COMP219: Artificial Intelligence

Lecture 11: Search in Complex Environments
Overview

• **Last time**
  – Uniform cost search
  – Heuristics and heuristic search (greedy, A*)

• **Today:**
  – Search with partial observations
  – Belief states

• **Learning outcome covered today:**
  Identify, contrast and apply to simple examples the major search techniques that have been developed for problem-solving in AI;
Problem Types

• Deterministic, fully observable single-state problem
  – Agent knows exactly which state it will be in; solution is a sequence

• Non-observable sensorless problem (conformant problem)
  – Agent may have no idea where it is; solution is a sequence

• Non-deterministic and/or partially observable contingency problem
  – predicting the evolution of the environment becomes impossible
  – percepts provide new information about current state

  “For this reason, many people keep their eyes open while walking around or driving” – Russel&Norvig

  – often interleave search, execution

• Unknown state space exploration problem
Search Without Full Observation

• Agent’s percepts do not determine the exact state
• If agent in one of several possible states then an action may lead to one of several possible outcomes
• Belief state: agent’s current belief about the possible physical states it might be in (given history – sequence of actions + percepts)
Search with No Observations

• Sensorless problem
• No need to rely on sensors working properly, e.g. manufacturing
• Less costly
• Search in belief states not physical states
Example:
Robot Vacuum Cleaner World

- Actions:
  - Right
  - Left
  - Suck
Example: vacuum world – 1

Single-state:
• Start in #5

Solution?
Answer: vacuum world – 1

Single-state:
• Start in #5

Solution?
• [Right, Suck]
Example: vacuum world – 2

Sensorless:
• Start in \{1,2,3,4,5,6,7,8\}
• e.g. Right goes to \{2,4,6,8\}

Solution?
Answer: vacuum world – 2

Sensorless:

• Start in
  \{1,2,3,4,5,6,7,8\}

• e.g. Right goes to
  \{2,4,6,8\}

Solution?

• \([\text{Right}, \text{Suck}, \text{Left}, \text{Suck}]\)
Example: vacuum world – 3

Contingency:

- **Non-deterministic:** suck may dirty a clean carpet
- **Partially observable:** location, dirt at current location
- Percept: [A, Clean] i.e. start in #5 or #7

Solution?
Contingency:

- Non-deterministic: suck may dirty a clean carpet
- Partially observable: location, dirt at current location
- Percept: [A, Clean] i.e. start in #5 or #7

Solution?

- [Right, if dirt then Suck]
No Observations: Constructing a Belief State Search Problem

- Physical problem $P$ is defined by $\text{Actions}_p$, $\text{Result}_p$, $\text{Goal-Test}_p$, $\text{Step-Cost}_p$
- Sensorless problem is defined by:
  - Belief States – every possible set (B) of physical states
  - Initial State – set of all states in $P$
  - Actions
  - Transition model
  - Goal test – all states in belief state must satisfy goal
  - Path cost
Determining Possible Actions

• Depends on whether it's safe to execute actions in states where they are not applicable
  - have an effect on the environment?
• If safe, union of all actions:

\[ \text{Actions}(b) = \bigcup_{s \in b} \text{Actions}_p(s) \]

• Otherwise, only allow the intersection, i.e. actions which are legal in all states
Transition Model

• For deterministic actions, the set of states that might be reached is:
  \[ b' = Result(b, a) = \{ s' : s' = Result_p(s, a) \text{ and } s \in b \} \]
  
  - b’ is never larger than b

• For non-deterministic actions: b' may be larger

• **Prediction step** is process of generating the new belief state after the action

  \[ b' = Predict_p(b, a) \]
Prediction Step: Vacuum World

- Action: [Right]

Deterministic

Non-deterministic ‘slippery’
Belief State Problem: Vacuum World
Pruning the Belief State Graph

• Repeated belief states: don't add to agenda
  – E.g., [Suck,Left,Suck] reaches the same $b$ as [Right,Left,Suck] = \{5,7\}

• Moreover, if an action sequence is a solution for a belief state $b$, it is also a solution for any subset of $b$
  – Suppose \{5,7\} has already been generated
  – Consider [Left]: $b$={1,3,5,7}
  – Can discard that path as its subset \{5,7\} will lead to solution whenever \{1,3,5,7\} does
Sensorless Problem Solving

• **Problem**: Size of each belief state

• e.g.
  10 x 10 vacuum world
  $100 \times 2^{100} = 10^{32}$ physical states
Incremental Belief State Search

• Unlike standard search algorithms, look inside $b$
• Build up solution one physical state at a time
• One solution for all states
• Find action sequence that works for all states:
  – Find solution for state 1
  – Check if it works for state 2, then state 3, etc.
  – If not, find different solution for state 1, etc.
• Advantage: detects failure quickly
  – If $b$ unsolvable, usually the small subset of first few states examined is also unsolvable
Searching with Partial Observations

• Specify how the environment generates percepts
  – e.g. vacuum agent has position and local dirt sensor but no dirt sensor for other squares
  – Percept(state 1) = [A,Dirty]

• Usually several states could have produced the same percept
  – e.g. [A,Dirty] = {1, 3}
Searching with Partial Observations – Transitions

• 3 stages:
  – **Prediction** stage – same as sensorless problems
    \[ \hat{b} = \text{Predict}(b, a) \]
  – **Observation prediction** stage determines set of percepts \( o \) that could be observed in predicted belief state
    \[ \text{Possible - Percepts}(\hat{b}) = \{ o : o = \text{Percept}(s) \text{ and } s \in \hat{b} \} \]
  – **Update** stage – for each possible percept, determine which belief states could result from the percept
    \[ b_o = \text{Update}(\hat{b}, o) = \{ s : o = \text{Percept}(s) \text{ and } s \in \hat{b} \} \]

• Percepts reduce uncertainty
Transitions: Vacuum World

Deterministic

Non-deterministic ‘slippery’
Exercise

• A robot has the task of localisation, i.e. working out where it is given a map of the world and a sequence of percepts and actions
• 4 sonar sensors tell the robot whether there is an obstacle in each compass direction (NESW)
• MOVE action moves randomly to an adjacent square
Exercise: Localisation

- Where is the robot?

- After one percept $P_1=NSW$?
Exercise: Localisation

• Possible locations of the robot after one percept $P_1=$NSW

• After MOVE and next percept $P_2=$NS?
Exercise: Localisation

• After MOVE and next percept $P_2=\text{NS}$ we have a solution!
Summary

• Search with no observation
  – Belief states
  – Pruning the belief state graph
  – Incremental belief state search

• Search with partial observation
  – Transitions: prediction; observation prediction; update

• Next time
  – Applying search to games