Based on ppt slides for CMSC 421 by B.J. Dorr

Artificial Intelligence I: knowledge representation

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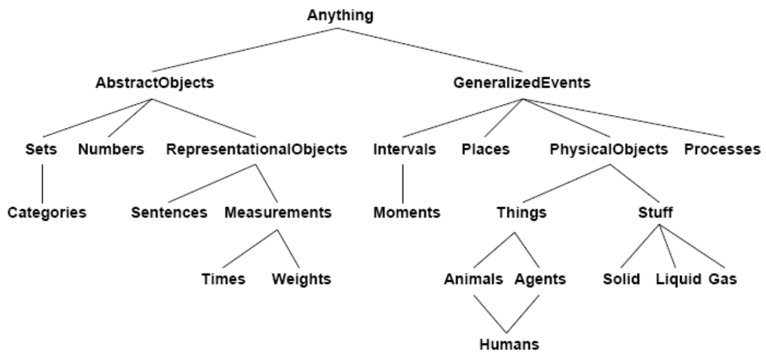
Outline

- Ontological engineering
- Categories and objects
- Actions, situations and events
- Mental events and mental objects
- The internet shopping world
- Reasoning systems for categories
- Reasoning with default information
- Truth maintenance systems

Ontological engineering

- How to create more general and flexible representations.
  - **Concepts like actions, time, physical object and beliefs**
  - **Operates on a bigger scale than K.E.**
- Define general framework of concepts
  - **Upper ontology**
- Limitations of logic representation
  - **Red, green and yellow tomatoes: exceptions and uncertainty**

The upper ontology of the world



Difference with special-purpose ontologies

- A general-purpose ontology should be applicable in more or less any special-purpose domain.
  - **Add domain-specific axioms**
- In any sufficiently demanding domain different areas of knowledge need to be unified.
  - **Reasoning and problem solving could involve several areas simultaneously**
- What do we need to express?

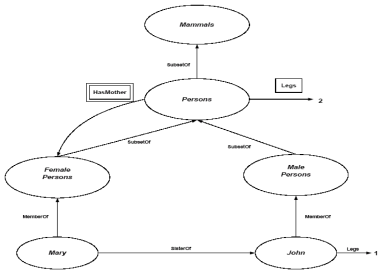
  Categories, Measures, Composite objects, Time, Space, Change, Events, Processes, Physical Objects, Substances, Mental Objects, Beliefs

Categories and objects

- KR requires the organisation of objects into categories
  - **Interaction at the level of the object**
  - **Reasoning at the level of categories**
- Categories play a role in predictions about objects
  - **Based on perceived properties**
- Categories can be represented in two by FOL
  - **Predicates: apple(x)**
  - ***Reification* of categories into objects: apples**
- Category = set of its members

Category organization

- Relation = *inheritance*:
  - **All instance of food are edible, fruit is a subclass of food and apples is a subclass of fruit then an applied is edible.**
- Defines a taxonomy



FOL and categories

- An object is a member of a category
  - **MemberOf(BB_{12},Basketballs)**
- A category is a subclass of another category
  - **SubsetOf(Basketballs,Balls)**
- All members of a category has some properties
  - **∀ x (MemberOf(x,Basketballs) ⇒ Round(x))**
- All members of a category can be recognized by some properties
  - **∀ x (Orange(x) ∧ Round(x) ∧ Diameter(x)=9.5in ∧ MemberOf(x,Balls) ⇒ MemberOf(x,BasketBalls))**
- A category as a whole has some properties
  - **MemberOf(Dogs,DomesticatedSpecies)**

