
INF5390 – Kunstig intelligens

Knowledge Representation

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Outline

- General ontology
- Categories and objects
- Events and processes
- Reasoning systems
- Internet shopping world
- Summary

Extracts from AIMA
Chapter 12: Knowledge Representation

Ontologies

- An *ontology* is a “vocabulary” and a “theory” of a certain “part of reality”
- *Special-purpose* ontologies apply to restricted domains (e.g. electronic circuits)
- *General-purpose* ontologies have wider applicability across domains, i.e.
 - ✓ Must include concepts that cover many subdomains
 - ✓ Cannot use special “short-cuts” (such as ignoring time)
 - ✓ Must allow unification of different types of knowledge
- GP ontologies are useful in widening applicability of reasoning systems, e.g. by including time

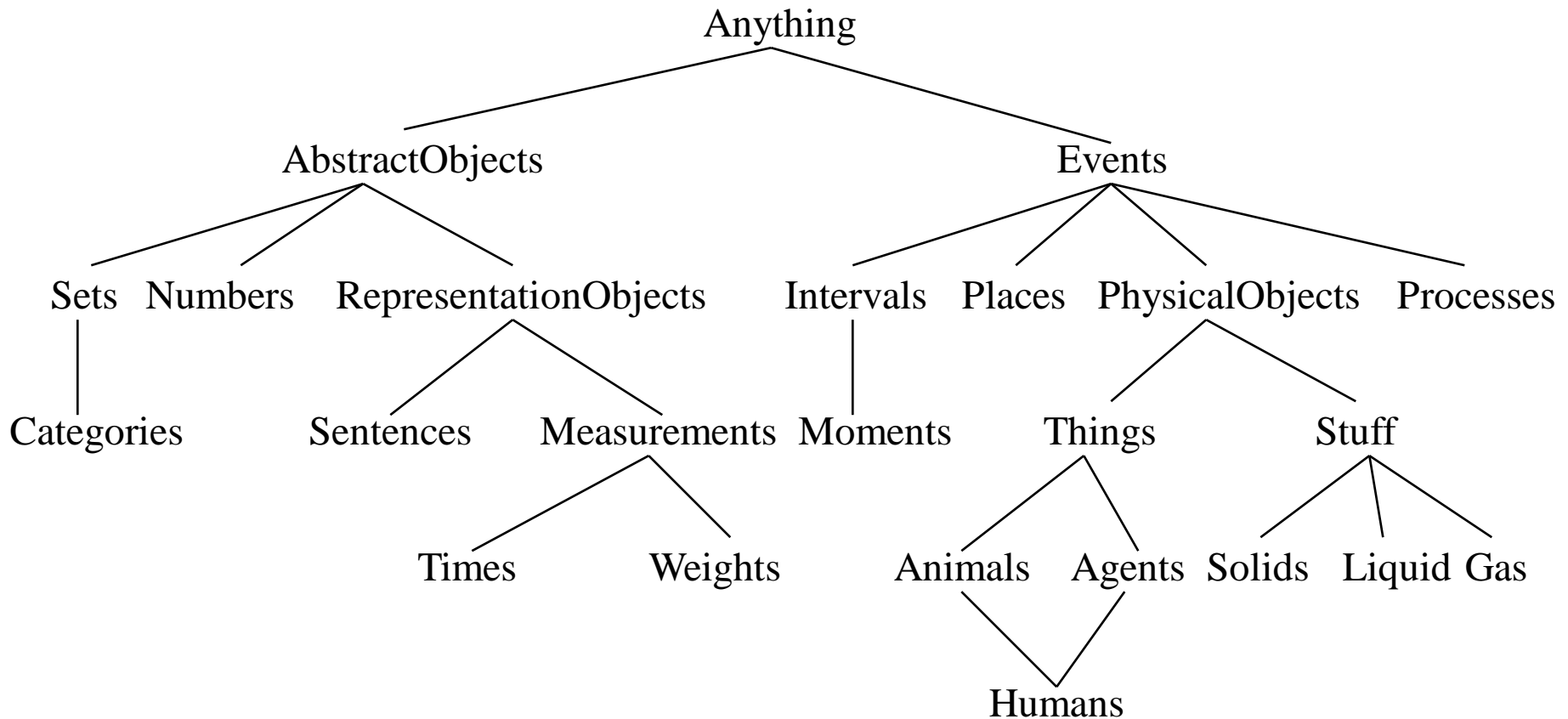
Ontological engineering

- Representing a general-purpose ontology is a difficult task called *ontology engineering*
- Existing GP ontologies have been created in different ways:
 - ✓ By team of trained ontologists
 - ✓ By importing concepts from database(s)
 - ✓ By extracting information from text documents
 - ✓ By inviting anybody to enter commonsense knowledge
- Ontological engineering has only been partially successful, and few large AI systems are based on GP ontologies (use special purpose ontologies)

Elements of a general ontology

- Categories of objects
- Measures of quantities
- Composite objects
- Time, space, and change
- Events and processes
- Physical objects
- Substances
- Mental objects and beliefs

