Knowledge Representation

Chapter 10

Outline

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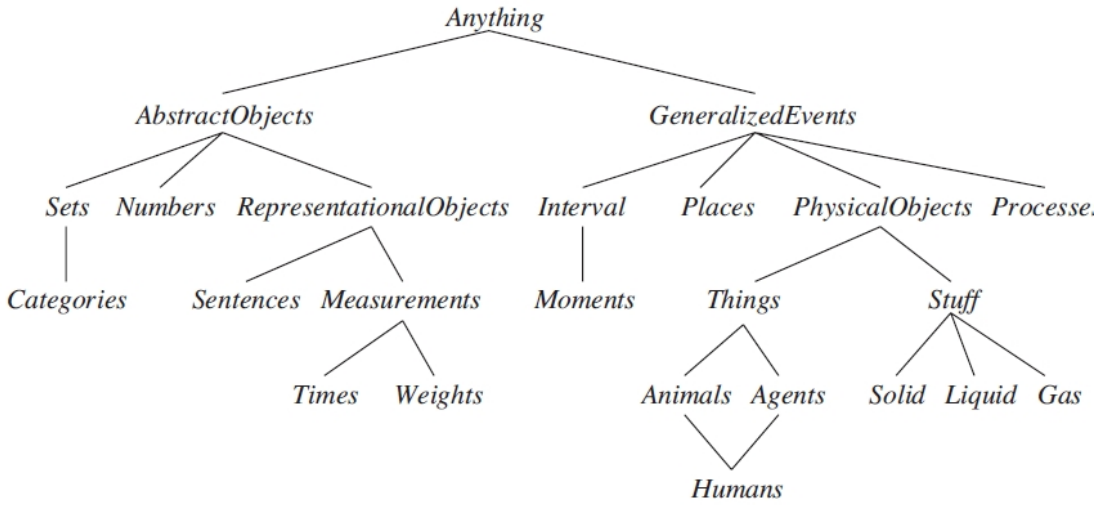
1 Ontological Engineering

2 Events
- Event calculus
- Time intervals
- Semantic networks

3 The Internet shopping world

Ontologies

An ontology is a *vocabulary* and a *theory* of a certain *part of reality* (Special-purpose/General-purpose ontologies)



Ontology engineering

- team of trained ontologists (CYC)
- importing concepts from databases (DBpedia)
- extracting information from text documents (ReVerb)
- inviting anybody to enter commonsense knowledge

Categories

Reasoning takes place at the level of categories

e.g., buying a basketball
Classify objects according to common properties (green and yellow mottled skin, one-foot diameter, ovoid shape, red flesh, black seeds, and presence in the fruit aisle)
$\forall x,\ x \in \mathit{Tomates} \Rightarrow \mathit{Red}(x) \wedge \mathit{Round}(x)$

Two choices for representing categories in FOL

- Predicates: *Basketball(b)*
- Objects (sets): *Basketballs* (reification: turning a proposition into an object)
  $b \in \mathit{Basketballs} \equiv \mathit{Member}(b, \mathit{Basketballs})$,
  $\mathit{Basketballs} \subset \mathit{Balls} \equiv \mathit{Subset}(\mathit{Basketballs}, \mathit{Balls})$

Facts about categories

- Instance relations (is-a): $b \in Basketballs$
- Taxonomical hierarchies (Subset): $Basketballs \subset Balls$ (species, library, occupations and commercial products)
- Inheritance of properties: *Food* are edible, $Fruit \subset Food$
- All members of a category have some properties: $(x \in Basketballs) \Rightarrow Spherical(x)$
- Members of a category can be recognized by some properties $Orange(x) \wedge Round(x) \wedge Diameter(x) = 9.5'' \wedge x \in Balls \Rightarrow x \in Basketballs$
- A category as a whole has some properties. $Dogs \in DomesticatedSpecies$

Categories can also be defined by providing necessary and sufficient conditions for membership

$$x \in Bachelors \Leftrightarrow Unmarried(x) \wedge x \in Adults \wedge x \in Males$$