Relations between categories

- Two or more categories are ***disjoint*** if they have no members in common:
  - **Disjoint(s)⇔(∀ c_1,c_2 $c_1 \in s \wedge c_2 \in s \wedge c_1 \neq c_2 \Rightarrow$ Intersection(c_1,c_2) ={})**
  - **Example; Disjoint({animals, vegetables})**
- A set of categories *s* constitutes an ***exhaustive decomposition*** of a category *c* if all members of the set *c* are covered by categories in *s*:
  - **E.D.(s,c) ⇔ (∀ i $i \in c \Rightarrow \exists c_2$ $c_2 \in s \wedge i \in c_2$)**
  - **Example: ExhaustiveDecomposition({Americans, Canadian, Mexicans},NorthAmericans).**

Relations between categories

- A ***partition*** is a disjoint exhaustive decomposition:
  - **Partition(s,c) ⇔ Disjoint(s) ∧ E.D.(s,c)**
  - **Example: Partition({Males,Females},Persons).**
- Is ({Americans,Canadian, Mexicans},NorthAmericans) a partition?
- Categories can be defined by providing necessary and sufficient conditions for membership
  - **∀ x Bachelor(x) ⇔ Male(x) ∧ Adult(x) ∧ Unmarried(x)**

Natural kinds

- Many categories have no clear-cut definitions (chair, bush, book).
- Tomatoes: sometimes green, red, yellow, black. Mostly round.
- One solution: category *Typical(Tomatoes).*
  - **$\forall$ x, x $\in$ Typical(Tomatoes) $\Rightarrow$ Red(x) $\wedge$ Spherical(x).**
  - **We can write down useful facts about categories without providing exact definitions.**
- What about "bachelor"? Quine challenged the utility of the notion of *strict definition*. We might question a statement such as "the Pope is a bachelor".

Physical composition

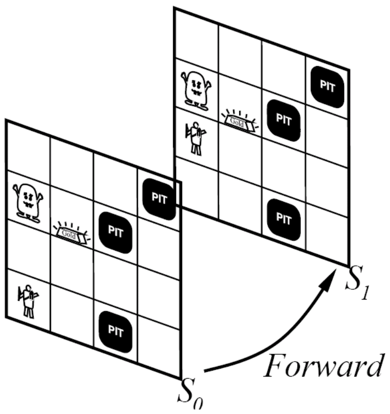
- One object may be part of another:
  - **PartOf(Bucharest,Romania)**
  - **PartOf(Romania,EasternEurope)**
  - **PartOf(EasternEurope,Europe)**
- The PartOf predicate is transitive (and irreflexive), so we can infer that PartOf(Bucharest,Europe)
- More generally:
  - **$\forall$ x PartOf(x,x)**
  - **$\forall$ x,y,z PartOf(x,y) $\wedge$ PartOf(y,z) $\Rightarrow$ PartOf(x,z)**
- Often characterized by structural relations among parts.
  - **E.g. Biped(a) $\Rightarrow$**

$$(\exists l_1, l_2, b)(Leg(l_1) \wedge Leg(l_2) \wedge Body(b) \wedge$$
$$PartOf(l_1, a) \wedge PartOf(l_2, a) \wedge PartOf(b, a) \wedge$$
$$Attached(l_1, b) \wedge Attached(l_2, b) \wedge$$
$$l_1 \neq l_2 \wedge (\forall l_3)(Leg(l_3) \Rightarrow (l_3 = l_1 \vee l_3 = l_2)))$$

Measurements

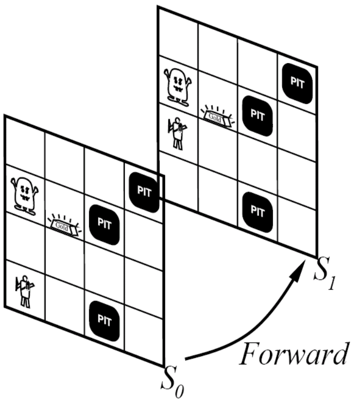
- Objects have height, mass, cost, ...
  Values that we assign to these are **measures**
- Combine Unit functions with a number: Length(L_1) = Inches(1.5) = Centimeters(3.81).
- Conversion between units:
  ∀ i Centimeters(2.54 x i)=Inches(i).
- Some measures have no scale: Beauty, Difficulty, etc.
  - **Most important aspect of measures: is that they are orderable.**
  - **Don't care about the actual numbers. (An apple can have deliciousness .9 or .1.)**