Top-level ontology of the world



Categories and objects

- Categories are used to classify objects according to common properties or definitions

$$\forall x x \in Tomatoes \Rightarrow Red(x) \wedge Round(x)$$

- Categories can be represented by

- ✓ Predicates: $Tomato(x)$

- ✓ Sets: The constant $Tomatoes$ represents set of tomatoes (reification)

- Roles of category representations

- ✓ Instance relations (is-a): $x_1 \in Tomatoes$

- ✓ Taxonomical hierarchies ($Subset$): $Tomatoes \subset Fruit$

- ✓ Inheritance of properties

- ✓ (Exhaustive) decompositions

Objects and substance

- Need to distinguish between substance and discrete objects
- Substance (“stuff”)
 - ✓ Mass nouns - not countable
 - ✓ Intrinsic properties
 - ✓ Part of a substance is (still) the same substance
- Discrete objects (“things”)
 - ✓ Count nouns - countable
 - ✓ Extrinsic properties
 - ✓ Parts are (generally) not of same category

Composite objects

- A *composite object* is an object that has other objects as parts
- The *PartOf* relation defines the object containment, and is transitive and reflexive
$$PartOf(x, y) \wedge PartOf(y, z) \Rightarrow PartOf(x, z)$$
$$PartOf(x, x)$$
- Objects can be grouped in *PartOf* hierarchies, similar to *Subset* hierarchies
- The *structure* of the composite object describes how the parts are related

Measurements

- Need to be able to represent properties like height, mass, cost, etc. Values for such properties are *measures*
 - *Unit functions* represent and convert measures
$$\text{Length}(L_1) = \text{Inches}(1.5) = \text{Centimeters}(3.81)$$
$$\forall l \text{ Centimeters}(2.54 \times l) = \text{Inches}(l)$$
 - Measures can be used to describe objects
$$\text{Mass}(\text{Tomato}_1) = \text{Kilograms}(0.16)$$
$$\forall d \ d \in \text{Days} \Rightarrow \text{Duration}(d) = \text{Hours}(24)$$
 - Non-numerical measures can also be represented, but normally there is an *order* (e.g. $>$). Used in *qualitative physics*
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Event calculus

- *Event calculus*: How to deal with change based on representing points of time
- Reifies fluents (No: "forløp") and events
 - ✓ A fluent: $At(Shankar, Berkeley)$
 - ✓ The fluent is true at time t : $T(At(Shankar, Berkeley), t)$
- Events are instances of event categories
 - $E_1 \in Flyings \wedge Flyer(E_1, Shankar) \wedge Origin(E_1, SF) \wedge Destination(E_1, LA)$
- Event E_1 took place over interval i
 - ✓ $Happens(E_1, i)$
- Time intervals represented by (start, end) pairs
 - ✓ $i = (t_1, t_2)$

Event calculus predicates

- $T(f, t)$ Fluent f is true at time t
- $Happens(e, i)$ Event e happens over interval i
- $Initiates(e, f, t)$ Event e causes fluent f to start at t
- $Terminates(e, f, t)$ Event e causes f to cease at t
- $Clipped(f, t)$ Fluent f ceases to be true in int. i
- $Restored(f, i)$ Fluent f becomes true in interval i

Time intervals

- Time intervals are partitioned into *moments* (zero duration) and *extended intervals*

$Partition(\{Moments, ExtendedIntervals\}, Intervals)$

$\forall i i \in Intervals \Rightarrow (i \in Moments \Leftrightarrow Duration(i) = 0)$

- Functions *Start* and *End* delimit intervals

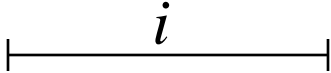
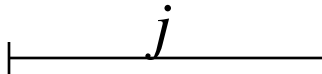
$\forall i Interval(i) \Rightarrow Duration(i) = (Time(End(i)) - Time(Start(i)))$

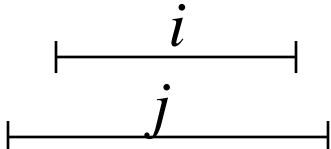
- May use e.g. January 1, 1900 as arbitrary time 0

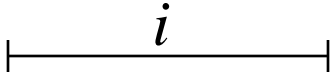
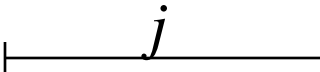
$Time(Start(AD1900)) = Seconds(0)$

Relations between time intervals

Meet(*i*, *j*) 

Before(*i*, *j*) 
After(*j*, *i*) 

During(*i*, *j*) 

Overlap(*i*, *j*) 
Overlap(*j*, *i*) 

Can be expressed logically, e.g.

