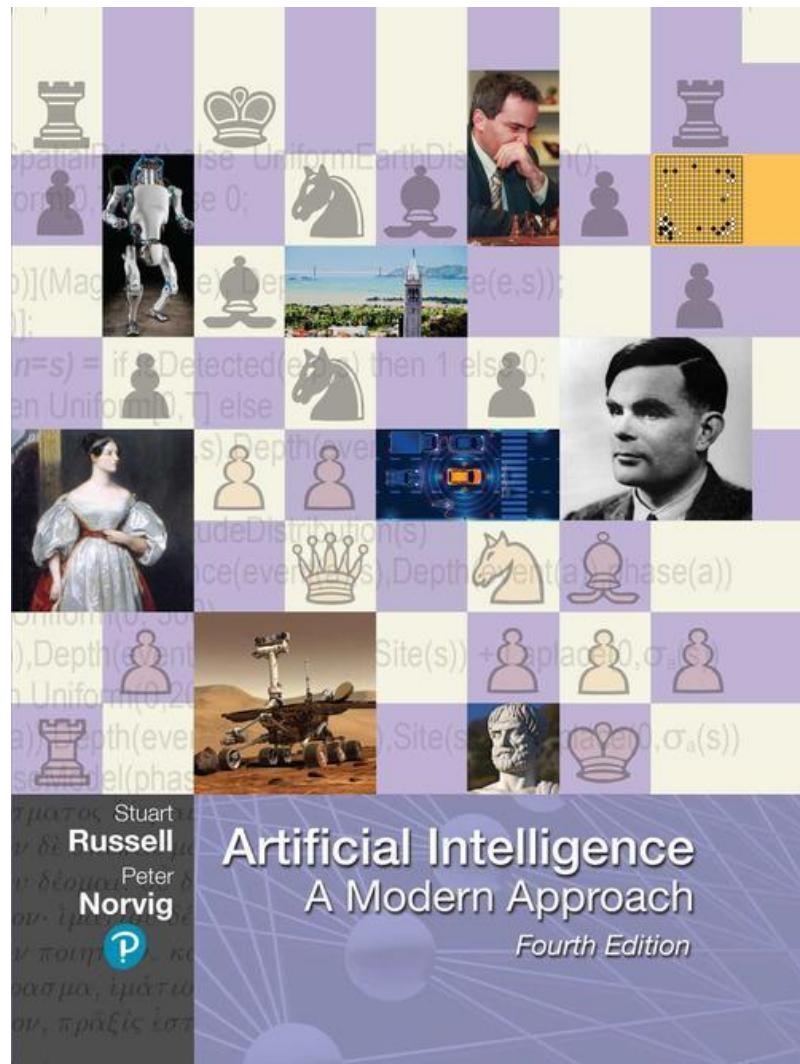


Artificial Intelligence: A Modern Approach

Fourth Edition



Chapter 10

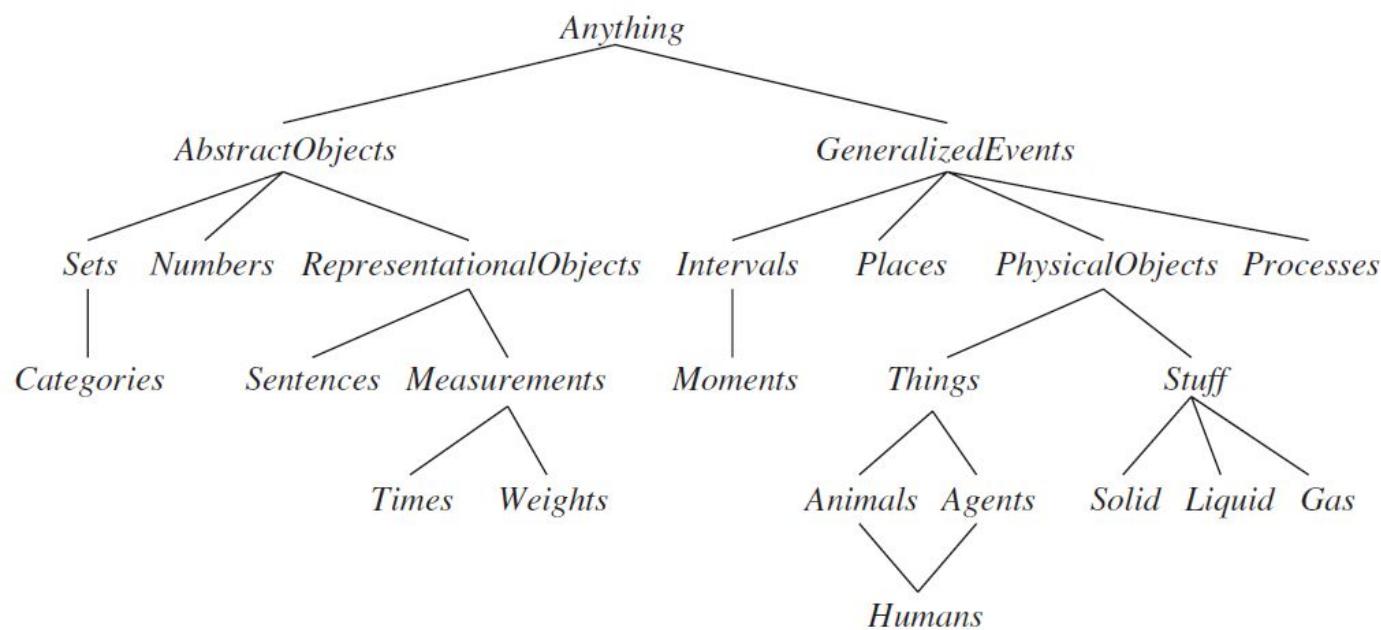
Knowledge Representation

Outline

- ◆ Ontological Engineering
- ◆ Categories and Objects
- ◆ Events
- ◆ Mental Objects and Modal Logic
- ◆ Reasoning Systems for Categories
- ◆ Reasoning with Default Information

Ontological Engineering

- **Ontological Engineering:** General and flexible representations for complex domains.
- **Upper ontology:** The general framework of concepts
- Example of ontology of the world:



Categories and Objects

- The organization of objects into categories is a vital part of knowledge representation
- Categories for FOL can be represented by predicates and objects.
- **Physical composition:** one object can be part of another is a familiar one
 - Eg: Romania is part of Bucharest. *PartOf(Bucharest, Romania)*
- **Measurements:** values that we assign for properties of objects
 - Eg: *Length(L₁)=Inches(1.5)=Centimeters(3.81)*

Categories and Objects

- **Stuff:** a significant portion of reality that seems to defy any obvious individuation—division into distinct objects
- **Intrinsic:** they belong to the very substance of the object, rather than to the object as a whole.
