CSE 591 - FALL 04. HANDOUT 3. VERSION 0.3

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November 16, 2004

REASONING AND PLANNING WITH SENSING ACTIONS

Motivation

- Fluents: locked, jammed, open
- $push\_door$ **causes** $open$ **if** $\neg locked, \neg jammed$
  $push\_door$ **causes** $jammed$ **if** $locked$
  $flip\_lock$ **causes** $locked$ **if** $\neg locked$
  $flip\_lock$ **causes** $\neg locked$ **if** $locked$
- **initially** $\neg jammed, \neg open$
- Goal: To make *open* true.
- Is there a conformant plan?
- How about the following program P_1?
  If $\neg locked$ then $push\_door$ else $flip\_lock; push\_door$
- A correct plan P_2:
  sense_locked;
  If $\neg locked$ then $push\_door$ else $flip\_lock; push\_door$

Formalizing sensing actions

- Previously: States described the (status of objects in the) world at particular moments of time.
- How to distinguish between such *phsyical states* and the *mental state of an agent* in terms of what it knows and what it does not.
- Philosophers use a modal operator **K** to express knowledge.
  - For example, $\mathbf{K}\ p$ means that the agent knows that p is true.
  - In presence of multiple agents multiple modal operators $\mathbf{K}_1, \mathbf{K}_2, \mathbf{K}_3, \ldots$ are used.
  - John knows that Mary does not know the password is expressed as: $\mathbf{K}_{john} \neg\ \mathbf{K}_{mary}$ password.
  - I know that I don't know the answer is expressed as: $\mathbf{K}\ \neg\ \mathbf{K}$ answer.
  - Semantics of modal logics are given using possible world models.

- A certain king wishes to test his three wise men. He arranges them in a circle so that they can see and hear each other and tells them that he will put a white or black spot on each of their foreheads but that at least one spot will be white. In fact all three spots are white. He then repeatedly asks them, "Do you know the color of your spot?" What do they answer?

  The solution is that they answer, "No," the first two times the question is asked and answer "Yes" thereafter.

  (From: http://www-formal.stanford.edu/jmc/puzzles/puzzles.html)

- Possible model semantics uses Kripke models (s, S, R), where s is a possible world (a state), S is the set of all possible worlds, and R is an accessibility relation from one state to another.

  $(s, S, R) \models p$ if p is true in s.

  $(s, S, R) \models \mathbf{K}p$ if p is true in all s' where $(s, s') \in R$.

- If R is reflexive, symmetric, and transitive then we have the modal logic **S5** which is axiomatized as follows:
  * K: $(\mathbf{K}\ \alpha \wedge \mathbf{K}\ (\alpha \rightarrow \beta)) \rightarrow \mathbf{K}\ \beta$
  * T: $\mathbf{K}\ \alpha \rightarrow \alpha$
  * 4: $\mathbf{K}\ \alpha \rightarrow \mathbf{K}\ \mathbf{K}\ \alpha$
  * 5: $\neg\ \mathbf{K}\ \alpha \rightarrow \mathbf{K}\ \neg\ \mathbf{K}\ \alpha$

- Simple 3-valued logics are not adequate to express and reason about knowledge.
  - Usually the truth values of such logics have $uknown \vee unknown$ as $unknown$.
  - Suppose we know $a \vee b$ is true, but don't know which one.
  - Now a is $unknown$, b is $unknown$, but $a \vee b$ is true.
- Sensing actions: The effect of *sense_locked* is that it takes us to the mental state where $\mathbf{K}\ locked \vee \mathbf{K}\ \neg locked$ is true.

  We abbreviate $\mathbf{K}\ p \vee \mathbf{K}\ \neg p$ by $\mathbf{K}_{whether}\ p$;

  and $\neg\ \mathbf{K}\ p \wedge \neg\ \mathbf{K}\ \neg p$ by $\mathbf{UNK}\ p$

  sense_p takes us from a mental state of $\mathbf{UNK}\ p$ to a mental state of $\mathbf{K}_{whether}\ p$.
- Q1: How do we represent mental states.
- Q2: How do we define transition between mental states due to world changing actions and sensing actions?
- Q3: What is a plan in presence of sensing actions?
- Q4: How difficult is it to find a plan in presence of incompleteness and sensing actions?

Knowledge states, Combined states and transitions

- Ans 1
  - A *knowledge state (k-state)* is a set of states the agent thinks it may be in.
  - A *combined state (c-state)* is a pair consisting of a state and a k-state containing that state.
  - The combined state gives a possible mental picture of the world.
  - $s_1 = \{\neg jammed, \neg open, \neg locked\}$; $s_2 = \{\neg jammed, \neg open, locked\}$; $s_3 = \{\neg jammed, open, \neg locked\}$; $s_4 = \{\neg jammed, open, locked\}$; $s_5 = \{jammed, \neg open, \neg locked\}$; $s_6 = \{jammed, \neg open, locked\}$; $s_7 = \{jammed, open, \neg locked\}$; $s_8 = \{jammed, open, locked\}$.
  - Given the information that the door is not jammed and the door is not open, the initial c-states are:
    $(s_1, \{s_1, s_2\})$ and $(s_2, \{s_1, s_2\})$.
- Ans 2:
  - $(s_1, \{s_1, s_2\}) \stackrel{sense\_locked}{\longrightarrow}$

- $(s_2, \{s_1, s_2\}) \stackrel{sense\_locked}{\longrightarrow}$
- $(s_1, \{s_1, s_2\}) \stackrel{push\_door}{\longrightarrow}$
- $(s_2, \{s_1, s_2\}) \stackrel{push\_door}{\longrightarrow}$
- $(s_1, \{s_1, s_2\}) \stackrel{flip\_lock}{\longrightarrow}$
- $(s_2, \{s_1, s_2\}) \stackrel{flip\_lock}{\longrightarrow}$

- The transition between c-states due to actions – denoted by $\Phi_c(a, \langle s, \Sigma \rangle)$ – can then be defined in terms of the original transition between states (Φ) in the following way:
  - If a is a non-sensing action then for any c-state $\sigma = \langle s, \Sigma \rangle$, $\Phi_c(a, \sigma)$ is defined as the pair $\langle \Phi(a, s), \{s' | s' = \Phi(a, s'') \text{ for some } s'' \in \Sigma\} \rangle$.
  - If $sense_f$ is a sensing action that senses the fluent f (i.e., we have $sense_f$ **determines** f in our domain description) then for any c-state $\sigma = \langle s, \Sigma \rangle$, $\Phi_c(sense_f, \sigma)$ is defined as the pair $\langle s, \{s' | s' \in \Sigma \text{ such that } f \in s \text{ iff } f \in s'\} \rangle$.

In the above we assume Φ to be deterministic.

Homework:

- Define Φ_c in the previous slide when Φ is non-deterministic.
- Let a conditional program be a program consisting of action sequences and if–then–else statements. Formally define the syntax of a conditional program.
- Define when a conditional program P achieves a goal g (where g is a fluent literal) with respect to Φ_c (based on a given domain description with sensing actions) and a set of possibly incomplete observations about the initial state.
- Show using figures that the conditional program P_1 in slide 7 (Set 3) does not achieve the goal *open* while the conditional program P_2 in slide 7 (Set 3) does achieve the goal P_2.
- Hint: Answers to the above questions are embedded in Section 4.1 of the paper "Formulating diagnostic problem solving ...". You need to make changes to those definitions by simplifying them to the current context. You may also refer to Sections 1 and 2.2 in the paper "Formalizing sensing actions – a transition ...".