# Solving Problems by Searching

CS 480
Intro to Artificial Intelligence

# Simplifying the problem

Our first intelligent agent will be restricted to work on environments that are

- **Known**
- **Fully observable**
- **Single-agent**
- **Deterministic**
- **Episodic***
- **Static**
- **Discrete**

Extensions that relax these assumptions

- **Unknown** (Learning agents)
- **Partially observable** (POMDPs)*
- **Multi-agent** (min-max search)
- **Stochastic** (probabilistic reasoning)
- **Sequential** (Hierarchical Planning)*
- **Dynamic** (Replanning)
- **Continuous** (RRTs and Controls)*

# Search-based agent

```
def __init__(self,init_state):
    self.state = init_state
    self.problem = None
    self.plan = list()
    self.goal = None
def search_based_agent(self,percept):
    self.state = self.update_state(percept)
    if len(self.plan)<=0:
        self.goal = self.make_goal(self.state)
        self.problem = self.make_problem(self.state,self.goal)
        self.plan = self.search(self.problem)
    action = self.plan.pop(0)
    return action
```

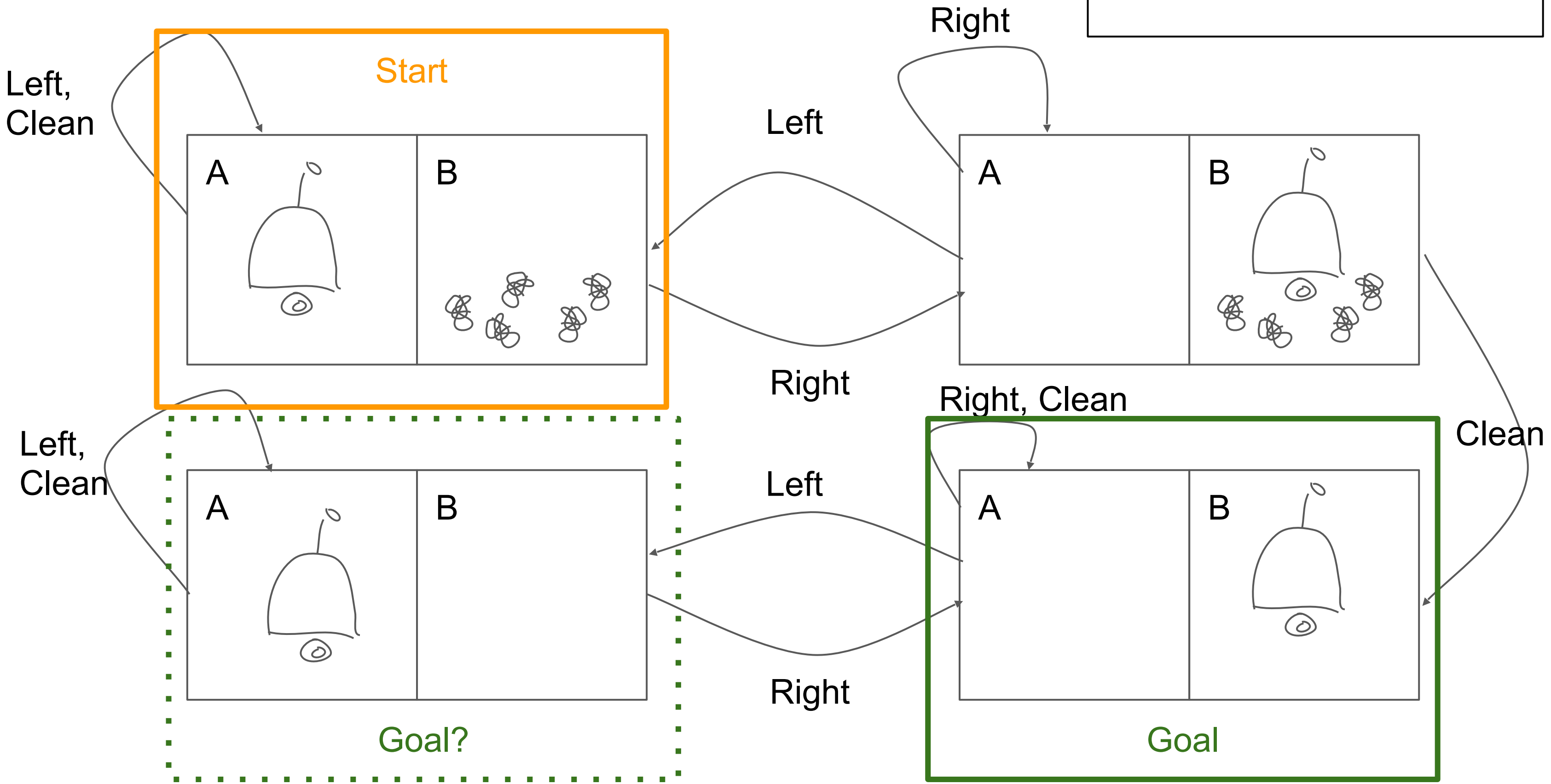
This agent is **offline**: it decides on a full plan of action before taking a single step

