CIS 471/571 (Winter 2020): Introduction to Artificial Intelligence

Lecture 2: Uninformed Search

Thanh H. Nguyen

Most slides are by Pieter Abbeel, Dan Klein, Luke Zettlemoyer, John DeNero, Stuart Russell, Andrew Moore, or Daniel Lowd
Source: http://ai.berkeley.edu/home.html
Announcement

- Project 1
  - Deadline: Jan 19th, 2020

- Written Assignment 1
  - Will be posted tomorrow
  - Deadline: Jan 20th, 2020
Today

- Agents that Plan Ahead

- Search Problems

- Uninformed Search Methods
  - Depth-First Search
  - Breadth-First Search
  - Uniform-Cost Search
Rational Agents

- An agent is an entity that perceives and acts.
- A rational agent selects actions that maximize its utility function.
- Characteristics of the percepts, environment, and action space dictate techniques for selecting rational actions.
Reflex Agents

- Reflex agents:
  - Choose action based on current percept (and maybe memory)
  - Do not consider future consequences of their actions
  - Consider how the world IS

- Can a reflex agent be rational?
Video of Demo Reflex Optimal
Video of Demo Reflex Odd
Goal-based Agents

- Goal-based agents:
  - Plan ahead
  - Ask “what if”
  - Decisions based on (hypothesized) consequences of actions
  - Must have a model of how the world evolves in response to actions
  - Act on how the world WOULD BE
Video of Demo Mastermind
Search Problem

- A search problem consists of:
  - A state space
  - A successor function (with actions, costs)
  - A start state and a goal test
  - A solution is a sequence of actions (a plan) which transforms the start state to a goal state
Example: Romania

- State space:
  - Cities
- Successor function:
  - Go to adjacent city with cost = dist
- Start state:
  - Arad
- Goal test:
  - Is state == Bucharest?
- Solution?
What is in State Space

- **Problem: Pathing**
  - States: (x,y) location
  - Actions: NSEW
  - Successor: update location only
  - Goal test: is (x,y)=END

- **Problem: Eat-All-Dots**
  - States: {(x,y), dot booleans}
  - Actions: NSEW
  - Successor: update location and possibly a dot boolean
  - Goal test: dots all false

The *world state* includes every last detail of the environment.
State Space Size

- Search Problem: Eat all of the food
- Pacman positions: 10 x 12 = 120
- Pacman facing: up, down, left, right
- Food Count: 30
- Ghost positions: 12
- How many
  - World states? 120*(2^{30})*(12^2)*4
  - States for pathing? 120
  - States for eat-all-dots? 120*(2^{30})
State Space Graphs

- **State space graph**: A mathematical representation of a search problem
  - Nodes are (abstracted) world configurations
  - Arcs represent successors (action results)
  - The goal test is a set of goal nodes (maybe only one)

- In a state space graph, each state occurs only once!

- We can rarely build this full graph in memory (it’s too big), but it’s a useful idea
State Space Graphs

- State space graph: A mathematical representation of a search problem
  - Nodes are (abstracted) world configurations
  - Arrows represent successors (action results)
  - The goal test is a set of goal nodes (maybe only one)

- In a state space graph, each state occurs only once!

- We can rarely build this full graph in memory (it’s too big), but it’s a useful idea
A search tree:
- A “what if” tree of plans and their outcomes
- The start state is the root node
- Children correspond to successors
- Nodes show states, but correspond to PLANS that achieve those states
- For most problems, we can never actually build the whole tree

This is now / start
Possible futures
State Space Graphs vs. Search Trees

State Space Graph

Each NODE in the search tree is an entire PATH in the state space graph.

Search Tree

We construct both on demand – and we construct as little as possible.
Quiz: State Space Graphs vs. Search Trees

Consider this 4-state graph: How big is its search tree (from S)?

![Graph Diagram]
Quiz: State Space Graphs vs. Search Trees

Consider this 4-state graph:

How big is its search tree (from S)?

