EECS 391: Introduction to AI

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Announcements

- HW due next Thursday

Today

- Goal-Directed Search (Chapter 3)

Environment Type

- We'll assume the environment is:
  - Fully observable (to track the state)
  - Static (shouldn't change while agent is searching)
  - Deterministic (agent needs to be able to precisely predict states resulting after each action)

- Some search algorithms also need discrete environments

Problem Setup

- Our agent is currently in some state of the world
  - Call this the *initial state*
- It wants to get to a different state of the world
  - Call this the *goal state*
  - In general, the desired target may be defined by a logical predicate (*goal test*) that encompasses a *set* of goal states
  - In this case the agent wants to get to *any* goal state satisfying the goal test

Problem Setup (2)

- To change the state of the world, the agent has actions
  - These will be called "search operators"
  - Also called "successor functions", same thing

- The search operators applied successively to the initial state generate a sequence of states
  - This is the "search space"

Problem Setup (3)

- Each search operator has an associated cost
- The search objective is to discover a sequence of operators that takes the agent from the initial state to any goal state with minimum cost

Checklist

- Initial state
- Goal Test
- Search Operator (agent "action"/successor fn)
- Operator/Step Cost
- Objective: Find a sequence of actions that get from initial state to goal with minimum cost

Basic Steps of Search Algorithms

- Add initial state to open list (list of unvisited states)
- While open list is not empty
  - Remove node from the open list
  - If this is the goal, solution found, return path
  - Else
    - Find the successors of this node (“expanding a state”)
    - Add the current state to the list of visited (expanded) states (closed list)
    - Add the new states to the open list (if they do not appear in the closed list)
      - State could already be in open list, set parent pointer correctly (based on minimum path cost)

