CPS 170
Search I

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What is Search?

- Search is a basic problem-solving method
- We start in an initial state
- We examine states that are (usually) connected by a sequence of actions to the initial state
- We aim to find a solution, which is a sequence of actions that brings us from the initial state to the goal state, minimizing cost

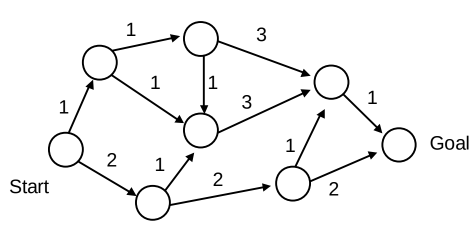
Overview

- Problem Formulation
- Uninformed Search
  - DFS, BFS, IDDS, etc.
- Informed Search
  - Greedy, A*
- Properties of Heuristics

Problem Formulation

- Four components of a search problem
  - Initial State
  - Actions
  - Goal Test
  - Path Cost
- Optimal solution = lowest path cost to goal

Example: Path Planning



Find shortest route from one city to another using highways.

Example 8(15)-puzzle

Possible Start State

8	3	4
1		7
2	6	5

Solution →

Goal State

	1	2
3	4	5
6	7	8

Actions: UP, DOWN, RIGHT, LEFT

“Real” Problems

- Robot motion planning
- Drug design
- Logistics
  - Route planning
  - Tour Planning
- Assembly sequencing
- Internet routing

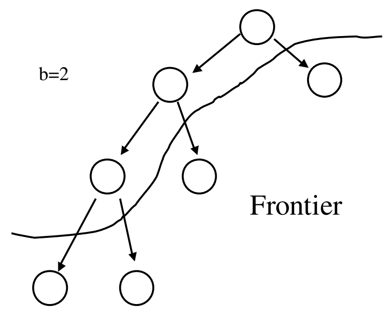
Why Use Search?

- Other algorithms exist for these problems:
  - Dijkstra’s Algorithm
  - Dynamic programming
  - All-pairs shortest path

Basic Search Concepts

- Assume a tree-structured space (for now)
- Nodes: Places in search tree
  (states exist in the problem space)
- Search tree: portion of state space visited so far
- Expansion: Generation of successors for a state
- Frontier: Set of states visited, but not expanded
- Branching factor: Max no. of successors = b
- Goal depth: Depth of shallowest goal = d

Example Search Tree



Generic Search Algorithm

```
Function Tree-Search(problem, Queuing-Fn)

        fringe = Make-Queue(Make-Node(Initial-State(problem)))
        loop do
                if empty(fringe) then return failure
                node = pop(fringe)
                if Goal-Test(problem, state) then return node
                fringe = Add-To-Queue(fringe, expand(node, problem))
        end
```

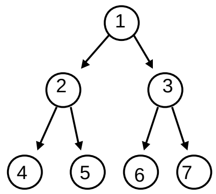
Interesting details are in the implementation of Add-To-Queue

Evaluating Search Algorithms

- Completeness:
  –
- Optimality:
  –
- Time complexity
- Space complexity

Uninformed Search: BFS

Frontier is a FIFO

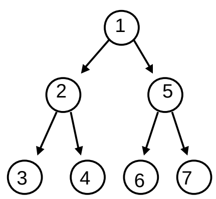


BFS Properties

- Completeness:
- Optimality:
- Time complexity:
- Space complexity:

Uninformed Search: DFS

Frontier is a LIFO



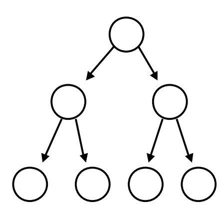
DFS Properties

- Completeness:
- Optimality:
- Time complexity:
- Space complexity:

Iterative Deepening

- Want:
  - – DFS memory requirements
  - – BFS optimality, completeness
- Idea:

IDDFS



IDDFS Properties

- Completeness:
- Optimality:
- Time complexity:
- Space complexity:

IDDFS vs. BFS

Theorem: IDDFS visits no more than twice as many nodes for a binary tree as BFS.

Proof: Assume the tree bottoms out at depth d, BFS visits:

$$2^d - 1$$

In the worst case, IDDFS does no more than:

What about b-ary trees? IDDFS relative cost is lower!

Bi-directional Search

Issues with Bi-directional Search

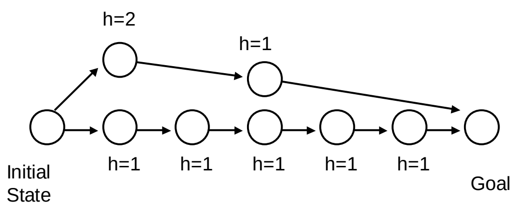
Informed Search

- Idea: Give the search algorithm hints
- Heuristic function: h(x)
- h(x) = estimate of cost to goal from x
- If h(x) is 100% accurate, then we can find the goal in O(bd) time

Greedy Search

- Expand node with lowest h(x)
- Optimal if h(x) is 100% correct
- How can we get into trouble with this?

What Price Greed?



What's broken with greedy search?

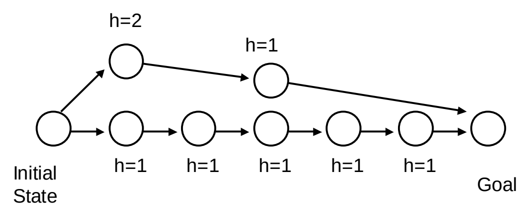
A*

- Path cost so far: g(x)
- Total cost estimate: f(x) = g(x) + h(x)
- Maintain frontier as a priority queue
- O(bd) time if h is 100% accurate
- We want h to be an *admissable* heuristic
- Admissable: never overestimates cost

A* Properties

Theorem: A* is optimal if h(x) is admissable.

Does A* fix the greedy problem?



Properties of Heuristics

- h2 dominates h1 if h2(x)>h1(x) for all x
- Does this mean that h2 is better?
- Suppose you have multiple admissable heuristics. How do you combine them?

Developing Heuristics

- Is it hard to develop admissable heuristics?
- What are some heuristics for the 8 puzzle?
- What is a general strategy for developing admissable heuristics?

Other Issues

- Graphs
  - What issues arise?
  - Monotonicity
- Non-uniform costs
- Accuracy of heuristic
- A* is optimally efficient