KRR6: Knowledge engineering, Situation Calculus

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23 Mar 2005

Outline

Ontological engineering

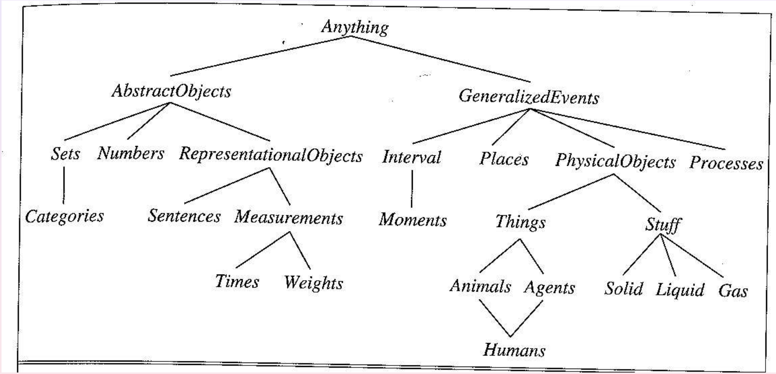
Definition

Ontological engineering: process for the representation of abstract concepts

Abstract concepts:

- Actions, Time, Objects, Knowledge (beliefs, possibilities...)

Upper Ontology



Categories and Objects

Definition

An object of the world always belongs to a category.

- organisation and simplification of a knowledge base
- use of inheritance (similar to object programming)
- taxonomy, taxonomy hierarchy

To make reasoning about the objects of the world, we generally make reasoning about the corresponding categories.

Categories and Objects: examples

Example

- An object is a member of a category

$$BB_9 \in \mathit{BasketBalls}$$

- A category can be a subclass of another category

$$\mathit{BasketBalls} \subset \mathit{Balls}$$

- All members of a category have some properties

$$\forall x \; x \in \mathit{BasketBalls} \Rightarrow \mathit{Round}(x)$$

- Members of a category can be recognised by some properties

$$\mathit{Orange}(x) \wedge \mathit{Round}(x) \wedge \mathit{Diameter}(x) = 9.5'' \wedge x \in \mathit{Balls} \Rightarrow x \in \mathit{BasketBalls}$$

- A category as a whole has some properties

$$\mathit{Dogs} \in \mathit{DomesticatedSpecies}$$

Composite objects

An object is part of another

To express that we can use terms like *PartOf* to say that one thing is part of another

- $PartOf(Bucharest, Romania)$
- $PartOf(Romania, EasternEurope)$
- $PartOf(EasternEurope, Europe)$
- $PartOf(Europe, Earth)$

How to express $PartOf(Bucharest, Earth)$?

We only need to express the transitivity of the *PartOf* relation:

$$PartOf(x, y) \wedge PartOf(y, z) \Rightarrow PartOf(x, z)$$

$$Part(x, x)$$

Composite objects

Example

What is a biped?

$$
\begin{aligned}
&\mathit{Biped}(a) \Rightarrow \\
&\qquad \exists l_1, l_2, b \; \mathit{Leg}(l_1) \wedge \mathit{Leg}(l_2) \wedge \mathit{Body}(b) \wedge \\
&\qquad \mathit{PartOf}(l_1, a) \wedge \mathit{PartOf}(l_2, a) \wedge \mathit{PartOf}(b, a) \wedge \\
&\qquad \mathit{Attached}(l_1, b) \wedge \mathit{Attached}(l_2, b) \wedge \\
&\qquad l_1 \neq l_2 \wedge [\forall l_3 \mathit{Leg}(l_3) \wedge \mathit{PartOf}(l_3, a) \Rightarrow (l_3 = l_1 \vee l_3 = l_2)]
\end{aligned}
$$

Organising and reasoning with categories

How to organise categories. We need a description language. There are two families:

1. Semantic networks
   - a graphical aids for visualising a KB
   - efficient algorithms for inferring properties of an object on the basis of its category membership
2. Description logic
   - Formal language for constructing and combining category definition
   - efficient algorithms for subset/uperset category relationships detection

Semantic network

Example

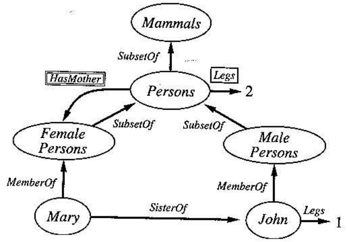


Figure 10.9 A semantic network with four objects (John, Mary, 1, and 2) and four categories. Relations are denoted by labeled links.

