Artificial Intelligence 1

Roman Barták
Department of Theoretical Computer Science and Mathematical Logic

Knowledge Representation

How to effectively construct a **knowledge base**?
How should axioms look like?

- Representing **objects**
  – objects, categories, and ontologies
- Representing **time** and **actions**
  – situation calculus
  – frame problem

Let us notice that

- agents **manipulate** with real **objects**
- but **reasoning** is done at the level of **categories**
- An agent uses observations to find properties of objects that are used to assign objects to categories. Reasoning on category then reveals useful information about the object itself.

Category

= a set of its members

= a complex object with relations

- MemberOf
- SubsetOf

How to represent a category in FOL?

- an object is a **member** of a category
  - MemberOf(BB_{12},Basketballs)
- a category is **subset** of another category
  - SubsetOf(Basketballs,Balls)
- all members of the category have some **property**
  - $\forall$x (MemberOf(x,Basketballs) $\Rightarrow$ Round(x))
- all members of the category can be **recognized** using common properties
  - $\forall$x (Orange(x) $\wedge$ Round(x) $\wedge$ Diameter(x)=9.5in $\wedge$ MemberOf(x,Balls) $\Rightarrow$ MemberOf(x,BasketBalls))
- category may also have some property
  - MemberOf(Dogs,DomesticatedSpecies)

Categories organize and simplify knowledge base by using **inheritance of properties**.

– properties are defined for a category, but they are inherited to all members of the category

– food is eatable, fruits are food, apples are fruits, and hence apples are eatable

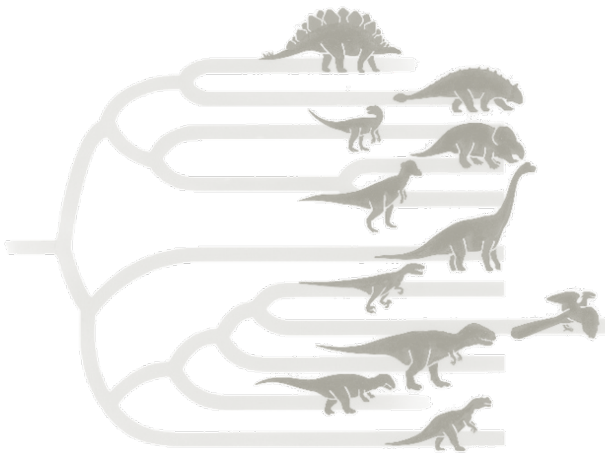
Subclasses organize categories to a **taxonomy**

– a hierarchical structure that is used to categorize objects

– originally proposed for classifying living organisms (alpha taxonomy)

– categories for all knowledge

- Used in libraries
- Dewey Decimal Classification
- 330.94 European economy



So far we modelled a static world only.

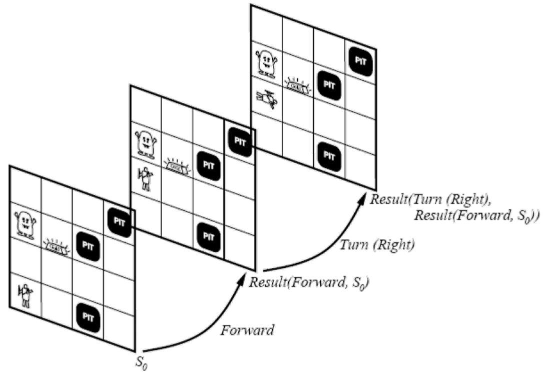
How to reason about actions and their effects in time?