Search algorithms differ in order of node removal

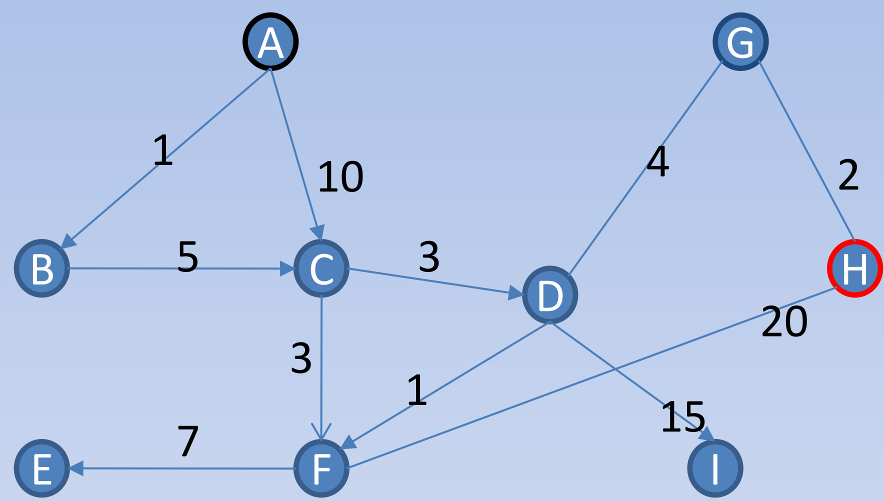
Blind Search 1: Breadth First Search

- Shallowest (lowest depth) nodes on open list are expanded first

- First expand successors of initial state, then their successors, etc

- Usually, the open list will be implemented via a queue

Example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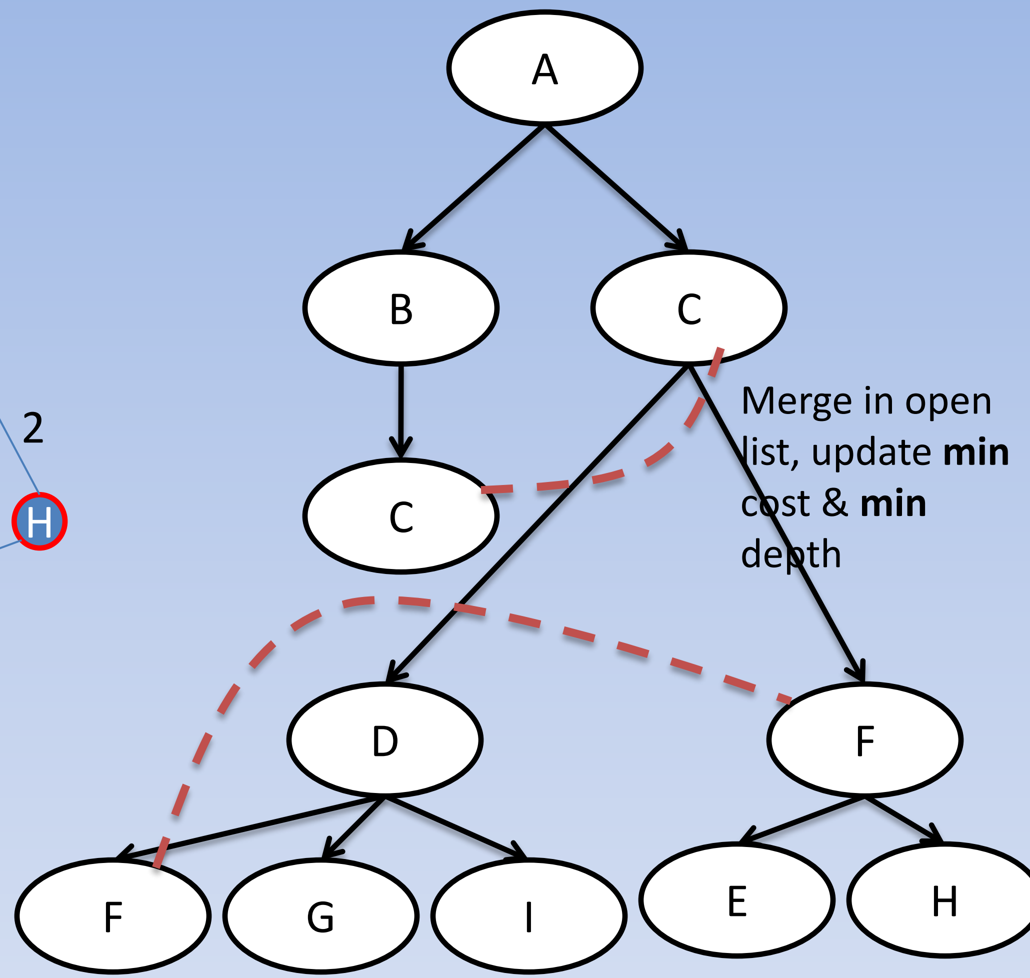
A
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C
Merge in open list, update **min** cost & **min** depth
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Uniform Cost Search

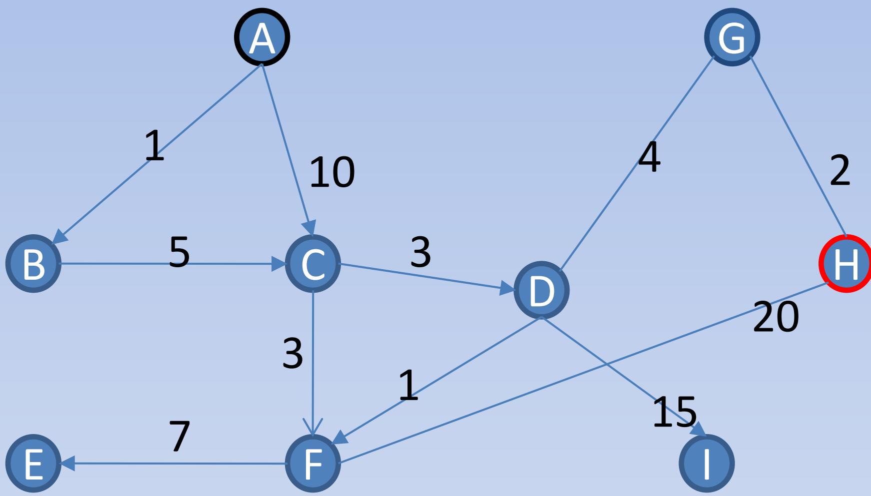
- Expand the node on the open list with the lowest path cost
  - otherwise same as BFS

