CS 1571 Introduction to AI
Lecture 17

Planning

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Administration announcements

Midterm:

- **Thursday, October 28, 2010**
- **In-class**
- **Closed book**

What does it cover?

- **All material covered by the end of lecture on October 21**

Homework 7:

- **first part is out - inferences in FOL**
- **Homework assignment due in 2 weeks**

Administration announcements

Simulated annealing competition:

1. Jesse Thomason
2. Brian Dicks
3. Yiran Lin

Administration announcements

Tic-tac-toe competition:

1. Brian Dicks
2. Yuxin Liu
3. Eric Fluharty
4. Bradlee Krupa
5. Bengi Johnson

Representation of actions, situations, events

Propositional and first order logic assume a static world
- Once something is true it cannot become false

But, the world is dynamic:
- What is true now may not be true tomorrow
- Changes in the world may be triggered by our activities

Problems:
- How to represent the change in the FOL ?
- How to represent actions we can use to change the world?

Planning

Planning problem:
- find a sequence of actions that achieves some goal
- an instance of a search problem
- the state description is typically very complex and relies on a logic-based representation

Methods for modeling and solving a planning problem:
- State space search
- Situation calculus based on FOL
- STRIPS – state space search algorithm
- Partial-order planning algorithms

Situation calculus

Provides a framework for representing change, actions and for reasoning about them

- **Situation calculus**
  - based on the first-order logic,
  - a situation variable models new states of the world
  - action objects model activities
  - uses inference methods developed for FOL to do the reasoning

Situation calculus

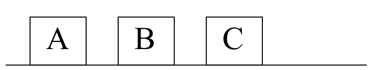
- Logic for reasoning about changes in the state of the world
- **The world is described by:**
  - Sequences of **situations** of the current state
  - Changes from one situation to another are **caused by actions**
- **The situation calculus allows us to:**
  - Describe the **initial state and a goal state**
  - Build the **KB that describes the effect of actions** (operators)
  - Prove that the KB and the initial state lead to a goal state
    - extracts a plan as side-effect of the proof

Situation calculus

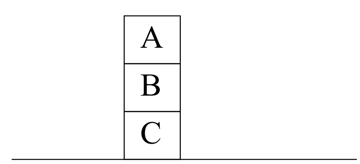
The language is based on the First-order logic plus:

- **Special variables:** *s,a* – objects of type situation and action
- **Action functions:** return actions.
  - E.g. *Move(A, TABLE, B)* represents a move action
  - *Move(x,y,z)* represents an action schema
- **Two special function symbols of type situation**
  - s_0 – initial situation
  - *DO(a,s)* – denotes the situation obtained after performing an action a in situation s
- **Situation-dependent functions and relations**
  (also called **fluents**)
  - **Relation:** *On(x,y,s)* – object x is on object y in situation s;
  - **Function:** Above(x,s) – object that is above x in situation s.

Situation calculus. Blocks world example.



Initial state



Goal

On(A,Table, s_0*)*
On(B,Table, s_0*)*
On(C,Table, s_0*)*
Clear(A, s_0*)*
Clear(B, s_0*)*
Clear(C, s_0*)*
Clear(Table, s_0*)*

Find a state (situation) s, such that

On(A,B, s)
On(B,C, s)
On(C,Table, s)

Knowledge base: Axioms.

Knowledge base needed to support the reasoning:

- Must represent changes in the world due to actions.

Two types of axioms:

- **Effect axioms**
  - changes in situations that result from actions
- **Frame axioms**
  - things preserved from the previous situation

Blocks world example. Effect axioms.

Effect axioms:

Moving x from y to z. $MOVE(x, y, z)$

Effect of move changes on **On** relations

$$On(x, y, s) \wedge Clear(x, s) \wedge Clear(z, s) \rightarrow On(x, z, DO(MOVE(x, y, z), s))$$

$$On(x, y, s) \wedge Clear(x, s) \wedge Clear(z, s) \rightarrow \neg On(x, y, DO(MOVE(x, y, z), s))$$

Effect of move changes on **Clear** relations

$$On(x, y, s) \wedge Clear(x, s) \wedge Clear(z, s) \rightarrow Clear(y, DO(MOVE(x, y, z), s))$$

$$On(x, y, s) \wedge Clear(x, s) \wedge Clear(z, s) \wedge (z \neq Table)$$
$$\rightarrow \neg Clear(z, DO(MOVE(x, y, z), s))$$

Blocks world example. Frame axioms.

- **Frame axioms.**
  - Represent things that remain unchanged after an action.