Relations between categories that are not subclasses

- Disjoint({Animals,Vegetables}) $Disjoint(s) \Leftrightarrow (\forall c_1, c_2\ c_1 \in s \wedge c_2 \in s \wedge c_1 \neq c_2 \Rightarrow Intersection(c_1, c_2) = \{\})$
- ExhaustiveDecomposition({Americans,Canadians, Mexicans},NorthAme)

  $ExhaustiveDecomposition(s, c) \Leftrightarrow (\forall i\ i \in c \Leftrightarrow \exists c_2\ c_2 \in s \wedge i \in c_2)$
- Partition({Males, Females}, Animals)

  $Partition(s, c) \Leftrightarrow Disjoint(s) \wedge ExhaustiveDecomposition(s, c)$

Composite objects

PartOf (Bucharest, Romania)
PartOf (Romania, EasternEurope)
PartOf (EasternEurope, Europe)
PartOf defines the object containment, and is transitive and reflexive
$PartOf(x, y) \wedge PartOf(y, z) \Rightarrow PartOf(x, z)$
$PartOf(x, x)$
Characterized by structural relations among parts

Example (A biped has two legs attached to a body)

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

Bunch

Composite objects with definite parts but no particular structure.

Example (The apples in this bag weigh two pounds)

$BunchOf(Apple_1, Apple_2, Apple_3)$
composite object with three apples as parts (not elements)
$BunchOf(\{x\}) = x$
$BunchOf(Apples)$ - composite object consisting of all apples

Logical minimization

Define *BunchOf* in terms of the *PartOf* relation:

$$\forall x \; x \in s \Rightarrow PartOf(x, BunchOf(s))$$

$BunchOf(s)$ is the smallest object satisfying this condition ($BunchOf(s)$ must be part of any object that has all the elements of s as parts):

$$\forall y[\forall x \; x \in s \Rightarrow PartOf(x, y)] \Rightarrow PartOf(BunchOf(s), y)$$

Measurements

Need to be able to represent properties like height, mass, cost, etc. Values for such properties are measures

Example (Unit functions)

$Length(L1) = Inches(1.5) = Centimeters(3.81)$
$Centimeters(2.54 \times d) = Inches(d)$
$Diameter(Basketball_{12}) = Inches(9.5)$
$ListPrice(Basketball_{12}) = (19)$
$d \in Days \Rightarrow Duration(d) = Hours(24)$

Representing non-quantitative measures

$e_1 \in Exam \wedge e_2 \in Exam \wedge During(FirstSession, e_1) \wedge$
$During(SecondSession, e_2) \Rightarrow Difficulty(e_2) > Difficulty(e_1)$
$e_1 \in Exam \wedge e_2 \in Exam \wedge Difficulty(e_2) > Difficulty(e_1) \Rightarrow$
$ExpectedScore(e_2) < ExpectedScore(e_1)$

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Event calculus

Continuous action, *filling a bathtub*. Situation calculus can say that the tub is empty before the action and full when the action is done, but it canât talk about what happens during the action.
Actions happening at the same time - brushing oneâs teeth while waiting for the tub to fill

$$T(At(Mircea, TUCN), t)$$

Events are described as instances of event categories
$E_1 \in Flyings \wedge Flyer(E_1, Mircea) \wedge Origin(E_1, Cluj) \wedge Destination(E_1, Bucuresti)$
$E_1 \in Flyings(Mircea, Cluj, Bucuresti)$

Predicates for event calculus

$T(f, t)$	Fluent f is true at time t
$Happens(e, i)$	Event e happens over the time interval i
$Initiates(e, f, t)$	Event e causes fluent f to start to hold at time t
$Terminates(e, f, t)$	Event e causes fluent f to cease to hold at time t
$Clipped(f, i)$	Fluent f ceases to be true at some point during time interval i
$Restored(f, i)$	Fluent f becomes true sometime during time interval i

Event, *Start*,- which fluents are initiated or terminated at the start time

Predicates of event calculus

T - a fluent holds at a point in time if the fluent was initiated by an event at some time in the past and was not made false (clipped) by an intervening event.