# Components of a Search-based agent

- **`update_state(percept)`** - Construct a state representation from a given percept.
  `{'loc':'A', status:'clean'}→`
  `{'robot-loc':'A', 'A-clean':True, 'B-clean':self.state['B-clean']}`
- **`make_goal(state)`** - Define success (goal state? goal test?)
  **`make_problem(state,goal)`** - set up actions, construct state space (explicit? successor function?), initialize book-keeping
- **`search(problem)`** - returns a sequence of actions that take the agent from the start state to the/a goal state

# Example problem: Vacuum World

Solution:
`['Right', 'Clean']`



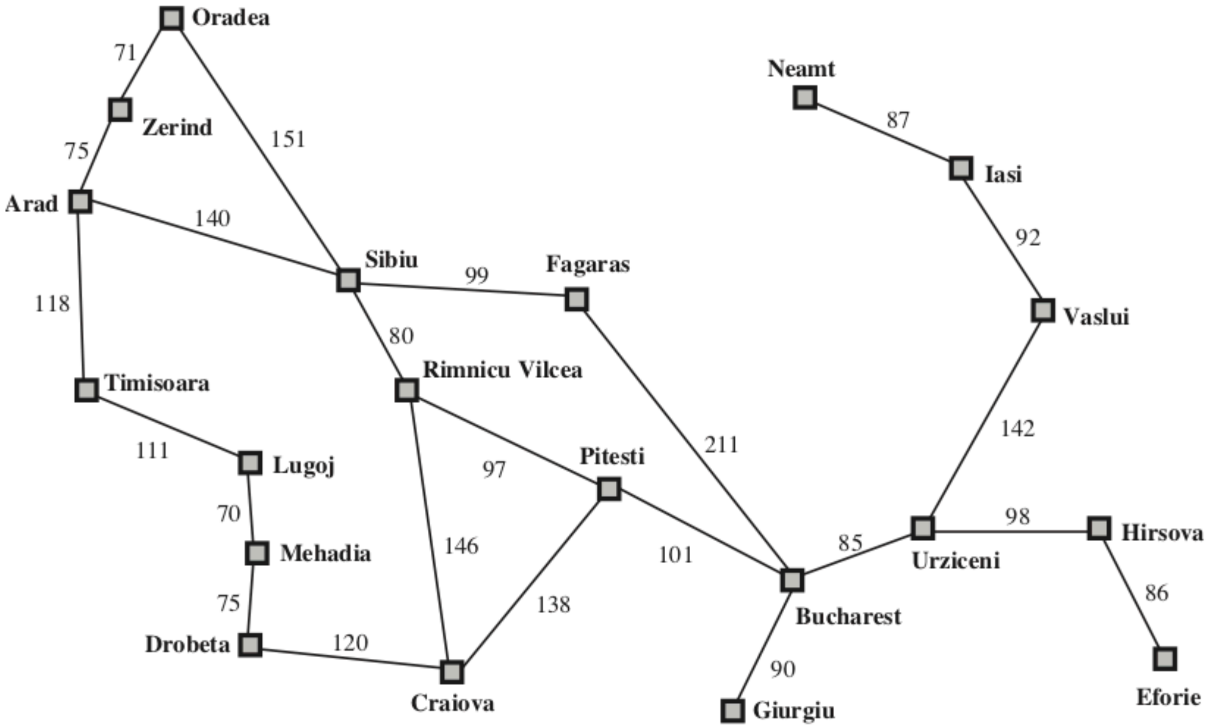
# Components of a problem

For non-trivial problems, we need a way to **generate** the state space without explicitly representing every node/edge

- **Start state**: The initial state, where the agent starts
