ECE 4524 Artificial Intelligence and Engineering Applications

Tree and Graph Search
Reading: AIAMA 3.1-3.4

- Problem Solving as State Space Search
- Example Problems
- Review Trees and Graphs
- Uniformed Search Strategies

Problem Solving Agents

Problem Solving Agents formulate problems by

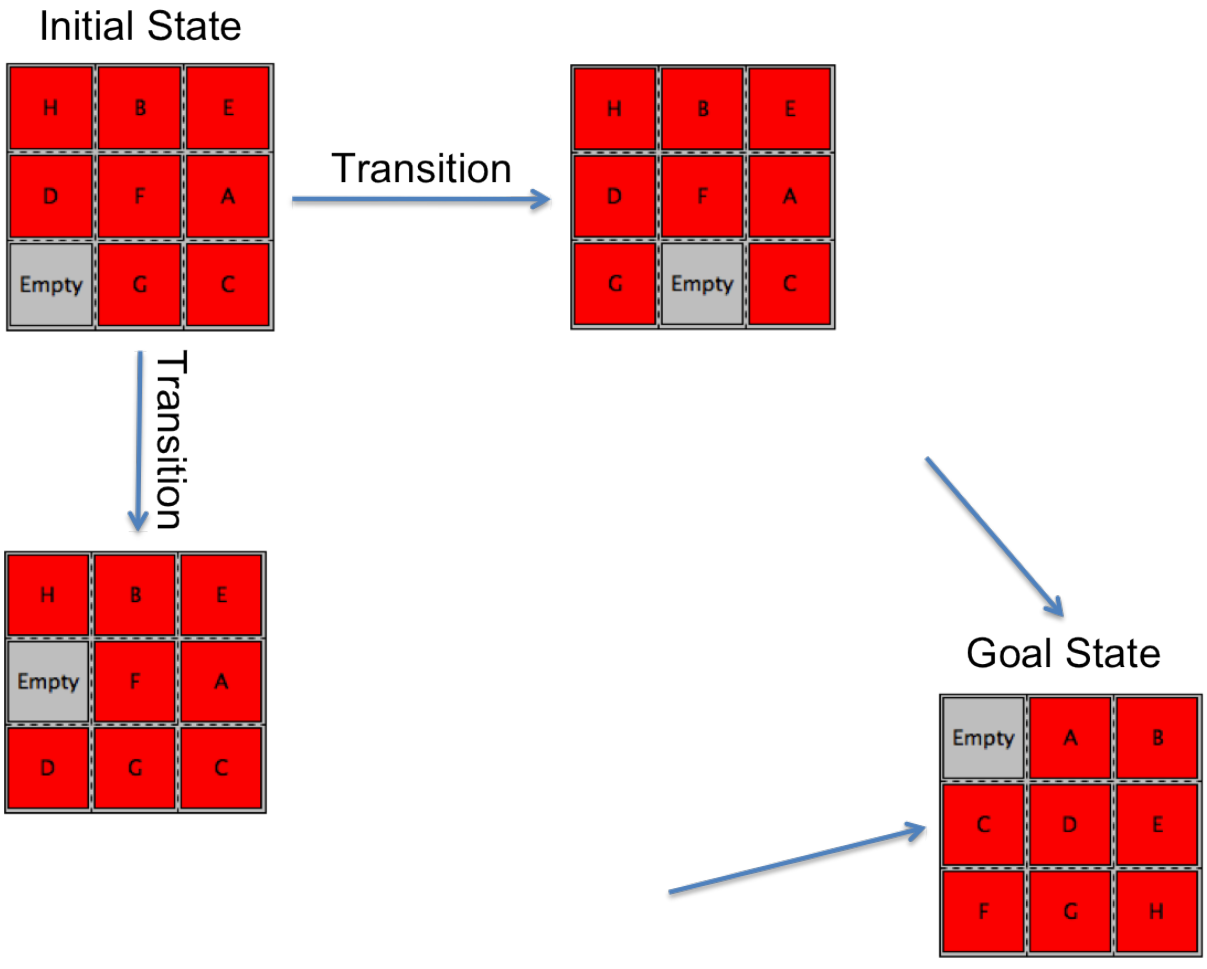
- representing (model) the world as atomic **states**,
- defining an **initial state** that represents the initial condition of the world,
- defining a **goal state** that represents what they want the world to look like,
- and defining a function for allowable **state transitions** which map onto actions in the world.

