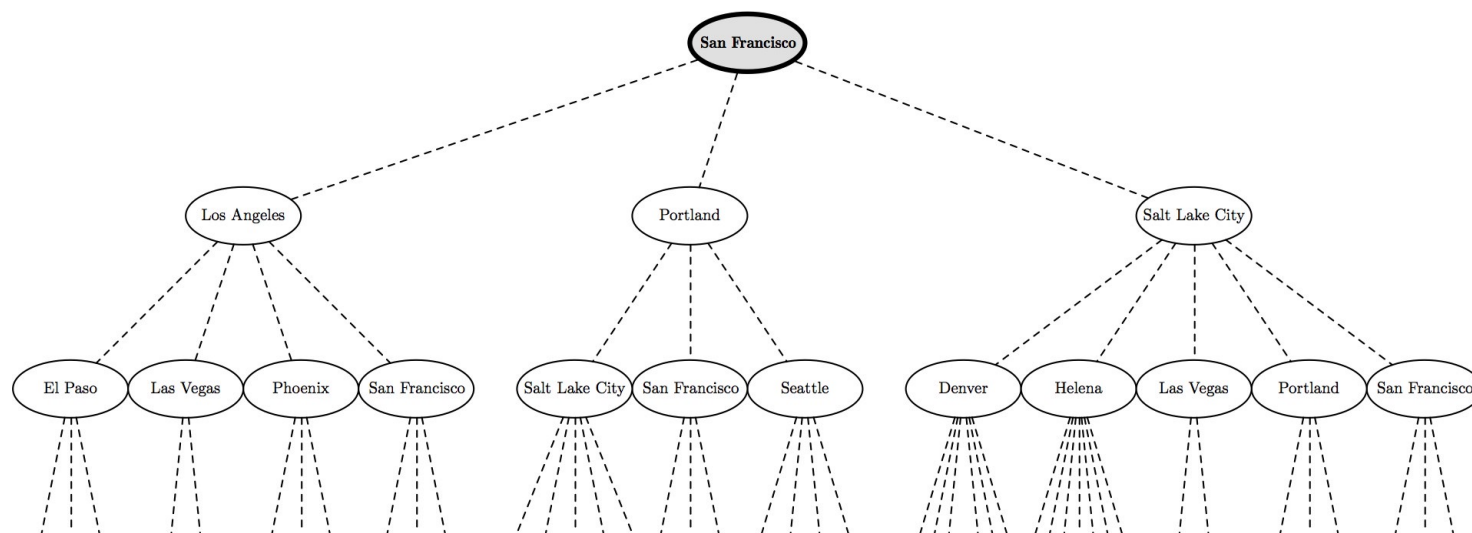
initialize frontier **with** initialState

while not frontier.isEmpty():
 state = frontier.remove()

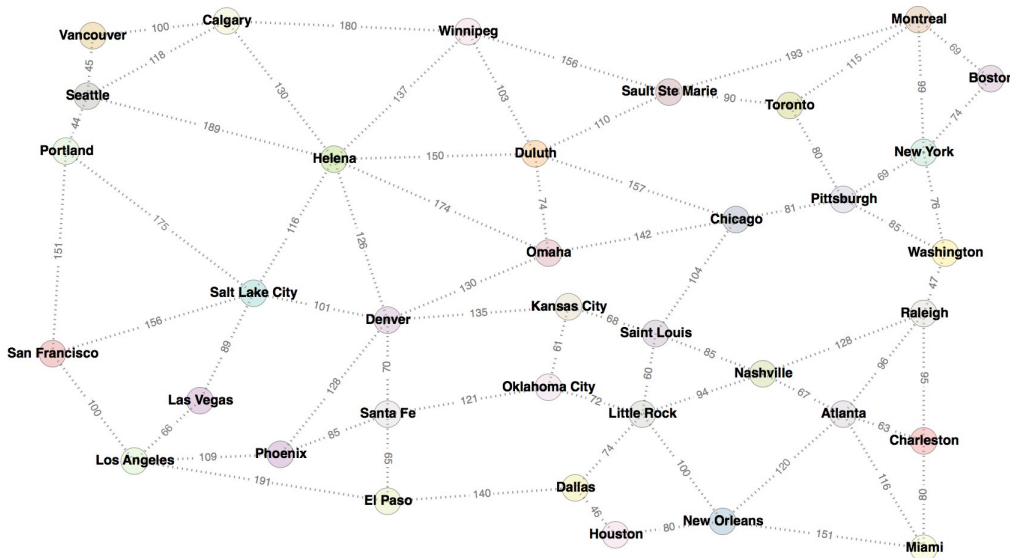
if goalTest(state):
 return **SUCCESS**(state)

for neighbor **in** state.neighbors():
 frontier.add(neighbor)

return **FAILURE**



Examples of search agents



function TREE-SEARCH(initialState, goalTest)
returns **SUCCESS** or **FAILURE** :