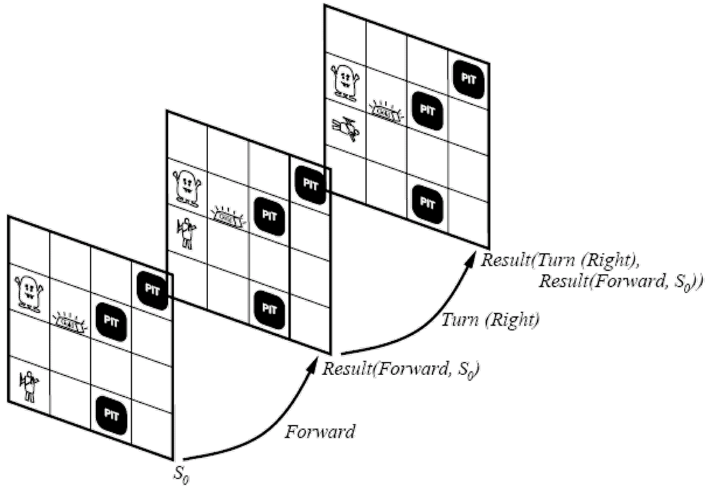
In propositional logic we need a copy of each action for each time (situation):

- $L^{t}_{x,y} \wedge FacingRight^{t} \wedge Forward^{t} \Rightarrow L^{t+1}_{x+1,y}$
- We need an upper bound for the number of steps to reach a goal but this will lead to a huge number of formulas.

Can we do it better in **first order logic**?

- We do not need copies of axioms describing state changes; this can be implemented using a universal quantifier for time (situation)
- $\forall t$ P is the result of action A in time t+1





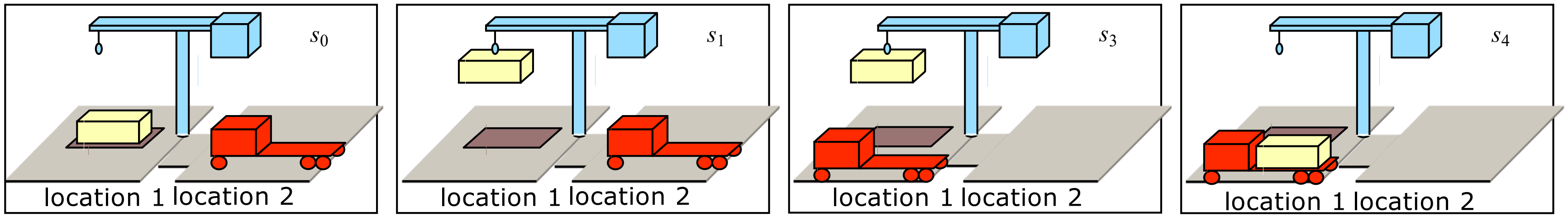
- **actions** are represented by terms
  - **Go(x,y)**
  - **Grab(g)**
  - **Release(g)**
- **situation** is also a term
  - initial situation: S_0
  - situation after applying action *a* to state *s*: **Result(a,s)**
- **fluent** is a predicate changing with time
  - the situation is in the last argument of that term
  - **Holding(G, S_0)**
- **rigid** (eternal) **predicates**
  - **Gold(G)**
  - **Adjacent(x,y)**

We need to reason about sequences of actions – about **plans**.

- $Result([],s) = s$
- $Result([a|seq],s) = Result(seq, Result(a,s))$

What are typical tasks related to plans?

- **projection task** – what is the state/situation after applying a given sequence of actions?
  - $At(Agent, [1,1], S_0) \wedge At(G, [1,2], S_0) \wedge \neg Holding(o, S_0)$
  - $At(G, [1,1], Result([Go([1,1],[1,2]),Grab(G),Go([1,2],[1,1])], S_0))$
- **planning task** – which sequence of actions reaches a given state/situation?
  - $\exists seq\ At(G, [1,1], Result(seq, S_0))$



Each **action** can be described using two axioms:

- **possibility axiom:** Preconditions $\Leftrightarrow$ Poss(a,s)
  - At(Agent,x,s) $\wedge$ Adjacent(x,y) $\Leftrightarrow$ Poss(Go(x,y),s)
  - Gold(g) $\wedge$ At(Agent,x,s) $\wedge$ At(g,x,s) $\Leftrightarrow$ Poss(Grab(g),s)
  - Holding(g,s) $\Leftrightarrow$ Poss(Release(g),s)
- **effect axiom:** Poss(a,s) $\Rightarrow$ Changes
  - Poss(Go(x,y),s) $\Rightarrow$ At(Agent,y,Result(Go(x,y),s))
  - Poss(Grab(g),s) $\Rightarrow$ Holding(g,Result(Grab(g),s))
  - Poss(Release(g),s) $\Rightarrow$ $\neg$Holding(g,Result(Release(g),s))

Beware! This is not enough to deduce that a plan reaches a given goal.

