Methods of Artificial Intelligence
WS 2002/2003

Situation Calculus

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Important Concepts of the last Lecture

- Plan: sequence of actions for transforming a given state into a state which fulfills a predefined set of goals.

- STRIPS:
  Relies to closed world assumption
  Language represents states, goals, and operators
  States are conjunctions of positive ground literals
  Operators are typically represented as schemes
  States can be changed by applying an action

- Blocks world as an application of STRIPS

- Important concepts are: termination, soundness, completeness, optimality, efficiency

Deductive Planning

- Deductive inference can be used to solve planning problems.
- Introduce a situation variable to store the partial plans:
  $s_{i+1} = \text{put}(A, B, s_i)$, ... $s_2 = puttable(A, s_1)$
  $s = \text{put}(A, B, \text{puttable}(A, [\text{on}(A, C), \text{clear}(A), ...]))$
- Situation calculus: Introduced by McCarthy (1963) and used for plan construction by resolution by Green (1969)
- In general: extensions of FOL (action languages)
- Proof logically, that a set of goals follows from an initial state given operator definitions (axioms)
- Perform the proof in a constructive way (plan is constructed as a byproduct of the proof)

Situation Calculus

A1 *on(a, table, s_1)* (literal of the initial state)

A2 $\forall S$[on(a, table, S) $\rightarrow$ on(a, b, put(a, b, S))] $\equiv$ (axiom for put-operator)
$\neg$*on(a, table, S)* $\vee$ *on(a, b, put(a, b, S))* *(clausal form)*

Proof the goal predicate *on(a, b, S_F)*

1. $\neg$*on(a, b, S_F)* (Negation of the theorem)
2. $\neg$ *on(a, table, S)* $\vee$ *on(a, b, put(a, b, S))* (A2)
3. $\neg$ *on(a, table, S)* (Resolve 1, 2)
   answer(put(a, b, S))
4. *on(a, table, s_1)* (A1)
5. contradiction (Resolve 3, 4) $\hookrightarrow$ answer(put(a, b, s_1))

$s_2 =$ *on(a, table, s_1)* with *on(a, b, s_2)* exists and s_2 can be reached by putting a on b in situation s_1.

Frame Problem Revisited

- No closed world assumption $\hookrightarrow$ full expressive power of FOL
- Problem: additionally to axioms describing the effects of actions, frame axioms become necessary
- Frame axioms are necessary to allow proving conjunctions of goal literals
- Frame axioms specify the invariants of the domain: relations that remain unaffected by the performance of an action
- Example for a frame axiom:
  $\forall\ S[\text{on}(Y, Z, S) \rightarrow \text{on}(Y, Z, \text{put}(X, Y, S))]$ `on(Y, Z, put(X, Y, S))` $\leftarrow$ `on(Y, Z, S)`
  After a block X was put on a block Y, it still holds that Y is lying on a block Z, if this did hold before the action was performed.

Blocks world in Prolog

Effect Axioms:

on(X, Y, put(X, Y, S)) $\leftarrow$ clear(X, S) $\wedge$ clear(Y, S)

clear(Z, put(X, Y, S)) $\leftarrow$ on(X, Z, S) $\wedge$ clear(X, S) $\wedge$ clear(Y, S)

clear(Y, puttable(X, S)) $\leftarrow$ on(X, Y, S) $\wedge$ clear(X, S)

ontable(X, puttable(X, S)) $\leftarrow$ clear(X, S)

Frame Axioms:

clear(X, put(X, Y, S)) $\leftarrow$ clear(X, S) $\wedge$ clear(Y, S)

clear(Z, put(X, Y, S)) $\leftarrow$ clear(X,S) $\wedge$ clear(Y, S) $\wedge$ clear(Z, S)

ontable(Y, put(X, Y, S)) $\leftarrow$ clear(X, S) $\wedge$ clear(Y, S) $\wedge$ ontable(Y, S)

ontable(Z, put(X, Y, S)) $\leftarrow$ clear(X, S) $\wedge$ clear(Y, S) $\wedge$ ontable(Z, S)

on(Y, Z, put(X, Y, S)) $\leftarrow$ clear(X, S) $\wedge$ clear(Y, S) $\wedge$ on(Y, Z, S)

on(W, Z, put(X, Y, S)) $\leftarrow$ clear(X, S) $\wedge$ clear(Y, S) $\wedge$ on(W, Z, S)

Blocks world in Prolog cont.

Frame Axioms cont.:

clear(Z, puttable(X, S)) $\leftarrow$	clear(X, S) $\wedge$ clear(Z, S)
ontable(Z, puttable(X, S)) $\leftarrow$	clear(X, S) $\wedge$ ontable(Z, S)
on(Y, Z, puttable(X, S)) $\leftarrow$	clear(X, S) $\wedge$ on(Y, Z, S)
clear(Z, puttable(X, S)) $\leftarrow$	on(X, Y, S) $\wedge$ clear(X, S) $\wedge$ clear(Z, S)
ontable(Z, puttable(X, S)) $\leftarrow$	on(X, Y, S) $\wedge$ clear(X, S) $\wedge$ ontable(Z, S)
on(W, Z, puttable(X, S)) $\leftarrow$	on(X, Y, S) $\wedge$ clear(X, S) $\wedge$ on(W, Z, S)

Facts (Initial State):

on(d, c, s_1)	on(c, a, s_1)
clear(d, s_1)	clear(b, s_1)
ontable(a, s_1)	ontable(b, s_1)

Theorem (Goal):
on(a, b, S) $\wedge$ on(b, c, S)

Remarks

- The term fluents denotes relations whose truth values may vary from state to state
- Although frame axioms are a general solution to the frame problem, the number of frame axioms can be significantly large: The axiomatizer must think of all these frame axioms
- Three major problems in planning approaches are: the frame problem, the qualification problem, and the ramification problem
- Qualification problem: What needs to be true for a particular action to be possible?
- Ramification problem: How can we specify all (and even implicit) consequences of an action?
- Frame axioms are a possibility to solve the frame problem, precondition axioms are a possibility to solve the qualification problem, certain rules can solve the ramification problem ("if an object is attached to another object and one of the objects is moved, the other object moves, too")

Further Topics

- Interleaving plan construction and plan execution
- Plan revision
- Planning with temporal/resource constraints
- Non-deterministic planning
- ...