$Happens(e,(t_1,t_2)) \wedge Initiates(e,f,t_1) \wedge \neg Clipped(f,(t_1,t)) \wedge t_1 < t \Rightarrow T(f,t)$

A fluent does not hold if it was terminated by an event and not made true (restored) by another event

$Happens(e,(t_1,t_2)) \wedge Terminates(e,f,t_1) \wedge \neg Restored(f,(t_1,t)) \wedge t_1 < t \Rightarrow \neg T(f,t)$

$Clipped(f,(t_1,t_2)) \Leftrightarrow \exists e,t,t_3\ Happens(e,(t,t_3)) \wedge t_1 \leq t < t_2 \wedge Terminates(e,f,t)$

$Restored(f,(t_1,t_2)) \Leftrightarrow \exists e,t,t_3 Happens(e,(t,t_3)) \wedge t_1 \leq t < t_2 \wedge Initiates(e,f,t)$

$T(f,(t_1,t_2)) \Leftrightarrow [\forall t(t_1 \leq t < t_2) \Rightarrow T(f,t)]$

Examples of event calculus

Example (Wumpus-world agent)

The only way a wumpus-world agent gets an arrow is at the start, and the only way to use up an arrow is to shoot it:
$Initiates(e, HaveArrow(a), t) \Leftrightarrow e = Start$
$Terminates(e, HaveArrow(a), t) \Leftrightarrow e \in Shootings(a)$

Processes

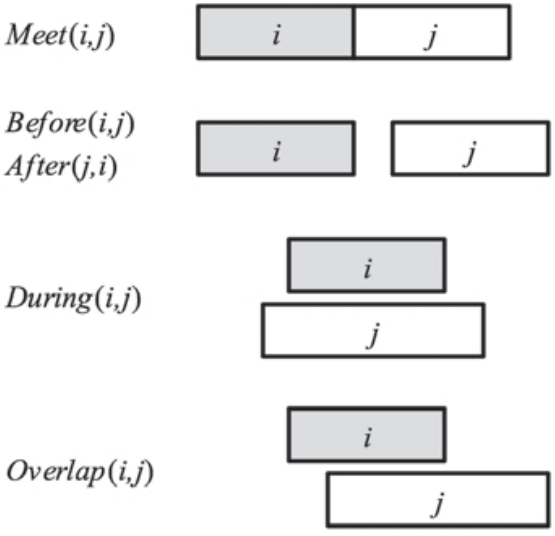
- Discrete events: Mircea's trip has a beginning, middle, and end. If interrupted halfway, the event would be something different
- Processes (liquid events) *Flyings* - If we take a small interval of Mircea's flight (i.e., 20-minute segment), that event is still a member of *Flyings*
- Any process e that happens over an interval also happens over any subinterval
  $(e \in \mathit{Processes}) \wedge \mathit{Happens}(e, (t_1, t_4)) \wedge (t_1 < t_2 < t_3 < t_4) \Rightarrow \mathit{Happens}(e, (t_2, t_3))$
- Temporal substances- same distinction as "stuff vs. things"

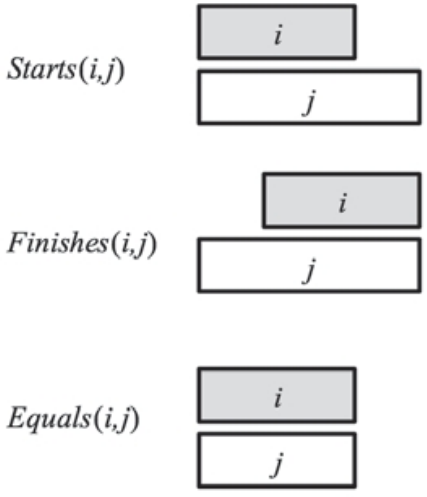
Moments and intervals

$$Partition(\{Moments, ExtendedIntervals\}, Intervals)$$
$$i \in Moments \Leftrightarrow Duration(i) = Seconds(0)$$
$$Interval(i) \Rightarrow Duration(i) = (Time(End(i)) - Time(Begin(i)))$$
$$Time(Begin(AD1900)) = Seconds(0)$$
$$Time(Begin(AD2001)) = Seconds(3187324800)$$
$$Time(End(AD2001)) = Seconds(3218860800)$$
$$Duration(AD2001) = Seconds(31536000)$$
$$Date : (hours, minutes, seconds, day, month, andyear) -> TimePoint$$
$$Time(Begin(AD2001)) = Date(0, 0, 0, 1, Jan, 2001)$$
$$Date(0, 20, 21, 24, 1, 1995) = Seconds(3000000000)$$