- **Successor function**: `S(state)` returns a set of (`action`, `successor_state`) pairs
- **Goal test function**: `Goal(state)` returns true if the state is a goal
- **Step cost**: `c(s1, a, s2)` returns the cost of moving from `s1` to `s2` using action `a`

# Components of a problem example: Romania

- **Start state**:
  'Arad'
- **Successor function**:
  `S(state)`: Neighboring cities of state
- **Goal test function**:
  `Goal(state)`:
  `state=='Bucharest'`
- **Step cost**:
  `c(s1, a, s2)`: distance (km) from `s1` to `s2` via highway `a`



# Components of a problem example: sudoku

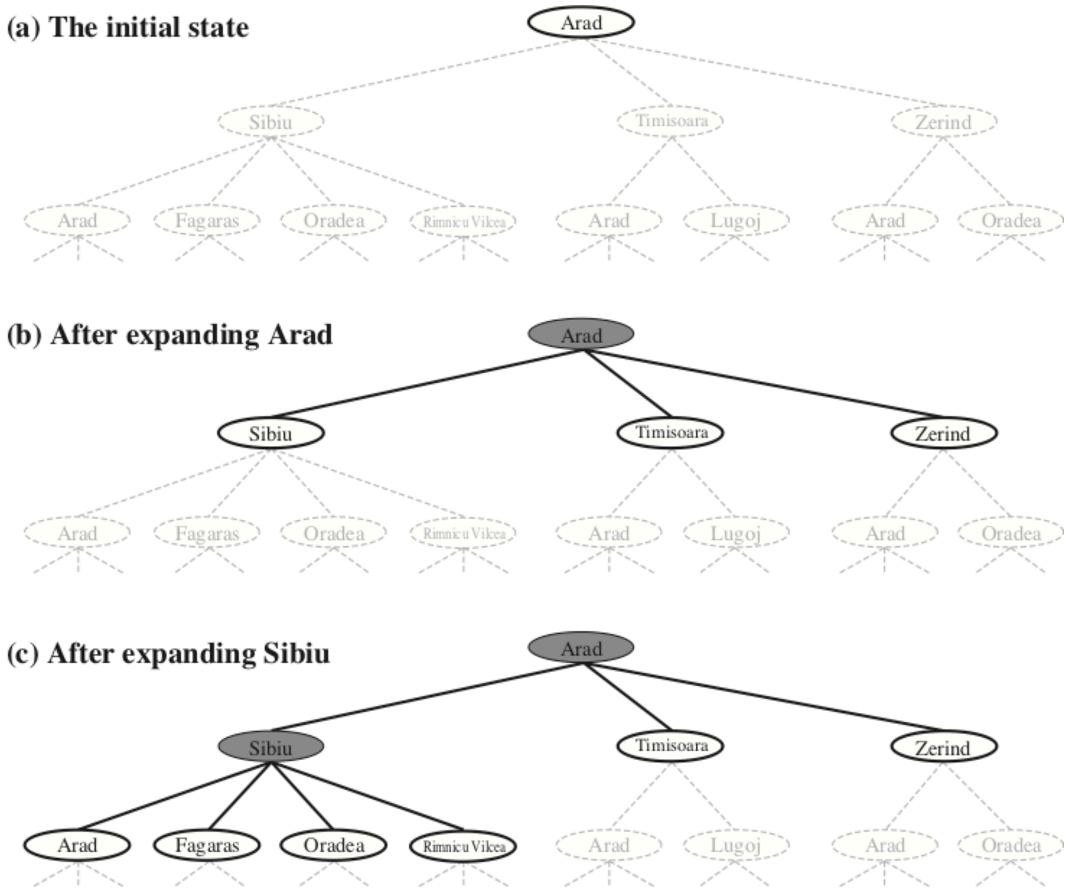
- **Start state**:
  Partially filled board
- **Successor function**:
  `S(state)`: states generated by filling in one blank space with a non-conflicting number 1-9
- **Goal test function**:
  `Goal(state)`: Is the entire board filled with non-conflicting numbers?
- **Step cost**:
  `c(s1, a, s2)`: 1