$\forall i, j \text{ Meet}(i, j) \Leftrightarrow$
 $\text{Time}(\text{End}(i)) =$
 $\text{Time}(\text{Start}(j))$

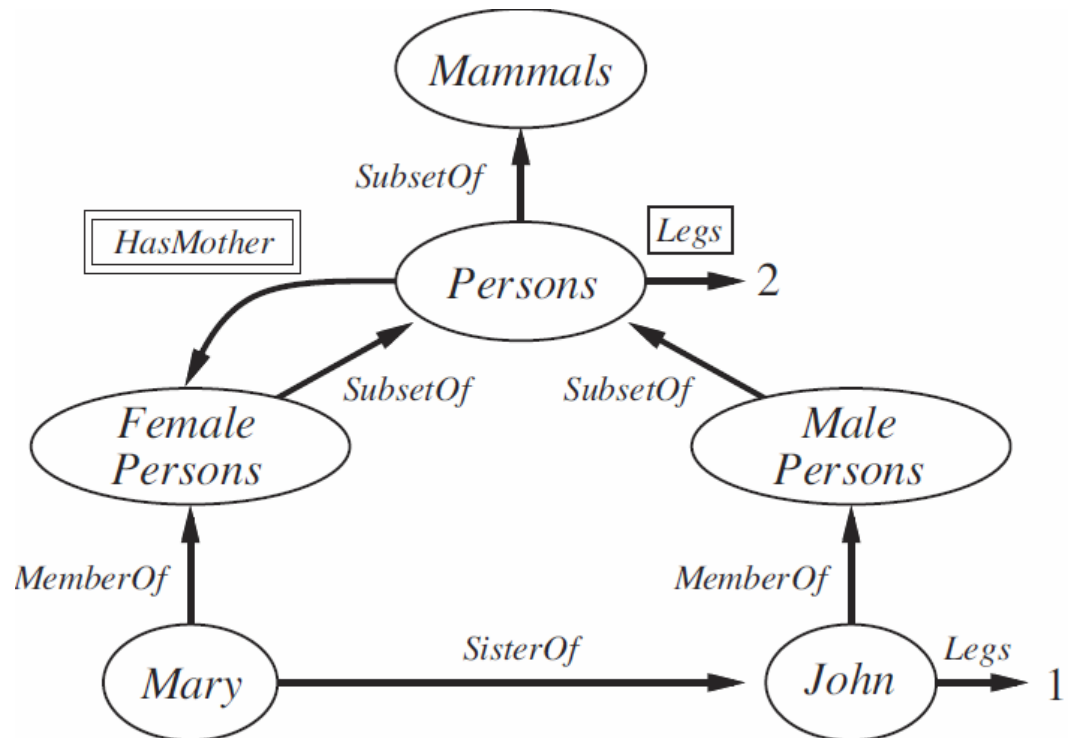
Mental events and mental objects

- Need to represent *beliefs* in self and other agents, e.g. for controlling reasoning, or for planning actions that involve others
- How are beliefs represented?
 - ✓ Beliefs are reified as *mental objects*
 - ✓ Mental objects are represented as *strings* in a language
 - ✓ Inference rules for this language can be defined
- Rules for reasoning about logical agents' use their beliefs
$$\forall a, p, q \text{ LogicalAgent}(a) \wedge \text{Believes}(a, p) \wedge$$
$$\text{Believes}(a, " p \Rightarrow q ") \Rightarrow \text{Believes}(a, q)$$
$$\forall a, p \text{ LogicalAgent}(a) \wedge \text{Believes}(a, p)$$
$$\Rightarrow \text{Believes}(a, " \text{Believes}(\text{Name}(a), p) ")$$

Semantic networks

- Graph representation of categories, objects, relations, etc. (i.e. essentially FOL)

- Natural representation of inheritance and default values



Other reasoning systems for categories

- Description logics
 - ✓ Derived from semantic networks, but more formal
 - ✓ Supports subsumption, classification and consistency
- Circumscription and default logic
 - ✓ Formalizes reasoning about default values
 - ✓ Assumes default in absence of other input; must be able to retract assumption if new evidence occurs
- Truth maintenance systems
 - ✓ Supports belief revision in systems where retracting belief is permitted

Internet shopping world

- An agent that understands and acts in an internet shopping environment
- The task is to shop for a product on the Web, given the user's product description
- The product description may be precise, in which case the agent should find the best price
- In other cases the description is only partial, and the agent has to compare products
- The shopping agent depends on having product knowledge, incl. category hierarchies

PEAS specification of shopping agent

- Performance goal
 - ✓ Recommend product(s) to match user's description
- Environment
 - ✓ All of the Web
- Actions
 - ✓ Following links
 - ✓ Retrieve page contents
- Sensors
 - ✓ Web pages: HTML, XML

Outline of agent behavior

- Start at home page of known web store(s)
 - ✓ Must have knowledge of relevant web addresses, such as www.amazon.com etc.
- Spread out from home page, following links to relevant pages containing product offers
 - ✓ Must be able to identify page relevance, using product category ontologies, as well parse page contents to detect product offers
- Having located one or more product offers, agent must compare and recommend product
 - ✓ Comparison range from simple price ranking to complex tradeoffs in several dimensions

Summary

- An *ontology* is an encoding of vocabulary and relationships. *Special-purpose* ontologies can be effective within limited domains
- A *general-purpose* ontology needs to cover a wide variety of knowledge, and is based on categories and an event calculus
- It covers structured objects, time and space, change, processes, substances, and beliefs
- The general ontology can support agent reasoning in a wide variety of domains, including the Internet shopping world