Problem Solving Agent

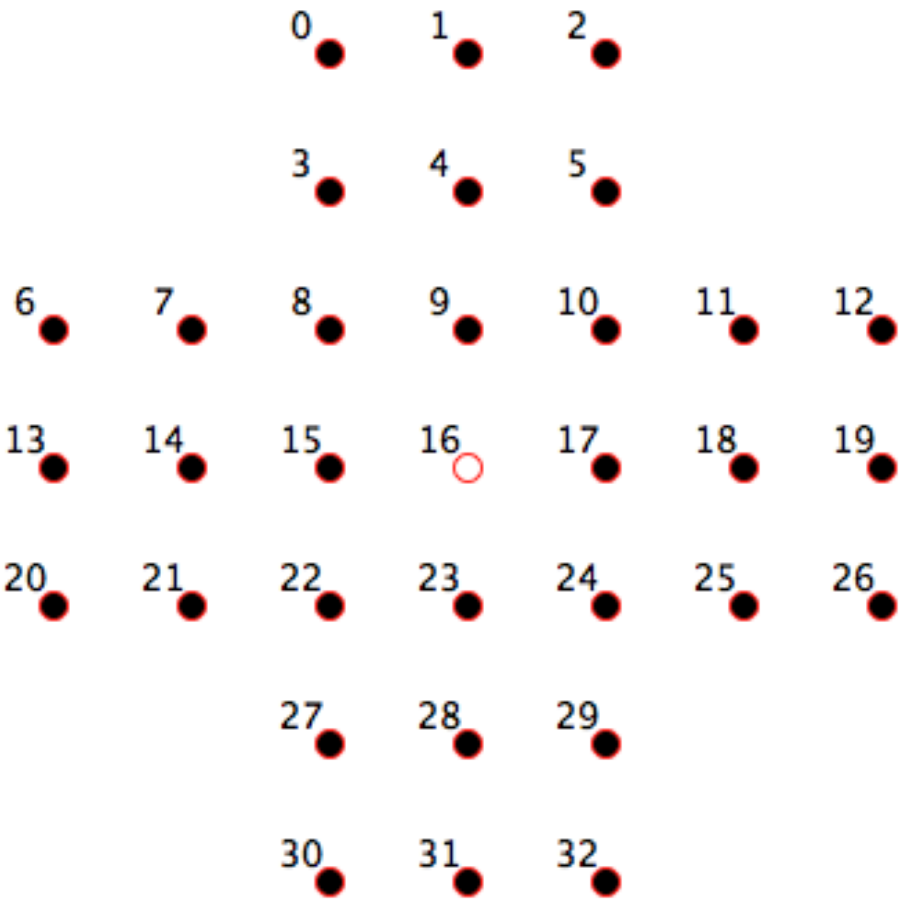
function SIMPLE-PROBLEM-SOLVING-AGENT(*percept*) **returns** an action
  persistent: *seq*, an action sequence, initially empty
    state, some description of the current world state
    goal, a goal, initially null
    problem, a problem formulation

  state ← UPDATE-STATE(*state*, *percept*)
  if *seq* is empty **then**
    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: Sliding Tile Puzzle



