CSE 3401: Intro to Artificial Intelligence
Search I

- Required Readings: R & N Chapter 3, Sec. 1-4.
- Lecture slides adapted from those of Fahiem Bacchus.

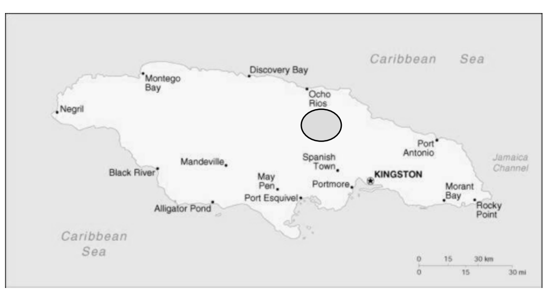
Why Search

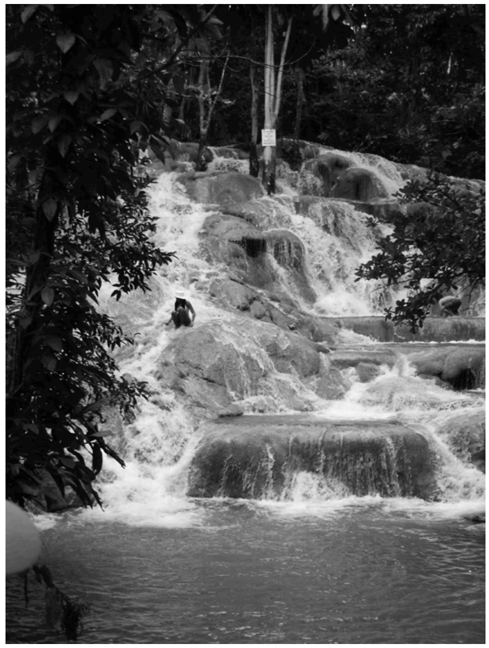
- Successful
  - Success in game playing programs based on search.
  - Many other AI problems can be successfully solved by search.
- Practical
  - Many problems don't have a simple algorithmic solution. Casting these problems as search problems is often the easiest way of solving them. Search can also be useful in approximation (e.g., local search in optimization problems).
  - Often specialized algorithms cannot be easily modified to take advantage of extra knowledge. Heuristics in search provide a natural way of utilizing extra knowledge.
- Some critical aspects of intelligent behaviour, e.g., planning, can be naturally cast as search.

Example, a holiday in Jamaica

Things to consider

- Prefer to avoid hurricane season.
- Rules of the road, larger vehicle has right of way (especially trucks).
- Want to climb up to the top of Dunns river falls.

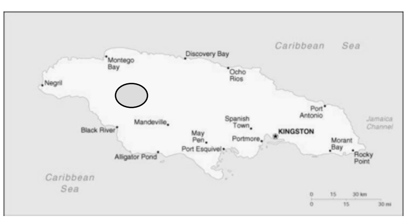




But you want to start your climb at 8:00 am before the crowds arrive!

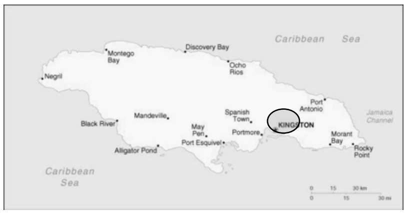
- Want to swim in the Blue Lagoon

- Want to hike the Cockpit Country



- No roads, need local guide and supplies.

- Easier goal, climb to the top of Blue Mountain



- Near Kingston.
- Organized hikes available.
- Need to arrive on the peak at dawn, before the fog sets in.
- Can get some Blue Mountain coffee!

How do we plan our holiday?

- We must take into account various preferences and constraints to develop a schedule.
- An important technique in developing such a schedule is “hypothetical” reasoning.
  - e.g., if I fly into Kingston and drive a car to Port Antonio, I’ll have to drive on the roads at night. How desirable is this?
  - If I’m in Port Antonio and leave at 6:30am, I can arrive a Dunns river falls by 8:00am.