- Can be implemented using a priority queue

Depth First Search

- Expands deepest nodes on open list first
- Can be implemented using a stack

Example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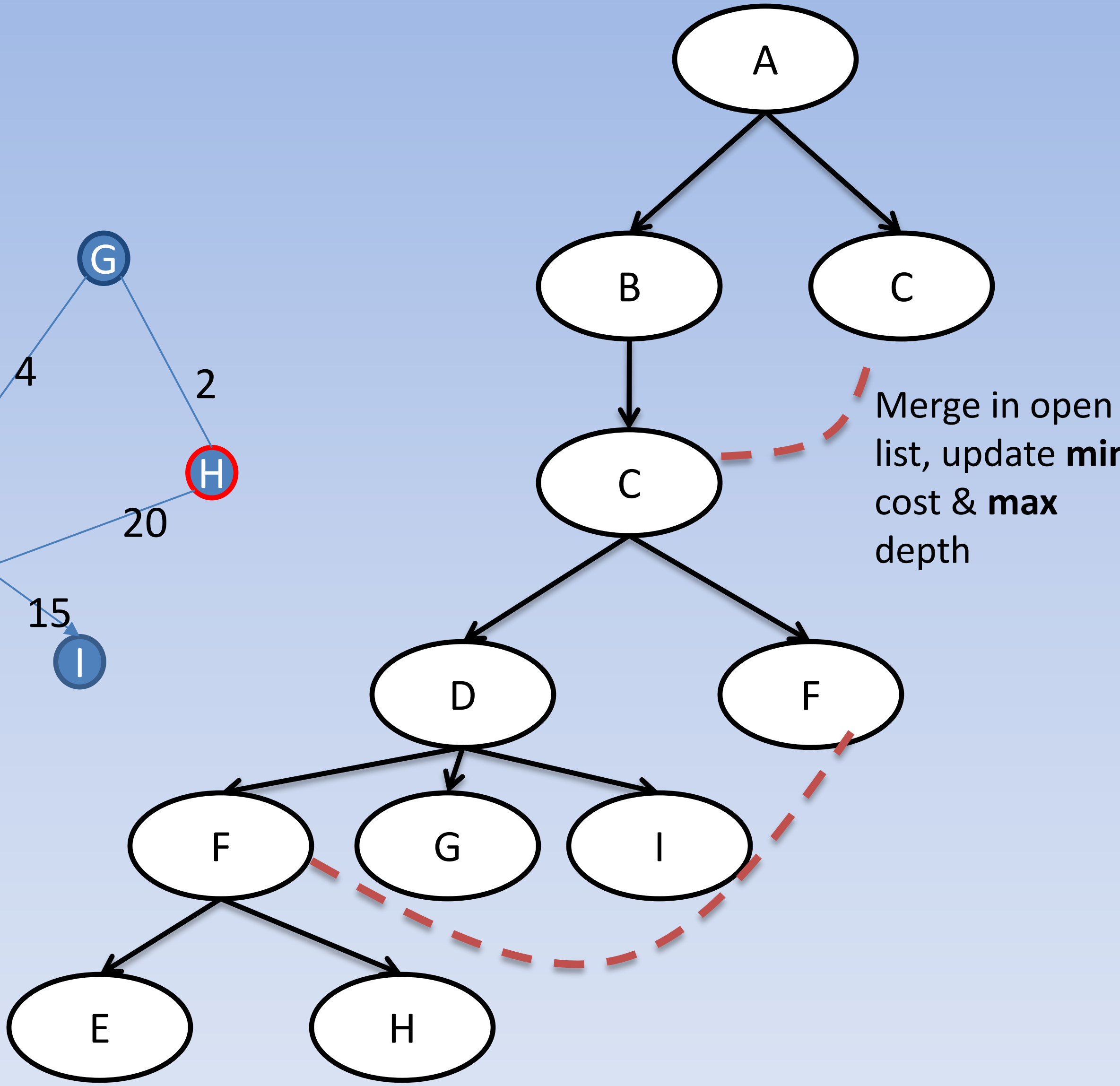
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C
Merge in open list, update **min** cost & **max** depth
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Iterative Deepening (ID-DFS)

- DFS may go down long, useless paths
  - We can parameterize it with a depth limit
  - If limit is reached, it will not expand further

- We can iteratively increase the depth parameter
  - Start with zero
  - If DFS with current depth fails, increment depth and restart

Bidirectional Search

- Why not search from both the initial state and the goal state?

- Idea: run simultaneous searches, checking for intersections between the open lists
  - If nonempty, path found
  - If using BFS at each end, and goal depth is d, time and space complexity will be reduced to $O(b^{d/2})$

But…

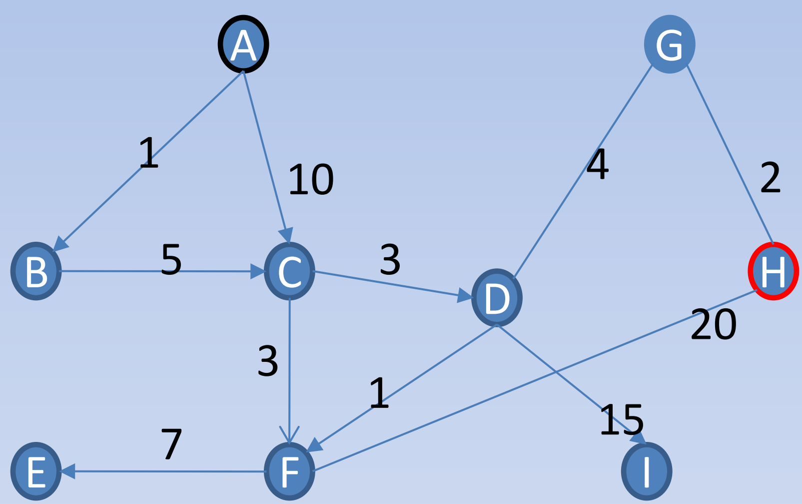
- What if the goal is defined in terms of a predicate?
  - Could have lots of satisfying states, or could be hard to satisfy (SAT problem)
- Also constrains the operators
  - Note when searching from goal, need to find "predecessors"---could be tricky!
    - "All states that led to this checkmate configuration"