Links: $SisterOf(Mary, John)$ $Mary \in FemalePersons$
$FemalePersons \subset Persons$...
Single-boxed: $\forall x\ x \in Persons \Rightarrow Legs(x, 2)$
Double-boxed:
$\forall x\ x \in Persons \Rightarrow [\forall y\ HasMother(x, y) \Rightarrow y \in FemalePersons]$

Description logics

Definition

Description logics are notations that are designed to make it easier to describe definitions and properties of categories.

Example

"Bachelors are unmarried adult males"

$$Bachelor = And(Unmarried, Adult, Male)$$

which is a "syntaxical sugar" for

$$\forall x \; Bachelor(x) \Leftrightarrow Unmarried(x) \wedge Adult(x) \wedge Male(x)$$

Summary

- To represent aspects of complex worlds, ontology engineering
- The world is a set of objects that belong to categories
- Categories are inherited from other categories: Taxonomy
- The description of the world is based on compositionality of objects

- The result of the description in a formal language (like FOL) is a Knowledge base
- The knowledge base contains
  - Facts
  - Axioms that allow to make reasoning about the facts in order to get other facts (by inference)

Outline

Situation calculus: an introduction

Static versus Dynamic

Previously, we saw FOL as a way to:

- Represent static worlds
- Prove atemporal sentences

Nothing is dynamical

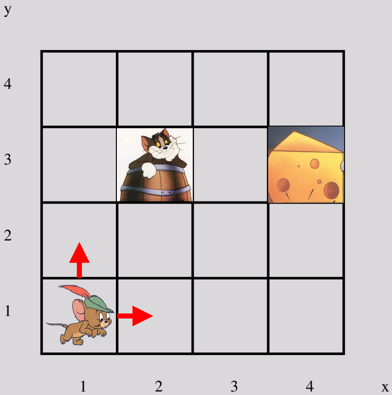
Situation calculus

The language of Situation calculus is specifically designed for representing dynamically changing worlds.

- a dynamical world is a sequence of situations
- a situation is a static world
- all changes to the world are the result of actions

Mouse, Cat and ... cheese

Example



The figure presents the initial situation. If Jerry moves from room 1,1 to room 1,2 the world is changed and we have a new situation. How to express that? This is the purpose of Situation Calculus.

Situation

Definition

A Situation is a logical term:

1. an initial term S_0 called the initial situation;
2. any term generated by applying an action to a situation:

$$Result(a, s)$$

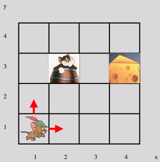
or

$$Do(a, s)$$

where a is an action and s is a situation.

Situation: examples

Example

S_0 represents 

A new situation could be:

$$Result(Go(Room(1,1), Room(1,2)), S_0)$$

If Jerry is in room (1,1) and goes to room (1,2) then we have a new situation.

Then, we can another situation:

$Result(Go(Room(1,2), Room(2,2)), Result(Go(Room(1,1), Room(1,2)), S_0))$

Fluents

Definition

A Fluent is a function or a predicate that vary from one situation to the next. By convention, the situation is always the last argument of the fluent.

$$function(a, b, c, S)$$

or

$$predicate(a, b, c, S)$$

where a, b, c are terms and S is a situation.

Example

- Jerry holds some cheese in the situation s (predicate)

$$Holding(Cheese(c), s)$$

- Here is the age of Tom in the situation s (function)

$$AgeOf(Tom, s)$$

Atemporal predicates/functions

Definition

An atemporal predicate/function is a predicate/function that do not vary from one situation to the next.

$$function(a, b, c)$$

or

$$predicate(a, b, c)$$

where a, b, c are terms (not situations).

Example

- Tom is a cat (predicate)

$$Cat(Tom)$$

- The left leg of Jerry (function)

$$LeftlegOf(Jerry)$$

Actions in situation calculus

Definition

An action is described with two axioms:

1. Possibility axiom: when it is possible to execute the action
2. Effect axiom: what happens when the action is executed

Definition

Possibility axiom

$$\mathit{Preconditions} \Rightarrow \mathit{Poss}(a, s)$$

where a is the action and s the situation.

Definition

Effect axiom

$$\mathit{Poss}(a, s) \Rightarrow \text{Changes that result from taking action } a \text{ in situation } s$$

where a is the action and s the situation. The changes are expressed with fluents.

Possibility axioms: examples

Example

Our agent: Jerry.