- **Extrinsic:** weight, length, shape
- **Substance:** a category of objects that includes in its definition only intrinsic properties (mass noun).
- **Count noun:** class that includes any extrinsic properties

Events

- **Event calculus:** events, fluents, and time points
 - Fluents (eg): *At(Shankar, Berkeley)*
 - Events (eg): Event E_1 of Shankar flying from San Francisco to DC
 - $E_1 \in Flyings \wedge Flyer(E_1, Shankar) \wedge Origin(E_1, SF) \wedge Destination(E_1, DC)$
 - *Flyings* is the category of all flying events.
- Categories for FOL can be represented by predicates and objects.
- **Physical composition:** one object can be part of another is a familiar one
 - Eg: Romania is part of Bucharest. *PartOf(Bucharest, Romania)*
- **Measurements:** values that we assign for properties of objects
 - Eg: $Length(L_1) = Inches(1.5) = Centimeters(3.81)$

Mental Objects and Modal Logic

Mental objects are knowledge in someone's head (or KB)

Propositional attitudes that an agent can have toward mental objects

- Eg: *Believes*, *Knows*, *Wants*, and *Informs*

Lois knows that Superman can fly:

$\text{Knows}(\text{Lois}, \text{CanFly}(\text{Superman}))$

Sentences can sometimes be verbose and clumsy. Regular logic is concerned with a single modality, the modality of truth.