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 1 | | 5 | |
| 7 | 2 | | 3 | 5 | | | 9 | 1 |
| | | | 8 | | 7 | | | |
| | | 8 | | | 5 | | | 4 |
| | 4 | 1 | | 3 | | 6 | 8 | |
| 5 | | | 4 | | | 7 | | |
| | | | 6 | | 3 | | | |
| 4 | 8 | | | 7 | 9 | | 1 | 6 |
| | 9 | | 1 | | | | | |

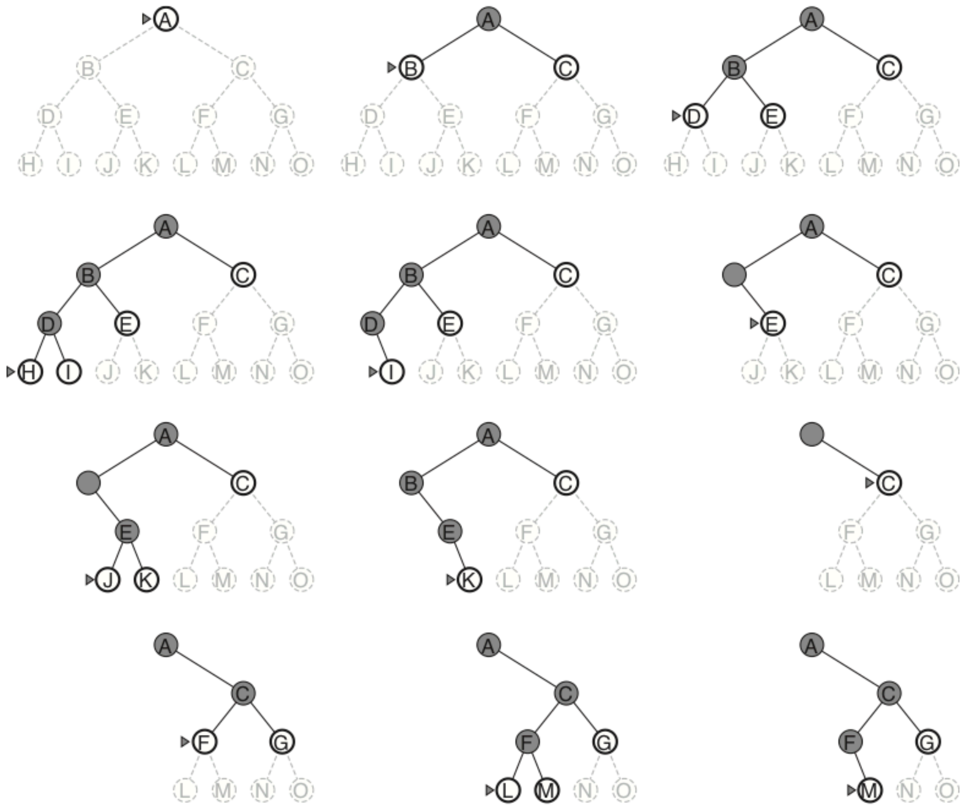
# Representing search space - tree version