We can deduce At(Agent, [1,2], Result(Go([1,1],[1,2]), S_0))
but we **cannot deduce** At(G, [1,2], Result(Go([1,1],[1,2]), S_0))

Effect axioms describe what has been changed in the world but they say nothing about the property that everything else is not changed!

This is a so called **frame problem.**

Frame problem

We need to represent properties that are not changed by actions.

A simple **frame axiom** says what is not changed:

$$At(o,x,s) \wedge o \neq Agent \wedge \neg Holding(o,s) \Rightarrow At(o,x,Result(Go(y,z),s))$$

- for F fluents and A actions we need O(FA) frame axioms
- This is a lot especially taking in account that most predicates are not changed.

Frame problem: better axioms

Can we use less axioms to model the frame problem?

- **successor-state axiom**

  $Poss(a,s) \Rightarrow$
  $\quad (\text{fluent holds in } Result(a,s) \Leftrightarrow$
  $\quad\quad \text{fluent is effect of } a \vee (\text{fluent holds in } s \wedge a \text{ does not change fluent}))$

  – We get F axioms (F is the number of fluents) with O(AE) literals in total (A is the number of actions, E is the number of effects).

  Examples:

  $Poss(a,s) \Rightarrow$
  $\quad (At(Agent,y,Result(a,s)) \Leftrightarrow a=Go(x,y) \vee (At(Agent,y,s) \wedge a \neq Go(y,z)))$

  $Poss(a,s) \Rightarrow$
  $\quad (Holding(g,Result(a,s)) \Leftrightarrow a=Grab(g) \vee (Holding(g,s) \wedge a \neq Release(g)))$

  Beware of implicit effects!

  - If an agent holds some object and the agent moves then the object also moves.
  - This is called a **ramification problem**.

  $Poss(a,s) \Rightarrow$
  $\quad (At(o,y,Result(a,s)) \Leftrightarrow$
  $\quad\quad (a=Go(x,y) \wedge (o=Agent \vee Holding(o,s))) \vee$
  $\quad\quad (At(o,y,s) \wedge \neg\exists z\, (y \neq z \wedge a=Go(y,z) \wedge (o=Agent \vee Holding(o,s)))))$

Frame problem: even better axioms

Successor-state axiom is still too big with O(AE/F) literals in average.

- To solve the projection task with t actions, the time complexity depends on the total number of actions – O(AEt) – rather than on the actions in plan.
- If we know each action, cannot we do it better, say O(Et)?

classical successor-state axiom:

$Poss(a,s) \Rightarrow$
$(F_i(Result(a,s)) \Leftrightarrow (a=A_1 \lor a=A_2 \lor \ldots) \lor (F_i(s) \land a \neq A_3 \land a \neq A_4 \ldots))$

actions having F_i among effects

actions having $\neg F_i$ among effects

We can introduce **positive** and **negative effects** of actions:

- **PosEffect(a, F_i)** action a causes F_i to become true
- **NegEffect(a, F_i)** action a causes F_i to become false

modified successor-state axiom:

$Poss(a,s) \Rightarrow (F_i(Result(a,s)) \Leftrightarrow PosEffect(a, F_i) \lor (F_i(s) \land \neg NegEffect(a,F_i)))$
$PosEffect(A_1, F_i)$
$PosEffect(A_2, F_i)$
$NegEffect(A_3, F_i)$
$NegEffect(A_4, F_i)$

Department of Theoretical Computer Science and Mathematical Logic
bartak@ktiml.mff.cuni.cz