On relations:

$$On(u,v,s) \wedge (u \neq x) \wedge (v \neq y) \rightarrow On(u,v,DO(MOVE(x,y,z),s))$$

Clear relations:

$$Clear(u,s) \wedge (u \neq z) \rightarrow Clear(u,DO(MOVE(x,y,z),s))$$

Planning in situation calculus

Planning problem:

- find a sequence of actions that lead to a goal

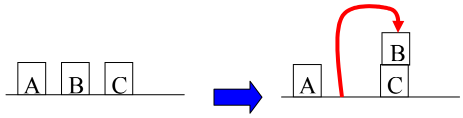
Planning in situation calculus is converted to the theorem proving problem

Goal state:

$$\exists s\ On(A,B,s) \wedge On(B,C,s) \wedge On(C,Table,s)$$

- Possible inference approaches:
  - **Inference rule approach**
  - **Conversion to SAT**
- **Plan** (solution) is a byproduct of theorem proving.
- **Example:** blocks world

Planning in the blocks world.



Initial state (s0) **s1**

$s_0 =$

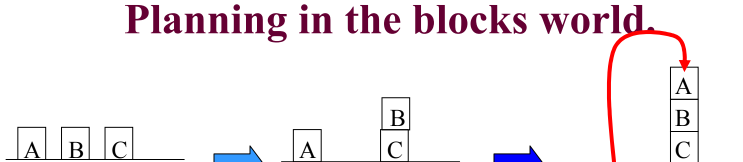
$On(A, Table, s_0)$ $Clear(A, s_0)$ $Clear(Table, s_0)$
$On(B, Table, s_0)$ $Clear(B, s_0)$
$On(C, Table, s_0)$ $Clear(C, s_0)$

Action: $MOVE(B, Table, C)$

$s_1 = DO(MOVE(B, Table, C), s_0)$

$On(A, Table, s_1)$ $Clear(A, s_1)$ $Clear(Table, s_1)$
$On(B, C, s_1)$ $Clear(B, s_1)$
$\neg On(B, Table, s_1)$ $\neg Clear(C, s_1)$
$On(C, Table, s_1)$

Planning in the blocks world.



Initial state (s0) **s1** **s2**

$s_1 = DO(MOVE(B, Table, C), s_0)$

$On(A, Table, s_1)$ $Clear(A, s_1)$ $Clear(Table, s_1)$
$On(B, C, s_1)$ $Clear(B, s_1)$
$\neg On(B, Table, s_1)$ $\neg Clear(C, s_1)$
$On(C, Table, s_1)$

Action: $MOVE(A, Table, B)$

$s_2 = DO(MOVE(A, Table, B), s_1)$
$= DO(MOVE(A, Table, B), DO(MOVE(B, Table, C), s_0))$

$On(A, B, s_2)$ $\neg On(A, Table, s_2)$ $\neg Clear(B, s_2)$
$On(B, C, s_2)$ $\neg On(B, Table, s_2)$ $\neg Clear(C, s_2)$
$On(C, Table, s_2)$ $Clear(A, s_2)$ $Clear(Table, s_2)$

Planning in situation calculus.

Planning problem:

- Find a sequence of actions that lead to a goal
- Is a special type of a search problem
- Planning in situation calculus is converted to theorem proving.

- **Problems:**
  - Large search space
  - Large number of axioms to be defined for one action
  - Proof may not lead to the best (shortest) plan.

Planning problems

Properties of many (real-world) planning problems:

- The description of the state of the world is very complex
- Many possible actions to apply in any step
- Actions are typically local
  - - they affect only a small portion of a state description
- Goals are defined as conditions referring only to a small portion of state
- Plans consists of a large number of actions

The state space search and situation calculus frameworks may be

- too cumbersome and inefficient to represent and solve the planning problems

Situation calculus: problems

Frame problem refers to:

- The need to represent a large number of frame axioms

Solution: combine positive and negative effects in one rule

$$On(u, v, DO(MOVE(x, y, z), s)) \Leftrightarrow (\neg((u = x) \wedge (v = y)) \wedge On(u, v, s)) \vee$$
$$\vee (((u = x) \wedge (v = z)) \wedge On(x, y, s) \wedge Clear(x, s) \wedge Clear(z, s))$$

Inferential frame problem:

- We still need to derive properties that remain unchanged

Other problems:

- **Qualification problem** – enumeration of all possibilities under which an action holds
- **Ramification problem** – enumeration of all inferences that follow from some facts

Solutions

- **Complex state description and local action effects:**
  - avoid the enumeration and inference of every state component, focus on changes only
- **Many possible actions:**
  - Apply actions that make progress towards the goal
  - Understand what the effect of actions is and reason with the consequences
- **Sequences of actions in the plan can be too long:**
  - Many goals consists of independent or nearly independent sub-goals
  - Allow goal decomposition & divide and conquer strategies

STRIPS planner

Defines a **restricted representation language** as compared to the situation calculus

Advantage: leads to more efficient planning algorithms.

- State-space search with structured representations of states, actions and goals
- Action representation avoids the frame problem

STRIPS planning problem:

- much like a standard search problem