Actions, events and situations



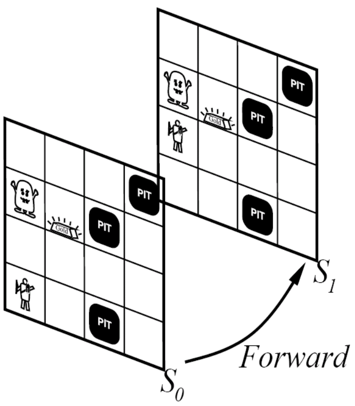
- Reasoning about outcome of actions is central to KB-agent.
- How can we keep track of location in FOL?
  - **Remember the multiple copies in PL.**
- Representing time by situations (states resulting from the execution of actions).
  - **Situation calculus**

Actions, events and situations



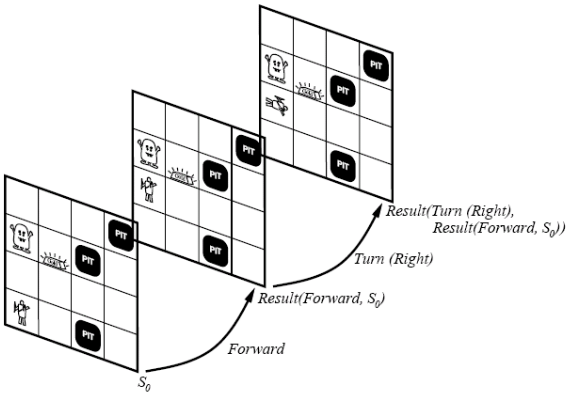
- Situation calculus:
  - **Actions are logical terms**
  - **Situations are logical terms consiting of**
    - The initial situation I
    - All situations resulting from the action on I (=*Result(a,s)*)
  - **Fluent are functions and predicates that vary from one situation to the next.**
    - E.g. $\neg Holding(G_1, S_0)$
  - **Eternal predicates are also allowed**
    - E.g. $Gold(G_1)$

Actions, events and situations



- Results of action sequences are determined by the individual actions.
- *Projection task:* an SC agent should be able to deduce the outcome of a sequence of actions.
- *Planning task:* find a sequence that achieves a desirable effect

Actions, events and situations



Describing change

- Simples Situation calculus requires to axioms to describe change:
  - **Possinility axiom: when is it possible to do the action**

    $At(Agent,x,s) \wedge Adjacent(x,y) \Rightarrow Poss(Go(x,y),s)$
  - **Effect axiom: describe changes due to action**

    $Poss(Go(x,y),s) \Rightarrow At(Agent,y,Result(Go(x,y),s))$
- What stays the same?
  - **Frame problem: how to represent all things that stay the same?**
  - **Frame axiom: describe non-changes due to actions**

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

Representational frame problem

- If there are F fluents and A actions then we need AF frame axioms to describe other objects are stationary unless they are held.
  - **We write down the effect of each actions**
- Solution; describe how each fluent changes over time
  - **Successor-state axiom:**

    $Pos(a,s) \Rightarrow (At(Agent,y,Result(a,s)) \Leftrightarrow (a = Go(x,y)) \vee$

    $(At(Agent,y,s) \wedge a \neq Go(y,z))$
  - **Note that next state is completely specified by current state.**
  - **Each action effect is mentioned only once.**

Other problems

- How to deal with secondary (implicit) effects?
  - **If the agent is carrying the gold and the agent moves then the gold moves too.**
  - **Ramification problem**
- How to decide whether fluents hold in the future?
  - **Inferential frame problem.**