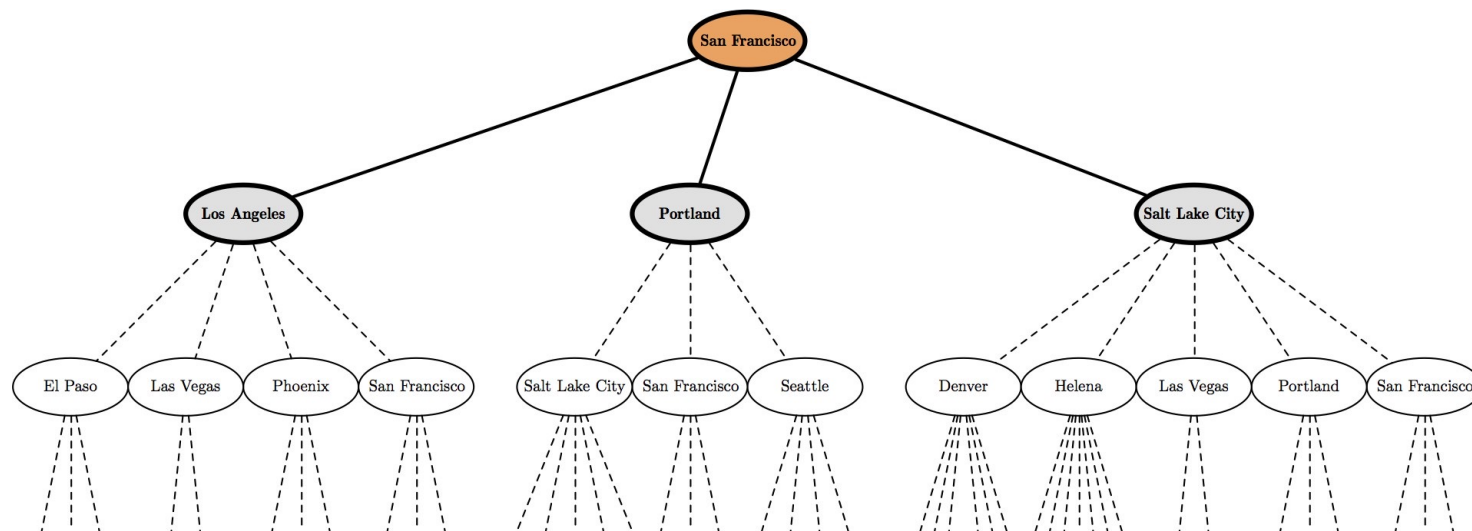
initialize frontier **with** initialState

while not frontier.isEmpty():
 state = frontier.remove()

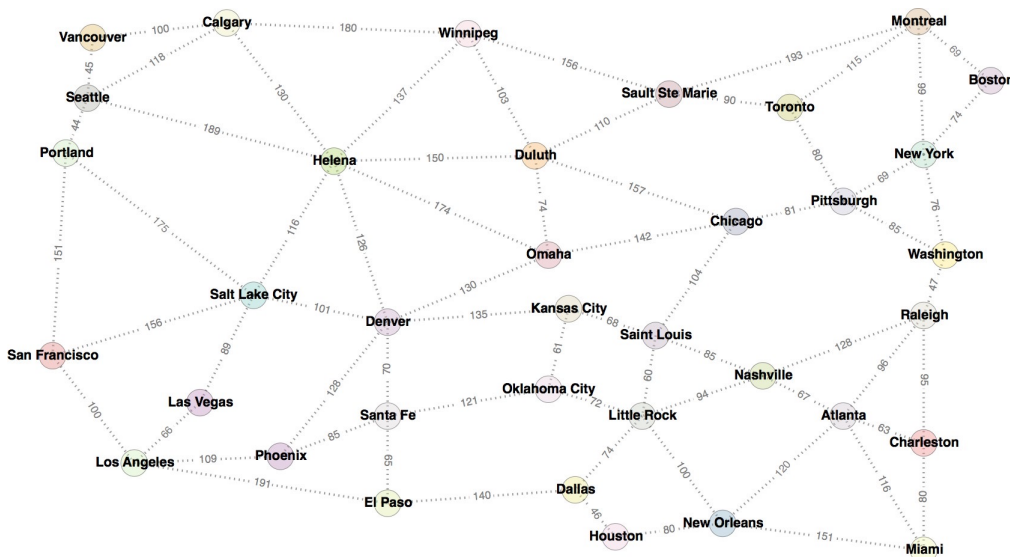
if goalTest(state):
 return **SUCCESS**(state)