Predicates on time intervals

$$
\begin{aligned}
Meet(i,j) &\Leftrightarrow End(i) = Begin(j)\\
Before(i,j) &\Leftrightarrow End(i) < Begin(j)\\
After(j,i) &\Leftrightarrow Before(i,j)\\
During(i,j) &\Leftrightarrow Begin(j) < Begin(i) < End(i) < End(j)\\
Overlap(i,j) &\Leftrightarrow Begin(i) < Begin(j) < End(i) < End(j)\\
Begins(i,j) &\Leftrightarrow Begin(i) = Begin(j)\\
Finishes(i,j) &\Leftrightarrow End(i) = End(j)\\
Equals(i,j) &\Leftrightarrow Begin(i) = Begin(j) \wedge End(i) = End(j)
\end{aligned}
$$





Example of time intervals predicates

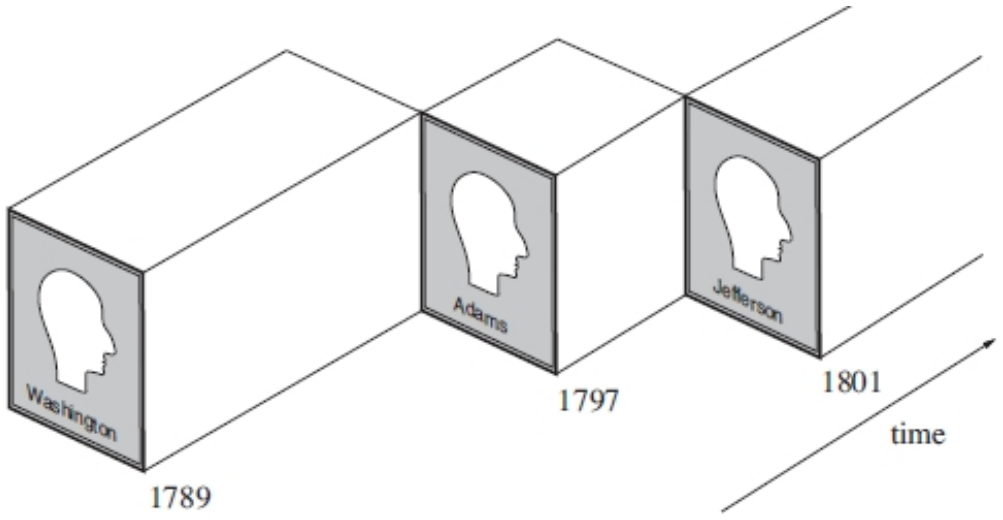
Reign of Elizabeth II immediately followed that of George VI, and the reign of Elvis overlapped with the 1950s:

Example

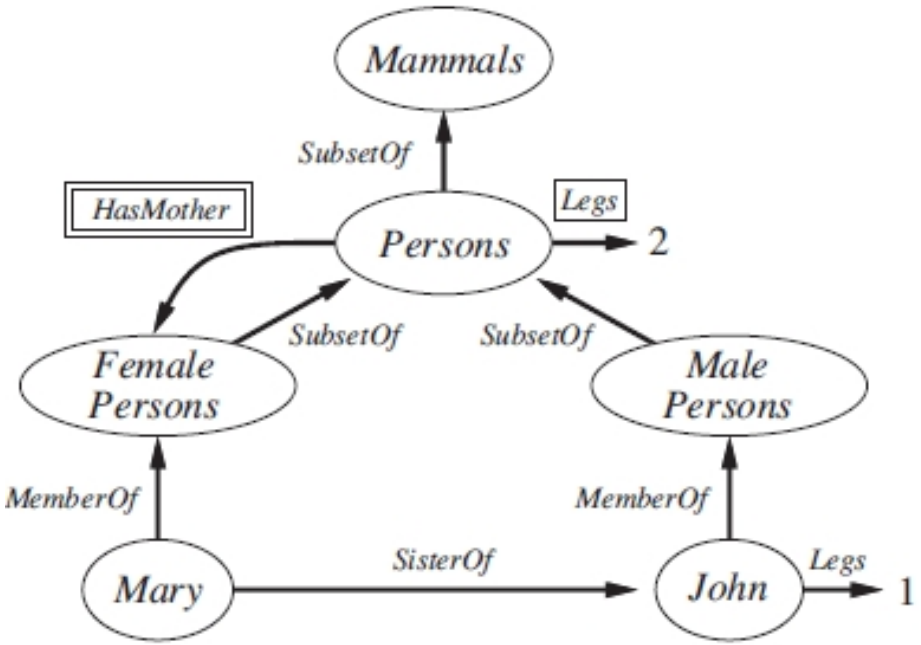
$Meets(ReignOf(GeorgeVI), ReignOf(ElizabethII))$
$Overlap(Fifties, ReignOf(Elvis))$
$Begin(Fifties) = Begin(AD1950)$
$End(Fifties) = End(AD1959)$

Fluents and objects

- A physical object: chunk of space-time (e.g., USA is an event that began in 1776 still in progress today)
- State fluents: describe the changing properties of USA (e.g., Population(USA), President(USA)
- President(USA) denotes a single object that consists of different people at different times.
  $T(Equals(President(USA), GeorgeWashington), AD1790)$



Semantic Networks



- Distinguish between relations between categories/relations between members of the categories

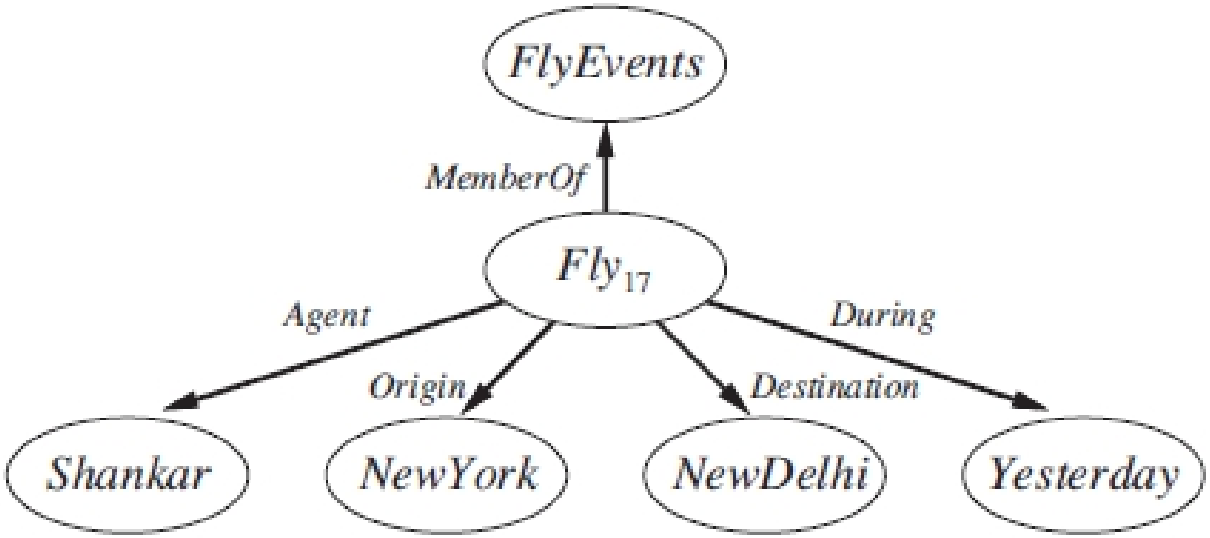
  $\forall x\ x \in \mathit{Persons} \Rightarrow [\forall y\ \mathit{HasMother}(x, y) \Rightarrow y \in \mathit{FemalePersons}]$

- Inheritance/Default values/Overriding

  $\forall x\ x \in \mathit{Persons} \wedge x \neq \mathit{John} \Rightarrow \mathit{Legs}(x, 2)$

Semantic Networks

Fly(Shankar , NewYork, NewDelhi ,Yesterday).