- Jerry can go between adjacent locations

$$At(Jerry, x, s) \wedge Adjacent(x, y) \Rightarrow Poss(Go(x, y), s)$$

- Jerry can grab some cheese in the current location

$$Cheese(c) \wedge At(Jerry, x, s) \wedge At(c, x, s) \Rightarrow Poss(Grab(c), s)$$

- Jerry can release some cheese that it is holding

$$Holding(c, s) \Rightarrow Poss(Release(c), s)$$

Effect axioms: examples

Example

- Jerry goes between adjacent locations

$$Poss(Go(x, y), s) \Rightarrow At(Jerry, y, Result(Go(x, y), s))$$

- Jerry grabs some cheese in the current location

$$Poss(Grab(c), s) \Rightarrow Holding(c, Result(Grab(c), s))$$

- Jerry releases some cheese that it is holding

$$Poss(Release(c), s) \Rightarrow \neg Holding(c, Result(Release(c), s))$$

And now? What happens?

We have an ontology (symbols, set of axioms) based on a formal system (FOL), let make some reasoning about situations!

Definition

Projection/prediction task: an agent (like Jerry) should be able to deduce the outcome of a given sequence of actions.

Example

- "going to room (2,3) is not a good idea"
- "going to room(1,2) is not dangerous"
- "going to room (4,3) is an excellent idea"

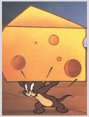
And now? What happens?

Definition

Planning task: an agent should be able to find a sequence that achieves a desired effect

Example

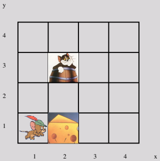
Desired effect: “I want to get some cheese and Tom must not see me”



A solution: “Go to room (2,1) then Go to room (3,1) then Go to room (4,1) hen Go to room (4,2) then Go to room (4,3) then grab the cheese then Go to room (4,2) then Go to room (4,1) then Go to room (3,1) then Go to room (2,1) then Go to room (1,1) then release the cheese”

Planning: example

Example

Initial situation $S_0 =$ 

Goal: “Jerry wants the cheese in 1,1”

In the initial situation, we must have:

$At(Jerry, Room(1,1), S_0) \wedge At(Gruyere, Room(1,2), S_0)$
$Cheese(Gruyere) \wedge Adjacent(Room(1,1), Room(1,2)) \wedge$
$Adjacent(Room(2,1), Room(1,1))$
(+ other things...)

The goal is also a sentence: $\exists seq\ At(Gruyere, Room(1,1), Result(seq, S_0))$

If the sentence is entailed by *KB* then we prove there is a plan for Jerry! If the inference algorithm is constructive then *seq* will be substituted with a term representing one plan!

Planning: example

Example

From S_0, we can get: (the action is $Go(Room(1,1), Room(1,2))$)

$$At(Jerry, Room(1,2), Result(Go(Room(1,1), Room(1,2)), S_0)$$

From this new sentence and KB we should be able to prove:

$$At(Gruyere, Room(1,2), Result(Go(Room(1,1), Room(1,2)), S_0)$$

... but we can't! (no axioms from KB can infer that)
Effect axioms say what changes but don't say what stays the same. The fact that Jerry moves from (1,1) to (1,2) does not change the fact that the cheese is still in (1.2).

Something is missing: frame problem

Frame problem

Definition

Purpose: representing all the things that stay the same. We need frame axioms that do say what stay the same.

Efficiency

The solution for solving the frame problem must be efficient.

- Frame axioms are numerous (an action generally changes a few fluents)
- One solution is to use successor-state axioms (not complete)
    - It solves the representational frame problem

Representational frame problem

Definition

Instead of writing effect axioms,

$$Poss(a, s) \Rightarrow \text{Changes that result from taking action } a \text{ in } s$$

we use successor-state axioms:

$Poss(a, s) \Rightarrow$

$$\text{Fluent is true in situation } s \Leftrightarrow$$

$$[\text{The effect of action } a \text{ made it true} \vee$$

$$\text{It was true before and action } a \text{ left it alone}]$$

Representational frame problem: example

Example

$Poss(a, s) \Rightarrow$

$[At(Jerry, y, Result(a, s)) \Leftrightarrow [a = Go(x, y) \vee (At(Jerry, y, s) \wedge a \neq Go(y, z))]]$

Informally: if a is possible in situation s then Jerry is in y in the “next situation” if either the action a is “go to y” or Jerry was “already” in y and a is not a movement action from y.

$Poss(a, s) \Rightarrow$

$[Holding(c, Result(a, s)) \Rightarrow [a = Grab(c) \vee (Holding(c, s) \wedge a \neq Release(c))]]$

Informally: if a is possible in situation s then Jerry holds the cheese in the “next situation” if either the action a is “Grab the cheese” or Jerry was already holding the cheese and the current action a is not to release it.

Summary

- Situation calculus: a way to represent actions, events in the world and make reasoning
  - Initial situation + axioms for actions
- Use of inference algorithms to do Deductive planning
- Frame Problem:
  - Use of frame axioms to express what the actions don't change in the world.