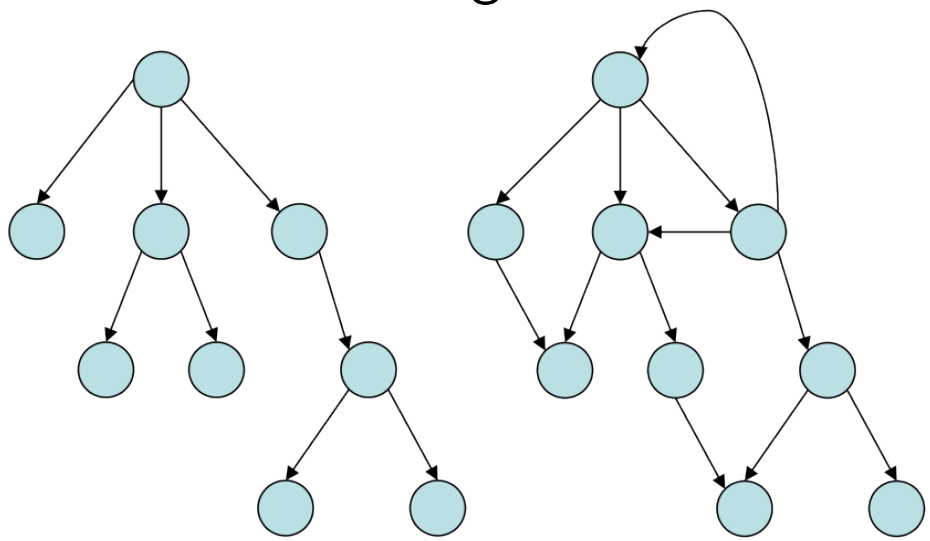
Another Example: Peg Solitaire



State space terminology

The state space is the collection of the following:

- initial state
- actions
- transition model
- successors



The problem solving agent searches through this space to find a path from the initial to the goal state.

Tree Search Algorithm

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

Generalized Graph Search

function GRAPH-SEARCH(*problem*) **returns** a solution, or failure
  initialize the frontier using the initial state of *problem*
  initialize the explored set to be empty
  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
    add the node to the explored set
    expand the chosen node, adding the resulting nodes to the frontier
      only if not in the frontier or explored set

Data structures supporting search

We need a few data structures to implement the graph search algorithms.

- Node structure
  - the state description
  - a parent pointer or reference
  - the action applied to get from parent to this node
  - path cost, the cost of the path from the initial to this node
- Function to return successor given state and action
- frontier queue (LIFO, FIFO, priority)
- explored set (dictionary or hash table)

How to compare specific search algorithms

We evaluate and compare algorithms based on the following criteria

- Completeness - does it find a solution if one exists?
- Optimality - does the solution have the lowest possible path cost?
- Time Complexity - how long does it take to find the solution?
- Space Complexity - how much memory is needed during the search?

The complexity of the graph is summarized by the:

- branching factor, b
- depth of the closest goal, d
- maximum depth, m

Specific Graph Search Algorithms

Uninformed search strategies

- breadth-first
- uniform-cost
- depth-first
- depth-limited
- iterative deepening
- bidirectional

```
function BREADTH-FIRST-SEARCH(problem) returns a solution, or failure

  node ← a node with STATE = problem.INITIAL-STATE, PATH-COST = 0
  if problem.GOAL-TEST(node.STATE) then return SOLUTION(node)
  frontier ← a FIFO queue with node as the only element
  explored ← an empty set
  loop do
      if EMPTY?(frontier) then return failure
      node ← POP(frontier)   /* chooses the shallowest node in frontier */
      add node.STATE to explored
      for each action in problem.ACTIONS(node.STATE) do
          child ← CHILD-NODE(problem, node, action)
          if child.STATE is not in explored or frontier then
              if problem.GOAL-TEST(child.STATE) then return SOLUTION(child)
              frontier ← INSERT(child, frontier)
```

```
function UNIFORM-COST-SEARCH(problem) returns a solution, or failure

  node ← a node with STATE = problem.INITIAL-STATE, PATH-COST = 0
  frontier ← a priority queue ordered by PATH-COST, with node as the only element
  explored ← an empty set
  loop do
      if EMPTY?(frontier) then return failure
      node ← POP(frontier)   /* chooses the lowest-cost node in frontier */
      if problem.GOAL-TEST(node.STATE) then return SOLUTION(node)
      add node.STATE to explored
      for each action in problem.ACTIONS(node.STATE) do
          child ← CHILD-NODE(problem, node, action)
          if child.STATE is not in explored or frontier then
              frontier ← INSERT(child, frontier)
          else if child.STATE is in frontier with higher PATH-COST then
              replace that frontier node with child
```