How do we plan our holiday?

- This kind of hypothetical reasoning involves asking
  - "what state will I be in after the following sequence of events?"
- From this we can reason about what sequence of events one should try to bring about to achieve a desirable state.
- Search is a computational method for capturing a particular version of this kind of reasoning.

Search

- There are many difficult questions that are not resolved by search. In particular, the whole question of how does an intelligent system formulate its problem as a search problem is not addressed by search.
- Search only shows how to solve the problem once we have it correctly formulated.

The formalism.

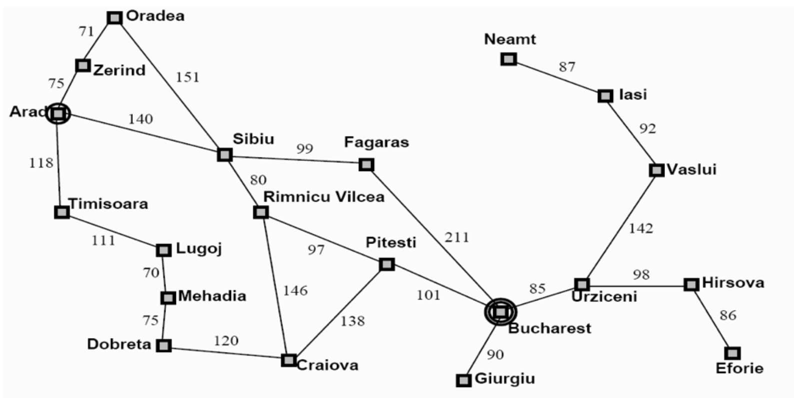
- To formulate a problem as a search problem we need the following components:
  - Formulate a state space over which to search. The state space necessarily involves abstracting the real problem.
  - Formulate actions that allow one to move between different states. The actions are abstractions of actions you could actually perform.
  - Identify the initial state that best represents your current state and the desired condition one wants to achieve.
  - Formulate various heuristics to help guide the search process.

The formalism.

- Once the problem has been formulated as a state space search, various algorithms can be utilized to solve the problem.
  - A solution to the problem will be a sequence of actions/moves that can transform your current state into state where your desired condition holds.

Example 1: Romania Travel.

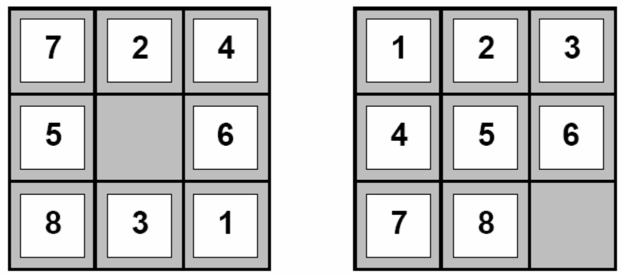
Currently in Arad, need to get to Bucharest by tomorrow to catch a flight.



Example 1.

- State space.
  - States: the various cities you could be located in.
    - Note we are ignoring the low level details of driving, states where you are on the road between cities, etc.
  - Actions: drive between neighboring cities.
  - Initial state: in Arad
  - Desired condition (Goal): be in a state where you are in Bucharest. (How many states satisfy this condition?)
- Solution will be the route, the sequence of cities to travel through to get to Bucharest.

Example 2. The 8-Puzzle



Start State   Goal State

- Can slide a tile into the blank spot. (Equivalently, can think of it as moving the blank around).

Example 2. The 8-Puzzle

- State space.
  - States: The different configurations of the tiles. How many different states?
  - Actions: Moving the blank up, down, left, right. Can every action be performed in every state?
  - Initial state: as shown on previous slide.
  - Desired condition (Goal): be in a state where the tiles are all in the positions shown on the previous slide.
- Solution will be a sequence of moves of the blank that transform the initial state to a goal state.

