Informatics 2D. Tutorial 7
Planning and Acting in the Real World

Week 8

The problem description

This week's tutorial builds on last week's tea making domain. Your personal robotic assistant who helps you make tea has the following information:

- a set of predicates:
  $cup(c)$, $kettle(k)$, $containsWater(x)$ where x is either a cup or a kettle, $containsTeabag(x)$ where x is usually a cup, $waterIsHot()$ which takes no arguments.

- a set of actions: $Action(\ FillWithWaterFromTap(k)\ )$
  $PRECONDITION:\ kettle(k)\ \wedge\ \neg\ containsWater(k)$
  $EFFECT:\ containsWater(k)$

  $Action(\ AddTeabagToCup(c)\ )$
  $PRECONDITION:\ \ cup(c)\ \wedge\ \neg\ containsTeabag(c)$
  $EFFECT:\ containsTeabag(c)$

  $Action(\ PourWaterToCupFromKettle(c,\ k)\ )$
  $PRECONDITION:\ kettle(k) \wedge cup(c) \wedge waterIsHot \wedge containsWater(k) \wedge \neg\ containsWater(c)$
  $EFFECT:\ containsWater(c)$

  $Action(\ BoilWaterInKettle(k)\ )$
  $PRECONDITION:\ kettle(k)\ \wedge \neg\ waterIsHot()\ \wedge\ containsWater(k)$
  $EFFECT:\ waterIsHot()$

You ask the robot to make you two cups of tea $C1$ and $C2$. This goal state can be represented as follows:

$$containsWater(C1)\ \wedge\ containsWater(C2)\ \wedge\ containsTeabag(C1)\ \wedge\ containsTeabag(C2)\ \wedge\ waterIsHot()$$

.

Part 1: Planning with certainty

With an initial state of:

$$kettle(K) \ \wedge \ cup(C1) \ \wedge \ cup(C2)$$

and everything else being false, since we are operating under a closed world assumption, produce a plan that takes you from the initial state to the goal state described above.

Solutions

One plan that takes us from the initial state to the goal state could be:

0: $FillWithWaterFromTap(K)$
1: $BoilWaterInKettle(K)$
2: $PourWaterToCupFromKettle(C1, K)$
3: $PourWaterToCupFromKettle(C2, K)$
4: $AddTeabagToCup(C1)$
5: $AddTeabagToCup(C2)$

Part 2: Conformant Planning

Assume that your robot does not have complete information about the state of the world at the start of the problem, and has no sensing abilities either. Let's assume that in the initial state the robot knows that K is a kettle, C1 and C2 are cups, but does not know whether any of the containers contain water or tea, or whether or not the water is hot.

1. Represent the agent's *belief state* as a compact logical representation, which expresses the agent's ignorance about predicates by not mentioning them, and by explicitly mentioning everything else in the world whether true or false.
2. Modify the description of your world by introducing new actions or by making changes to existing actions to enable your robot to produce a *conformant* plan, i.e. a plan that works regardless of what the true state of the world is at the start of the problem.
3. Give an example of a conformant plan to make two cups of tea for your updated domain.

Solution

1. The agent's belief state would be:

   $kettle(K) \wedge cup(C1) \wedge cup(C2) \wedge \neg kettle(C1) \wedge \neg kettle(C2) \wedge \neg cup(K)$

2. To be able to achieve a conformant plan, we need to introduce an action that would enable us neutralize the unknown aspects of the world. We have no means of discovering whether the containers contain water or

teabags, so one action we can introduce would be to $EmptyContents(x)$ of container x:

- $Action(\ EmptyContents(x)\ )$
  $EFFECT:\ \neg\ containsWater(x)\ \wedge\ \neg containsTeabag(x)$

this action allows us to deal with the uncertainty about the predicates $containsWater(x)$ and $containsTeabag(x)$

But we still need to deal with the fact the we don't know whether the water is hot or not. One way around this would be to remove the precondition $\neg\ waterIsHot()$ from the action $BoilWaterInKettle(k)$ which would just allow the robot to switch the kettle on again even if the water is already hot.

3. One conformant plan we can produce is as follows:

   0: $EmptyContents(K)$
   1: $EmptyContents(C1)$
   2: $EmptyContents(C2)$
   3: $FillWithWaterFromTap(K)$
   4: $BoilWaterInKettle(K)$
   5: $PourWaterToCupFromKettle(C1, K)$
   6: $PourWaterToCupFromKettle(C2, K)$
   7: $AddTeabagToCup(C1)$
   8: $AddTeabagToCup(C2)$

Part 3: Contingent Planning

Assume that your robot has incomplete information about the state of the world at the start of the problem, but is equipped with sensing abilities that allow it to detect the true value of the unknown predicates.

1. Add sensing actions to the original domain (which excludes changes you've made in step 2) to allow your agent to produce *contingent* plans that examine the different possibilities for the predicates $containsWater(x)$, $containsTeabag(x)$, and $waterIsHot()$.

2. Let's say that the agent's initial belief state is as follows:

$$kettle(K)\ \wedge\ cup(C)\ \wedge\ containsTeabag(C)$$
$$\wedge\ \neg containsWater(C)\ \wedge\ containsWater(K)$$

   this means that the agent does not know whether or not the water is hot. Write an example of a contingent plan that should result in a cup of tea in cup C.

Solutions

1. We can add three percepts, each of which senses one of the possible unknown predicates:

- $Percept(\ containsWater(x)\ )$
- $Percept(\ containsTeabag(x)\ )$
- $Percept(\ waterIsHot()\ )$

2. An example of a contingent plan would be:

   $[Percept(waterIsHot())$
   if $waterIsHot()$ **then** $PourWaterToCupFromKettle(C, K)$
   else $BoilWaterInKettle(K)$, $PourWaterToCupFromKettle(C, K)]$