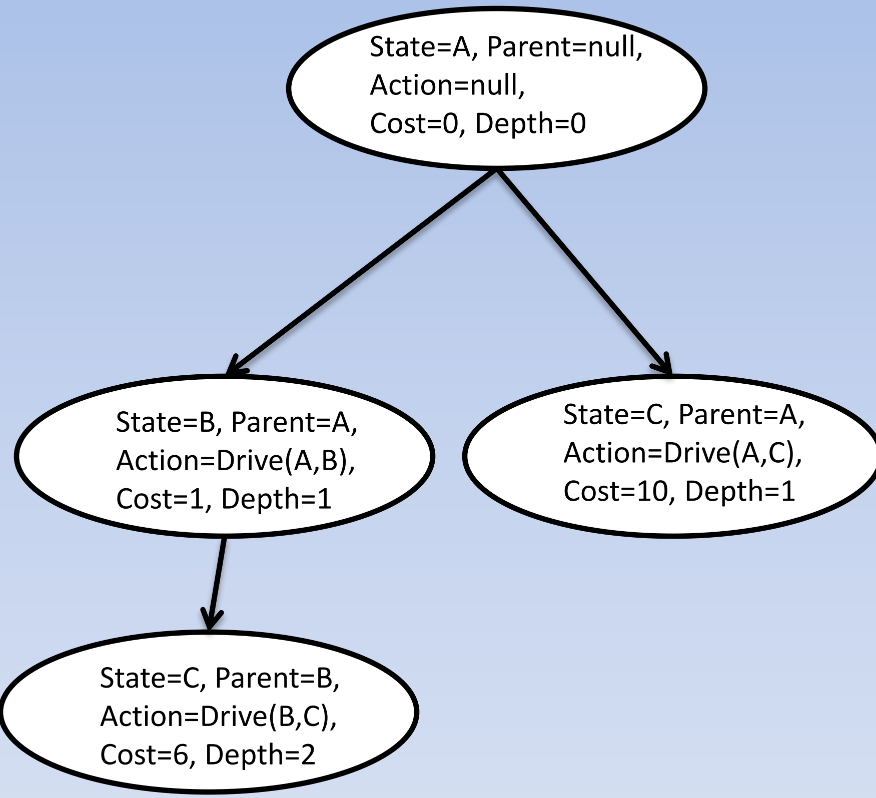
Search Algorithm Analysis

- As it searches, the agent generates a "search tree"
- Each node in the search tree represents some state in the search space, with extra bookkeeping information
  - The parent node
  - The action that was applied at the parent
  - Path cost
  - Depth

- NOTE: The search tree is only meant to visualize the flow of computation. It does not correspond to a data structure you would maintain in practice.

Example: Search Tree





Different search algorithms can be compared using characteristics of the search tree they generate.

Characteristics of the Search Tree

- Branching factor b
  - Maximum number of successors of any node
- Goal depth d
  - Depth of the shallowest goal in the search tree
- Max Path Length m
  - Maximum length of a path in the search space

Algorithm Performance

- Completeness
  - Algorithm always finds a solution if it exists?
- Optimality
  - Algorithm always finds minimum cost solution?
- Time Complexity
  - Time taken to find a solution?
- Space Complexity
  - Memory required to find a solution?

BFS Performance

- Complete?
- Optimal?
- Time Complexity?
- Space Complexity?

- Yes
- Sometimes (when?)
- $O(b^{d+1})$
- $O(b^{d+1})$

DFS Performance

- Complete?
- Yes, assuming no infinite paths
- Optimal?
- Sometimes
- Time Complexity?
- $O(b^m)$
- Space Complexity?
- $O(b^m)$

Uninformed vs. Informed Search

- Previous search methods use various methods to pick which node to expand

- But which node would we *really* like to expand, path costs being equal?
  - The one that is *really the closest to the goal*

- But we don't know this
  - If we did, wouldn't need to search

“Informed” Search

- Uninformed or Blind Search
  - These algorithms only use the information in the problem setup to find a solution
- Informed or Heuristic Search
  - These algorithms also use an extra function, a *search heuristic,* to find a solution
  - The search heuristic is not part of the problem definition---it is up to the agent designer to specify it (some recent work on *learning* the heuristic)