Example 2. The 8-Puzzle

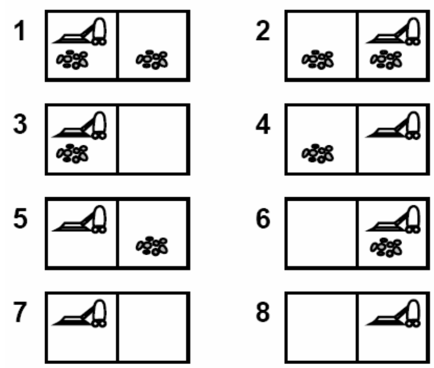
- Although there are 9! different configurations of the tiles (362,880), in fact the state space is divided into two disjoint parts.
- Only when the blank is in the middle are all four actions possible.
- Our goal condition is satisfied by only a single state. But one could easily have a goal condition like
  - The 8 is in the upper left hand corner.
    - How many different states satisfy this goal?

Example 3. Vacuum World.

- In the previous two examples, a state in the search space corresponded to a unique state of the world (modulo details we have abstracted away).
- However, states need not map directly to world configurations. Instead, a state could map to the agent's mental conception of how the world is configured: the agent's knowledge state.

Example 3. Vacuum World.

- We have a vacuum cleaner and two rooms.
- Each room may or may not be dirty.
- The vacuum cleaner can move left or right (the action has no effect if there is no room to the right/left).
- The vacuum cleaner can suck; this cleans the room (even if the room was already clean).

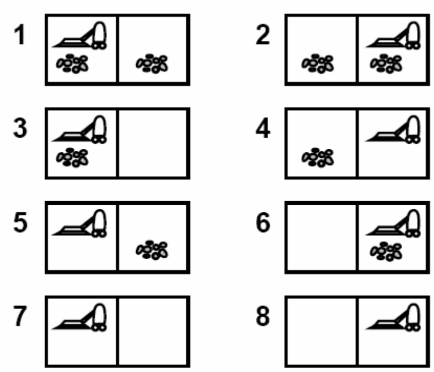


Physical states

Example 3. Vacuum World.

Knowledge level State Space

- The state space can consist of a set of states. The agent knows that it is in one of these states, but doesn't know which.

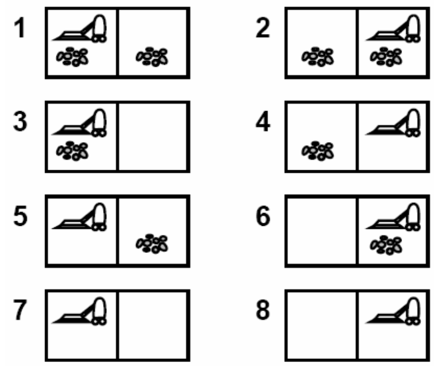


Goal is to have all rooms clean.

Example 3. Vacuum World.

Knowledge level State Space

- Complete knowledge of the world: agent knows exactly which state it is in. State space states consist of single physical states:
- Start in {5}:
  <right, suck>

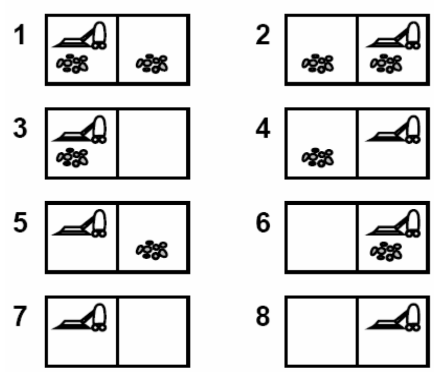


Goal is to have all rooms clean.

Example 3. Vacuum World.