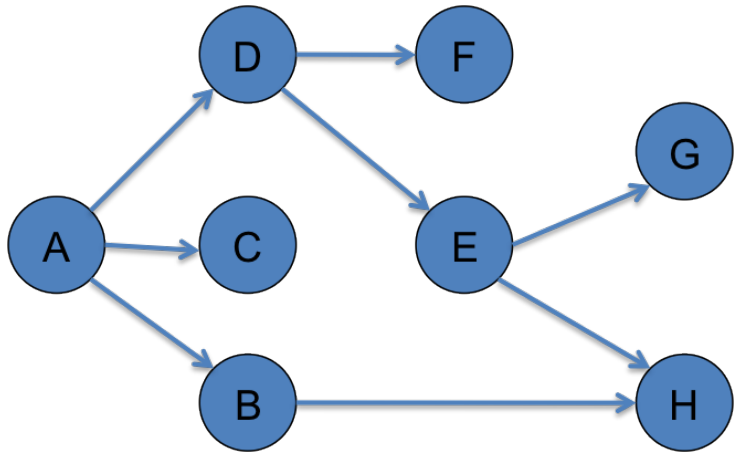
```
function DEPTH-LIMITED-SEARCH(problem, limit) returns a solution, or failure/cutoff
  return RECURSIVE-DLS(MAKE-NODE(problem.INITIAL-STATE), problem, limit)

function RECURSIVE-DLS(node, problem, limit) returns a solution, or failure/cutoff
  if problem.GOAL-TEST(node.STATE) then return SOLUTION(node)
  else if limit = 0 then return cutoff
  else
      cutoff_occurred? ← false
      for each action in problem.ACTIONS(node.STATE) do
          child ← CHILD-NODE(problem, node, action)
          result ← RECURSIVE-DLS(child, problem, limit − 1)
          if result = cutoff then cutoff_occurred? ← true
          else if result ≠ failure then return result
      if cutoff_occurred? then return cutoff else return failure
```

```
function ITERATIVE-DEEPENING-SEARCH(problem) returns a solution, or failure
    for depth = 0 to ∞ do
        result ← DEPTH-LIMITED-SEARCH(problem, depth)
        if result ≠ cutoff then return result
```

Warmup

Consider the following graph with initial nodes A and goal node H. All edges have unit weight.



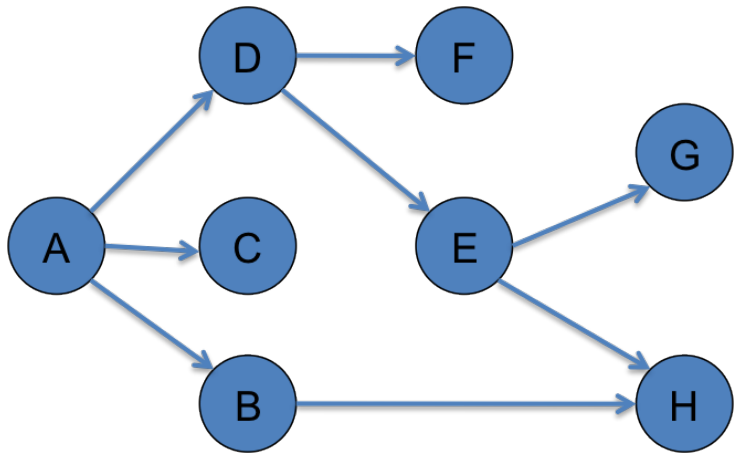
In what order are nodes expanded using:

1. breadth-first search
2. uniform cost search
3. depth-first search
4. depth-limited search with a max depth of 2
5. iterative-deepening search

Assume nodes are considered and ties resolved using alphabetical order if needed.

Another example

Consider the same graph as the warmup, but consider the goal node to be G. All edges have unit weight except the one between D and E, which has a weight of 2.



In what order are nodes expanded using:

1. breadth-first search
2. uniform cost search
3. depth-first search
4. depth-limited search with a max depth of 2
5. iterative-deepening search

Next Actions

- Reading: Heuristic Search - AIAMA 3.5 and 3.6
- Take warmup before noon on Thursday 1/29.

Note:

- PS1 has been released. Due 8am 2/16 via Scholar.
- The project proposal is due on or before 5pm on 2/10. See webpage for details.