Important: Lots of repeated structure in the search tree!
Tree Search
Search Example: Romania
Searching with a Search Tree

- **Search:**
  - Expand out potential plans (tree nodes)
  - Maintain a *fringe* of partial plans under consideration
  - Try to expand as few tree nodes as possible
General Tree Search

- Tree Search
  - Initialize the *root node* of the search tree with the *start state*
  - While there are unexpanded leaf nodes (fringe):
    - Choose a leaf node (strategy)
    - If the node contains a goal state:
      - return the corresponding solution
    - Else: expand the node and add its children to the tree

- Important ideas:
  - Fringe
  - Expansion

- Strategy: which fringe nodes to explore?
Example: Tree Search
Depth-First Search (DFS)

Strategy: expand a deepest node first

Implementation: Fringe is a LIFO stack
Search Algorithm Properties

- Complete: Guaranteed to find a solution if one exists?
- Optimal: Guaranteed to find the least cost path?
- Time complexity?
- Space complexity?

- Cartoon of search tree:
  - b is the branching factor
  - m is the maximum depth
  - solutions at various depths

- Number of nodes in entire tree?
  - $1 + b + b^2 + \ldots + b^m = O(b^m)$
What nodes DFS expand?
- Some left prefix of the tree.
- Could process the whole tree!
- If m is finite, takes time $O(b^m)$

How much space does the fringe take?
- Only has siblings on path to root, so $O(bm)$

Is it complete?
- $m$ could be infinite, so only if we prevent cycles (more later)

Is it optimal?
- No, it finds the “leftmost” solution, regardless of depth or cost

DFS Properties
Breadth-First Search (BFS)
Breadth-First Search (BFS)

Strategy: expand a shallowest node first

Implementation:
Fringe is a FIFO queue
BFS Properties

- What nodes does BFS expand?
  - Processes all nodes above shallowest solution
  - Let depth of shallowest solution be $s$
  - Search takes time $O(b^s)$

- How much space does the fringe take?
  - $O(b^{s+1})$

- Is it complete?
  - $s$ must be finite if a solution exists, so yes!

- Is it optimal?
  - Only if costs are all 1 (more on costs later)
DFS vs BFS

- When will BFS outperform DFS?
- When will DFS outperform BFS?
Iterative Deepening

- Idea: get DFS’s space advantage with BFS’s time / shallow-solution advantages
  - Run a DFS with depth limit 1. If no solution...
  - Run a DFS with depth limit 2. If no solution...
  - Run a DFS with depth limit 3. ....

- Isn’t that wastefully redundant?
  - Generally most work happens in the lowest level searched, so not so bad!
Cost on Actions

Note: BFS finds the shortest path in terms of number of actions. It does not find the least-cost path.
Uniform-Cost Search (UCS)
Uniform-Cost Search (UCS)

Strategy: expand a cheapest node first:

Fringe is a priority queue (priority: cumulative cost)
UCS Properties

- What nodes does UCS expand?
  - Processes all nodes with cost less than cheapest solution!
  - If that solution costs $C^*$ and arcs cost at least $\varepsilon$, then the “effective depth” is roughly $C^*/\varepsilon$
  - Takes time $O(b^{C^*/\varepsilon})$ (exponential in effective depth)

- How much space does the fringe take?
  - Has roughly the last tier, so $O(b^{C^*/\varepsilon})$

- Is it complete?
  - Assuming best solution has a finite cost and minimum arc cost is positive, yes!

- Is it optimal?
  - Yes! (Proof next lecture via A*)
Uniform Cost Issues

- Remember: UCS explores increasing cost contours

- The good: UCS is complete and optimal!

- The bad:
  - Explores options in every “direction”
  - No information about goal location

- We’ll fix that soon!
Search and Models

- Search operates over models of the world
  - The agent doesn’t actually try all the plans out in the real world!
  - Planning is all “in simulation”
- Your search is only as good as your models...
Search Gone Wrong?