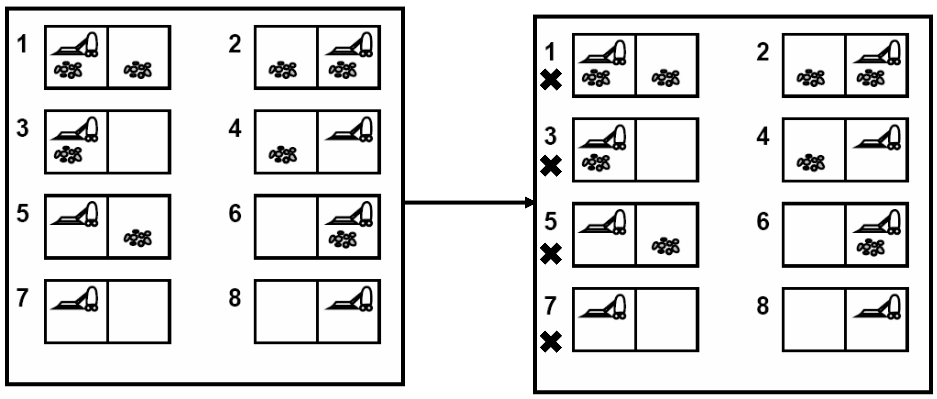
Knowledge level State Space

- No knowledge of the world. States consist of sets of physical states.
- Start in {1,2,3,4,5,6,7,8}, agent doesn't have any knowledge of where it is.
- Nevertheless, the actions <right, suck, left, suck> achieves the goal.



Goal is to have all rooms clean.

Example 3. Vacuum World.

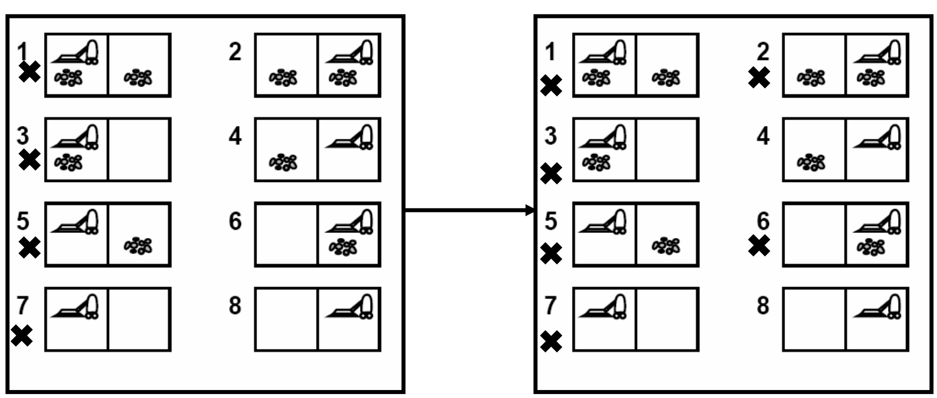


Initial state.

{1,2,3,4,5,6,7,8}

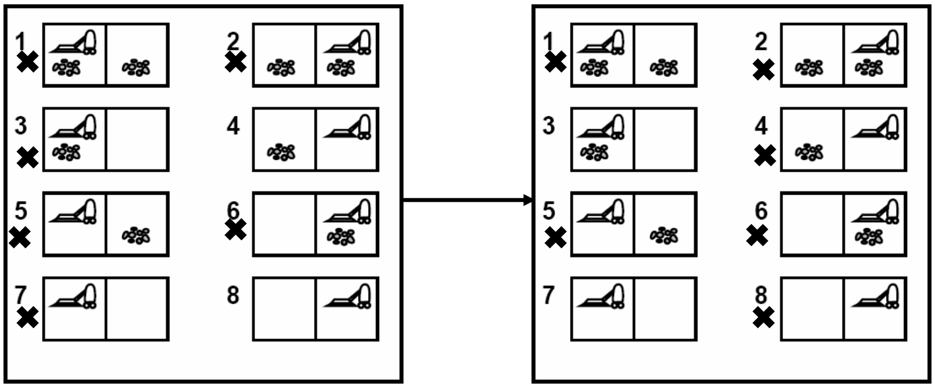
Right

Example 3. Vacuum World.