for neighbor **in** state.neighbors():
 frontier.add(neighbor)

return **FAILURE**



Examples of search agents



function TREE-SEARCH(initialState, goalTest)
returns **SUCCESS** or **FAILURE** :

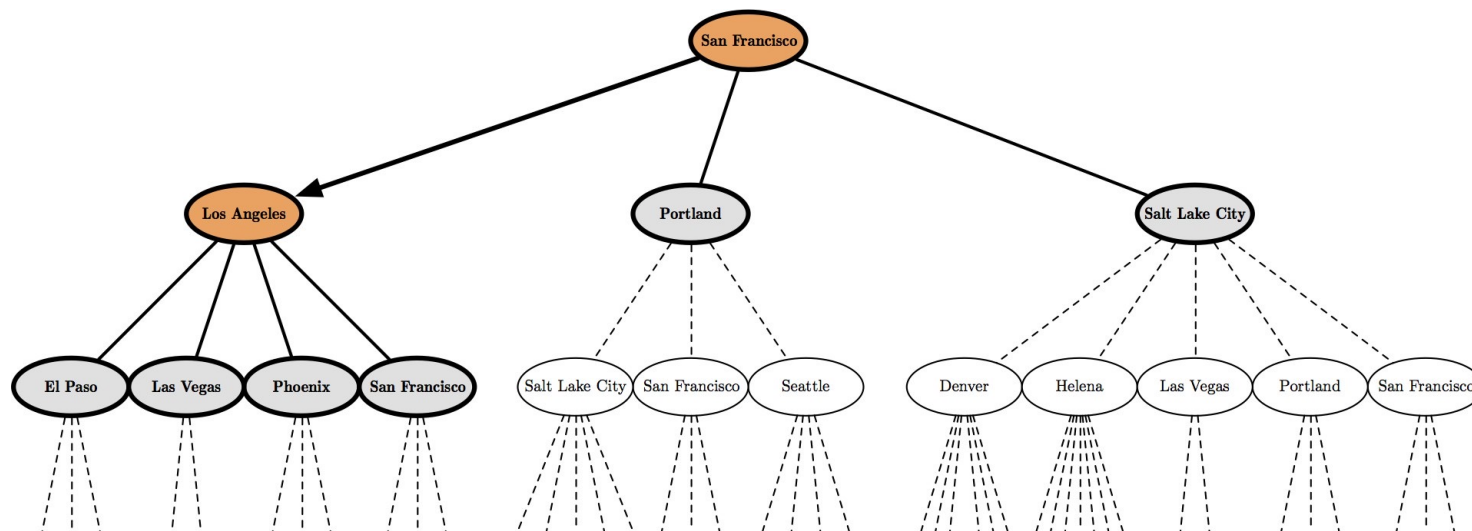
initialize frontier **with** initialState

while not frontier.isEmpty():
 state = frontier.remove()

if goalTest(state):
 return **SUCCESS**(state)

for neighbor **in** state.neighbors():
 frontier.add(neighbor)

return **FAILURE**



Graph search

How to handle repeated states?

function GRAPH-SEARCH(initialState, goalTest)
returns **SUCCESS** or **FAILURE** :

initialize frontier **with** initialState
explored = Set.new()

while not frontier.isEmpty():
 state = frontier.remove()
 explored.add(state)

if goalTest(state):
 return **SUCCESS**(state)

for neighbor **in** state.neighbors():
 if neighbor **not in** frontier \cup explored:
 frontier.add(neighbor)

return **FAILURE**

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?

Search strategies

- Time and space complexity are measured in terms of:
 - b : maximum branching factor of the search tree (actions per state).
 - d : depth of the solution
 - m : maximum depth of the state space (may be ∞) (also noted sometimes D).
- Two kinds of search: Uninformed and Informed.