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Shopping agent

Shoping world

Given a product description by the buyer and has the task of producing a list of Web pages that offer such a product for sale, and ranking which offers are best (Canon Rebel XTi digital camera/digital camera for under $300). A page is an offer if it contains the words ”buy” or ”price” or ”add to cart”

Link-following strategy

$Amazon \in OnlineStores \wedge Homepage(Amazon, \text{''}amazon.com\text{''})$
$Ebay \in OnlineStores \wedge Homepage(Ebay, \text{''}ebay.com\text{''})$
$ExampleStore \in OnlineStores \wedge Homepage(ExampleStore, \text{''}example.com\text{''})$

Relevant page

Reached by a chain of zero or more relevant category links from a store’s home page, and then from one more link to the product offer
$Relevant(page, query) \Leftrightarrow \exists store, home\ store \in OnlineStores \wedge Homepage(store, home) \wedge \exists url, url_2\ RelevantChain(home, url_2, query) \wedge Link(url_2, url) \wedge page = Contents(url)$

Taxonomy for relevant categories

Relevant chain

$RelevantChain(start, end, query) \Leftrightarrow (start = end) \vee (\exists u, text\ LinkText(start, u, text) \wedge RelevantCategoryName(query, text) \wedge RelevantChain(u, end, query))$

RelevantCategoryName(query, text)

- The text and query name the same category (synonymy/ambiguity)
- The text names a supercategory such as ”computers”
- The text names a subcategory such as ”ultralight notebooks”

$RelevantCategoryName(query, text) \Leftrightarrow \exists c_1, c_2 Name(query, c_1) \wedge Name(text, c_2) \wedge (c_1 \subset c_2 \vee c_2 \subset c_1)$

$Books \subset Products$
$MusicRecordings \subset Products$
$\quad MusicCDs \subset MusicRecordings$
$Electronics \subset Products$
$\quad DigitalCameras \subset Electronics$
$\quad StereoEquipment \subset Electronics$
$\quad Computers \subset Electronics$

$Name(\text{“}books\text{”}, Books)$
$Name(\text{“}music\text{”}, MusicRecordings)$
$\quad Name(\text{“}CDs\text{”}, MusicCDs)$
$Name(\text{“}electronics\text{”}, Electronics)$
$\quad Name(\text{“}digital\ cameras\text{”}, DigitalCameras)$
$\quad Name(\text{“}stereos\text{”}, StereoEquipment)$
$\quad Name(\text{“}computers\text{”}, Computers)$

Comparing offers

Wrappers for extracting information

IBM ThinkBook 970. Our price: $399.00

$\exists c, offer\ c \in LaptopComputers \wedge offer \in ProductOffers \wedge Manufacturer(c, IBM) \wedge Model(c, ThinkBook970) \wedge ScreenSize(c, Inches(14)) \wedge ScreenType(c, ColorLCD) \wedge MemorySize(c, Gigabytes(2)) \wedge CPUSpeed(c, GHz(1.2)) \wedge OfferedProduct(offer, c) \wedge Store(offer, GenStore) \wedge URL(offer, "example.com/computers/3.html") \wedge Price(offer, \$(399)) \wedge Date(offer, Today)$

Price is an attribute of offer, not the product itself (offer may change).
More complications: price depends on the method of payment
Buyer's qualifications for certain discounts

Dominance and Preferences among multiple attributes

X dominates Y if X has a better value on at least one attribute, and is not worse on any attribute
A : 1.4 GHz CPU, 2GB RAM, 250 GB disk, $299
B : 1.2 GHz CPU, 4GB RAM, 350 GB disk, $500