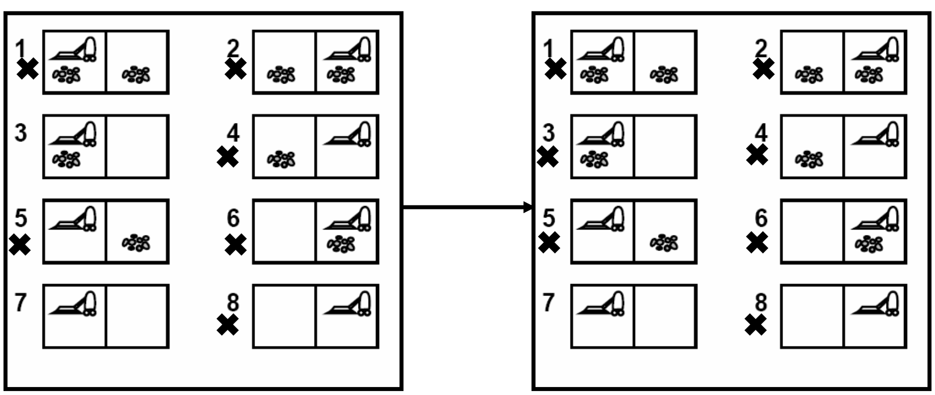
Suck

Example 3. Vacuum World.



Left

Example 3. Vacuum World.



Suck

More complex situations.

- The agent might be able to perform some sensing actions. These actions change the agent's mental state, not the world configuration.
- With sensing can search for a contingent solution: a solution that is contingent on the outcome of the sensing actions
  - <right, **if** dirt **then** suck>
- Now the issue of interleaving execution and search comes into play.

More complex situations.

- Instead of complete lack of knowledge, the agent might think that some states of the world are more likely than others.
- This leads to probabilistic models of the search space and different algorithms for solving the problem.
- Later we will see some techniques for reasoning and making decisions under uncertainty.

Algorithms for Search.

- Inputs:
  - a specified initial state (a specific world state or a set of world states representing the agent's knowledge, etc.)
  - a successor function S(x) = {set of states that can be reached from state x via a single action}.
  - a goal test a function that can be applied to a state and returns true if the state is satisfies the goal condition.
  - A step cost function C(x,a,y) which determines the cost of moving from state x to state y using action a. (C(x,a,y) = ∞ if a does not yield y from x)

Algorithms for Search.

- Output:
  - a sequence of states leading from the initial state to a state satisfying the goal test.
  - The sequence might be
    - annotated by the name of the action used.
    - optimal in cost for some algorithms.

Algorithms for Search

- Obtaining the action sequence.
  - The set of successors of a state x might arise from different actions, e.g.,
    - x → a → y
    - x → b → z
    - Successor function S(x) yields a set of states that can be reached from x via a (any) single action.
      - Rather than just return a set of states, we might annotate these states by the action used to obtain them:
        - S(x) = {<y,a>, <z,b>}
          y via action a, z via action b.
        - S(x) = {<y,a>, <y,b>}
          y via action a, also y via alternative action b.

Tree search

- Assuming search space is a tree, not a graph.
- We use the successor state function to simulate an exploration of the state space.
- Initial call has Frontier = initial state.
  - Frontier/fringe is the set of states we haven't yet explored/expanded.

```
TreeSearch(Frontier, Successors, Goal? )
   If Frontier is empty return failure
   Curr = select state from Frontier
   If(Goal?(Curr)) return Curr.
   Frontier' = (Frontier – {Curr}) U Successors(Curr)
   return TreeSearch(Frontier', Successors, Goal?)
```

Tree search in Prolog

```
treeS([[State|Path]|_],Soln) :-
  Goal?(State), reverse([State|Path], Soln).

treeS([[State|Path]|Frontier],Soln) :-
  GenSuccessors(State,Path,NewPaths),
  merge(NewPaths,Frontier,NewFrontier),
  treeS(NewFrontier,Soln).
```