Modal logic addresses this, with special modal operators that take sentences (rather than terms) as arguments

“A knows P” is represented with the notation $\mathbf{K}_A P$, where \mathbf{K} is the modal operator

for knowledge. It takes two arguments, an agent (written as the subscript) and a sentence.

The syntax of modal logic is the same as first-order logic, except that sentences can also be formed with modal operators

Mental Objects and Modal Logic

Agents are able to draw conclusions. If an agent knows P and knows that P implies Q , then the agent knows Q :

$$(K_a P \wedge K_a(P \Rightarrow Q)) \Rightarrow K_a Q$$

Logical agents (but not all people) are able to introspect on their own knowledge.

If they know something, then they know that they know it:

$$K_a P \Rightarrow K_a (K_a P)$$

Reasoning Systems for Categories

Semantic networks

- convenient to perform inheritance reasoning
- Eg: Mary inherits the property of having two legs. Thus, to find out how many legs Mary has, the inheritance algorithm follows the *MemberOf* link from *Mary* to the category she belongs to and then follows *SubsetOf* links up the hierarchy until it finds a category for which there is a *boxed* *Legs* link

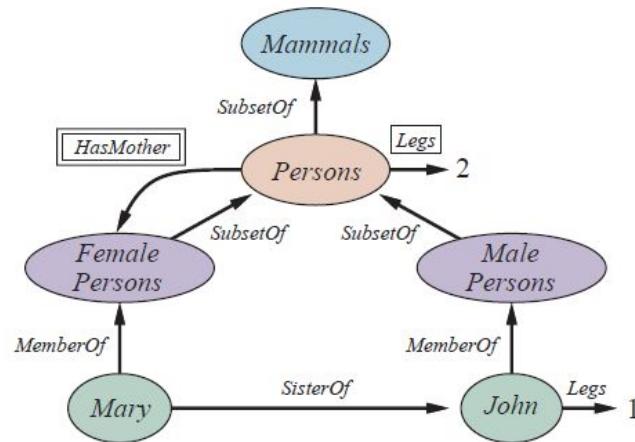


Figure 10.4 A semantic network with four objects (John, Mary, 1, and 2) and four categories. Relations are denoted by labeled links.

Reasoning Systems for Categories

Description logics

- notations that are designed to make it easier to describe definitions and properties of categories
- evolved from semantic networks in response to pressure to formalize what the networks mean while retaining the emphasis on taxonomic structure as an organizing principle
- Principal inference tasks:
 - **Subsumption**: checking if one category is a subset of another by comparing their definitions
 - **Classification**: checking whether an object belongs to a category
- The CLASSIC language (Borgida et al., 1989) is a typical description logic
 - Eg: bachelors are unmarried adult males
 - *Bachelor = And(Unmarried, Adult, Male)*

Reasoning with Default Information

Circumscription and default logic

- **Circumscription** can be seen as a more powerful and precise version of the closed-world assumption.
 - Specify particular predicates that are assumed to be “as false as possible”
 - It is an example of a model preference logic
- **Default logic** is a formalism in which default rules can be written to generate contingent nonmonotonic conclusions
 - Eg: $Bird(x) : Flies(x) / Flies(x)$
 - This rule means that if $Bird(x)$ is true, and if $Flies(x)$ is consistent with the knowledge base, then $Flies(x)$ may be concluded by default.

Reasoning with Default Information

Truth maintenance systems

- **Belief revision:** inferred facts will turn out to be wrong and will have to be retracted in
- **Truth maintenance systems**, or TMSs, are designed to handle complications of any additional sentences that inferred from a wrong sentence.
- **Justification-based truth maintenance system (JTMS)**
 - Each sentence in the knowledge base is annotated with a justification consisting of the set of sentences from which it was inferred
 - Justifications make retraction efficient
 - Assumes that sentences that are considered once will probably be considered again

Summary

- **Upper ontology** based on categories and the event calculus
- Special-purpose representation systems, such as **semantic networks** and **description logics**, have been devised to help in organizing a hierarchy of categories
- Nonmonotonic logics, such as **circumscription** and **default logic**, are intended to capture default reasoning in general.
- **Truth maintenance systems** handle knowledge updates and revisions efficiently