Mental events and objects

- So far, KB agents can have beliefs and deduce new beliefs
- What about knowledge about beliefs? What about knowledge about the inference proces?
  - **Requires a model of the mental objects in someone's head and the processes that manipulate these objects.**
- Relationships between agents and mental objects: believes, knows, wants, …
  - **Believes(Lois,Flies(Superman)) with Flies(Superman) being a function … a candidate for a mental object (reification).**
  - **Agent can now reason about the beliefs of agents.**

The internet shopping world

- A Knowledge Engineering example
- An agent that helps a buyer to find product offers on the internet.
  - **IN = product description (precise or ¬precise)**
  - **OUT = list of webpages that offer the product for sale.**
- Environment = WWW
- Percepts = web pages (character strings)
  - **Extracting useful information required.**

The internet shopping world

- Find relevant product offers

  RelevantOffer(page,url,query) ⇔ Relevant(page, url, query) ∧ Offer(page)

  - **Write axioms to define Offer(x)**
  - **Find relevant pages: Relevant(x,y,z) ?**
    - Start from an initial set of stores.
    - What is a relevant category?
    - What are relevant connected pages?
  - **Require rich category vocabulary.**
    - Synonymy and ambiguity
  - **How to retrieve pages: *GetPage(url)*?**
    - Procedural attachment
- Compare offers (information extraction).

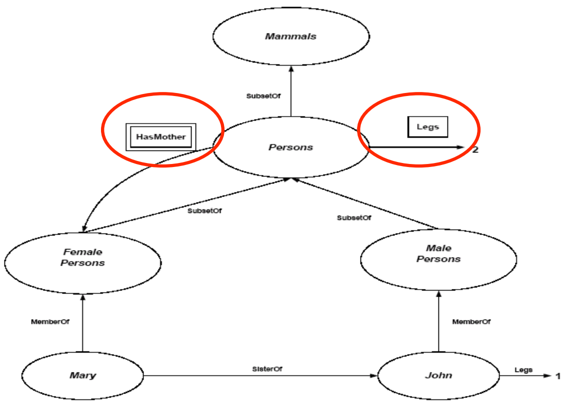
Reasoning systems for categories

- How to organise and reason with categories?
  - **Semantic networks**
    - Visualize knowledge-base
    - Efficient algorithms for category membership inference
  - **Description logics**
    - Formal language for constructing and combining category definitions
    - Efficient algorithms to decide subset and superset relationships between categories.

Semantic Networks

- Logic vs. semantic networks
- Many variations
  - **All represent individual objects, categories of objects and relationships among objects.**
- Allows for inheritance reasoning
  - **Female persons inherit all properties from person.**
  - **Cfr. OO programming.**
- Inference of inverse links
  - **SisterOf vs. HasSister**

Semantic network example



Semantic networks

- Drawbacks
  - **Links can only assert binary relations**
  - **Can be resolved by reification of the proposition as an event**
- Representation of default values
  - **Enforced by the inheritance mechanism.**

Description logics

- Are designed to describe defintions and properties about categories
  - **A formalization of semantic networks**
- Principal inference task is
  - ***Subsumption*: checking if one category is the subset of another by comparing their definitions**
  - ***Classification*: checking whether an object belongs to a category.**
  - **Consistency: whether the category membership criteria are logically satisfiable.**

Reasoning with Default Information

- "The following courses are offered: CS101, CS102, CS106, EE101"
  - Four (db)
    - **Assume that this information is complete (not asserted ground atomic sentences are false)**
    - **= CLOSED WORLD ASSUMPTION**
    - **Assume that distinct names refer to distinct objects**
    - **= UNIQUE NAMES ASSUMPTION**
  - Between one and infinity (logic)
    - **Does not make these assumptions**
    - **Requires completion.**

Truth maintenance systems

- Many of the inferences have default status rather than being absolutely certain
  - **Inferred facts can be wrong and need to be retracted = BELIEF REVISION.**
  - **Assume KB contains sentence P and we want to execute TELL(KB, ¬P)**
    - To avoid contradiction: RETRACT(KB,P)
    - But what about sentences inferred from P?
- Truth maintenance systems are designed to handle these complications.