- For some problems, the number of states is too large (infinite?) to construct an explicit graph
- We can build the pieces of the state space we need to search 'as we go'
- The **search tree** is rooted at the initial state, leaves are expanded into their successors, may contain duplicate states (but not **nodes**!)
- Implementation note: children have 'back-pointers' to parents

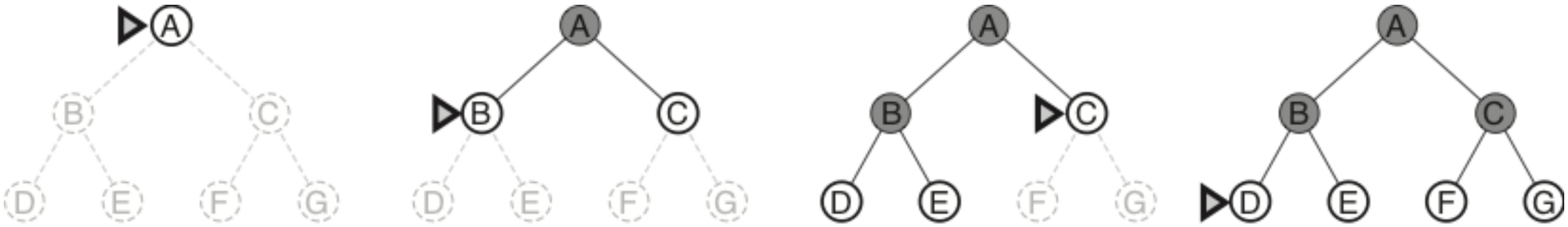
**We know how to traverse trees!**



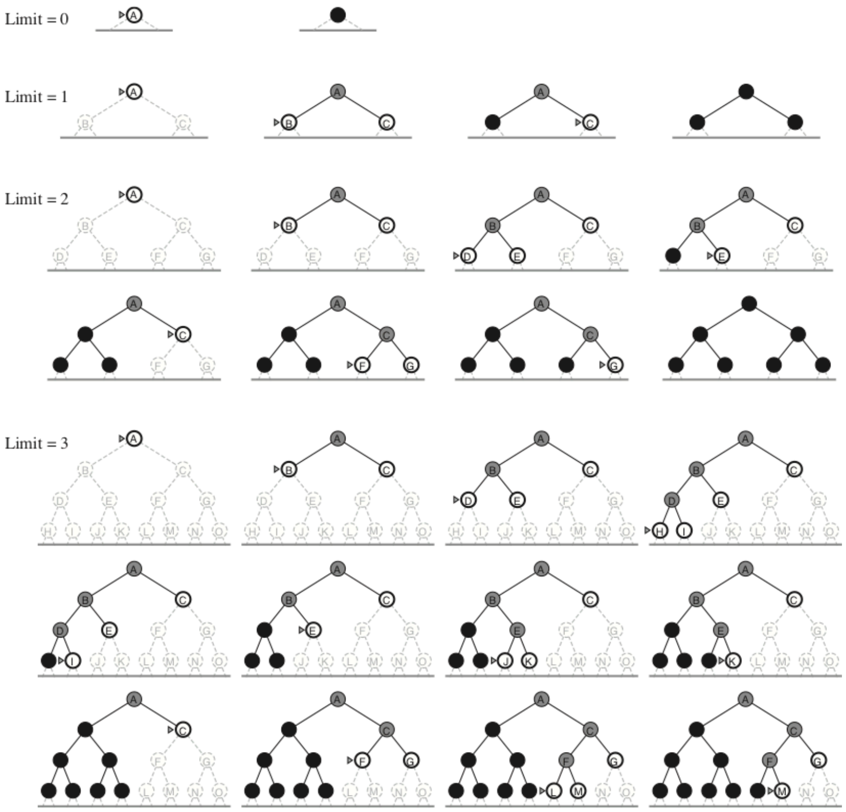
# Depth First Search



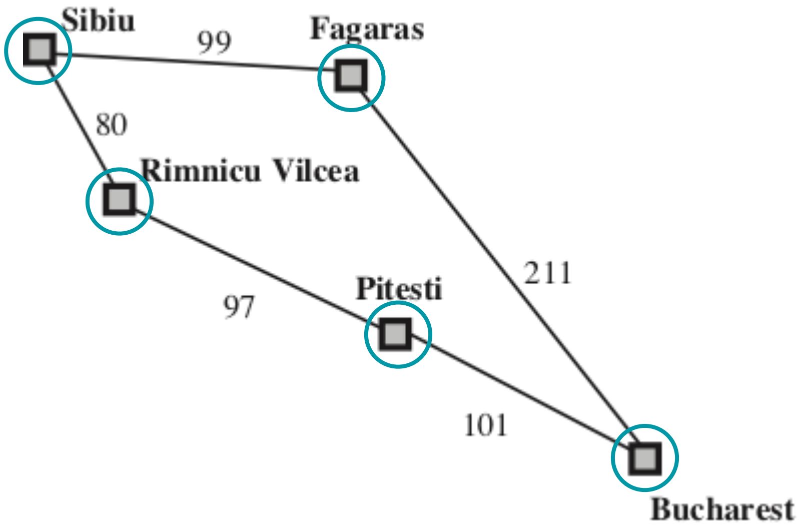
# Breadth First Search

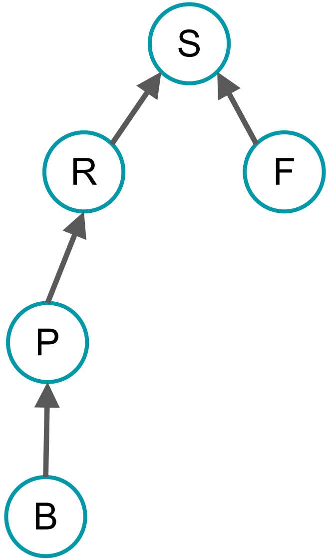


# Iterative Deepening Search



# Uniform Cost Search (Dijkstra's)



# Comparing search algorithms

| | BFS | UCS | DFS | IDS |
|---|---|---|---|---|
| Time | $O(b^d)$ | $O(b^{1+C^*/\epsilon})$ | $O(b^m)$ | $O(b^d)$ |
| Space | $O(b^d)$ | $O(b^{1+C^*/\epsilon})$ | $O(b^*m)$ | $O(b^*d)$ |

**b**: branching factor, **d**: depth of shallowest solution
**m**: maximum depth of the tree, $\epsilon$: smallest step cost, **C***: cost of optimal solution

**Complete**: BFS & IDS (if $b<\infty$), DFS(if $m<\infty$), UCS (if $\epsilon>0$, and $b<\infty$)

**Optimal**: BFS & IDS (if all steps cost $\epsilon$), UCS

# Preview: Generic Search Algorithm

DFS, BFS, and UCS can be implemented with **a single algorithm**! Choice of data structure for the “next child to expand” determines which one.

- BFS: queue (children are expanded in the order they are added)
- DFS: stack (children are expanded in last-in-first-out order)
- UCS: priority queue (children are expanded based on cost-from-start)

IDS requires a small tweak: a depth limit parameter

# Summary and preview

Wrapping up

- Search based agents work offline to find a sequence of actions that gets them from the initial state to a goal state
- A **search problem** can be represented explicitly as a graph, or implicitly by a start state, a successor function, a goal test function, and a cost function
- With this formulation, we can use any number of well known search algorithms to solve search problems

Preview

- Generic Search Algorithm, Worked Examples