Informatics 2D: Reasoning and Agents

Alex Lascarides

School of informatics

The University of Edinburgh

Lecture 18b: Planning and acting in the real world: beliefs and sensorless planning

Where are we?

Last time. . .

- We have impractical assumptions about planning
  - actions have deterministic outcomes
  - states are fully observable

  that we now need to drop.
- General discussion of challenges and planning strategies to deal with more realistic planning problems.

Now: More formal detail.

What's needed?

When sensors aren't powerful enough

- Don't know the value of all relevant fluents
- So you must plan using your **beliefs**, not the representation of the actual state.
- How do we represent beliefs?

When actions can have more than one outcome

- Need to represent **conditional effects** in action schemata.

What's needed?

When sensors aren't powerful enough

- Don't know the value of all relevant fluents
- So you must plan using your **beliefs**, not the representation of the actual state.
- How do we represent beliefs?

When actions can have more than one outcome

- Need to represent **conditional effects** in action schemata.

How to represent belief states

1. Sets of state representations, e.g.

$$\{(AtL \wedge CleanR \wedge CleanL), (AtL \wedge CleanL)\}$$

   (2^n states!)

2. Logical sentences can capture a belief state, e.g. $AtL \wedge CleanL$ shows ignorance about $CleanR$ by not mentioning it!
   - This often offers a more compact representation, but
   - Many equivalent sentences; need **canonical** representation to avoid general theorem proving; E.g:
     - All representations are ordered conjunctions of literals (under open-world assumption)
     - But this doesn't capture everything (e.g. $AtL \vee CleanR$)
3. Knowledge propositions, e.g. $K(AtR) \wedge K(CleanR)$ (closed-world assumption)

- Will use second method, but clearly loss of expressiveness

Beliefs and Sensorless Planning

- When you have no sensors, you need:
  - to represent and track your (changing) **beliefs** as you perform actions . . .
  - . . . and so cope with **sensorless planning**

Example

Table and chair, two cans of paint
you know these objects exist, but you can't see them
You can open cans, and paint furniture
Goal: table and chair to be same colour

Sensorless Planning Example: The Belief States

- There are no *InView* fluents, because there are no sensors!
- There are unchanging facts:
  $Object(Table) \land Object(Chair) \land Can(C_1) \land Can(C_2)$
- And we know that the objects and cans have colours:
  $\forall x \exists c\, Color(x, c)$
- After skolemisation this gives an initial belief state:

$$b_0 = Color(x, C(x))$$

- A belief state corresponds exactly to the set of possible worlds that satisfy the formula—open world assumption.

The Plan

$$[RemoveLid(C_1), Paint(Chair, C_1), Paint(Table, C_1)]$$

Rules:

- You can only apply actions whose preconditions are satisfied by your current belief state b.
- The update of a belief state b given an action a is the set of all states that result (in the physical transition model) from doing a in each possible state s that satisfies belief state b:
  $$b' = \text{Result}(b, a) = \{s' : s' = \text{Result}_P(s, a) \wedge s \in b\}$$

Or, when a belief b is expressed as a formula:

1. If action adds l, l becomes a conjunct of the formula b' (and the conjunct $\neg l$ removed, if necessary); so $b' \models l$
2. If action deletes l, $\neg l$ becomes a conjunct of b' (and l removed).
3. If action says nothing about l, it retains its b-value.

Showing the Plan Works

$$
\begin{aligned}
b_0 =\ & Color(x, C(x)) \\
b_1 =\ & \text{Result}(b_0, RemoveLid(C_1)) \\
=\ & Color(x, C(x)) \wedge Open(C_1) \\
b_2 =\ & \text{Result}(b_1, Paint(Chair, C_1)) \\
& \text{(binding } \{x/C_1, c/C(C_1)\} \text{ satisfies Precond)} \\
=\ & Color(x, C(x)) \wedge Open(C_1) \wedge Color(Chair, C(C_1)) \\
b_3 =\ & \text{Result}(b_2, Paint(Table, C_1)) \\
=\ & Color(x, C(x)) \wedge Open(C_1) \wedge \\
& Color(Chair, C(C_1)) \wedge Color(Table, C(C_1))
\end{aligned}
$$

Summary

- When your sensors aren't powerful enough to fully observe the current state, you need to reason about your beliefs
- Various ways of representing beliefs
- Examined how you can keep track of beliefs as you act, and so cope with sensorless planning.