Knowledge Representation

Contents

Ontology

- In AI, an ontology is a representation of knowledge as a set of concepts and relationships that exist among those concepts

> In philosophy, ontology is the study of the nature of existence and what is real. It concerns what entities can be said to exist, how they can be categorized, and the relationships among the categories.

- Knowledge representation is the discipline that represents knowledge in a manner that facilitates drawing inference from the knowledge

Taxonomic Knowledge

- The entities can often be arranged in hierarchical structure or taxonomy

Example: Taxonomy represented by first-order logic

- Subset (subcategory) information:

$$\forall x\ bird(x) \rightarrow animal(x)$$

$$\forall x\ canary(x) \rightarrow bird(x)$$

$$\forall x\ ostrich(x) \rightarrow bird(x)$$

. . . .

- Set (category) membership of entities:

$$bird(Tweety)$$

$$shark(Bruce)$$

. . . .

Taxonomic Knowledge

Example: Taxonomy represented by first-order logic

- Properties of the sets (categories) and entities:

  $$\forall x \; animal(x) \rightarrow has\_skin(x)$$

  $$\forall x \; bird(x) \rightarrow can\_fly(x)$$

  . . . . . .

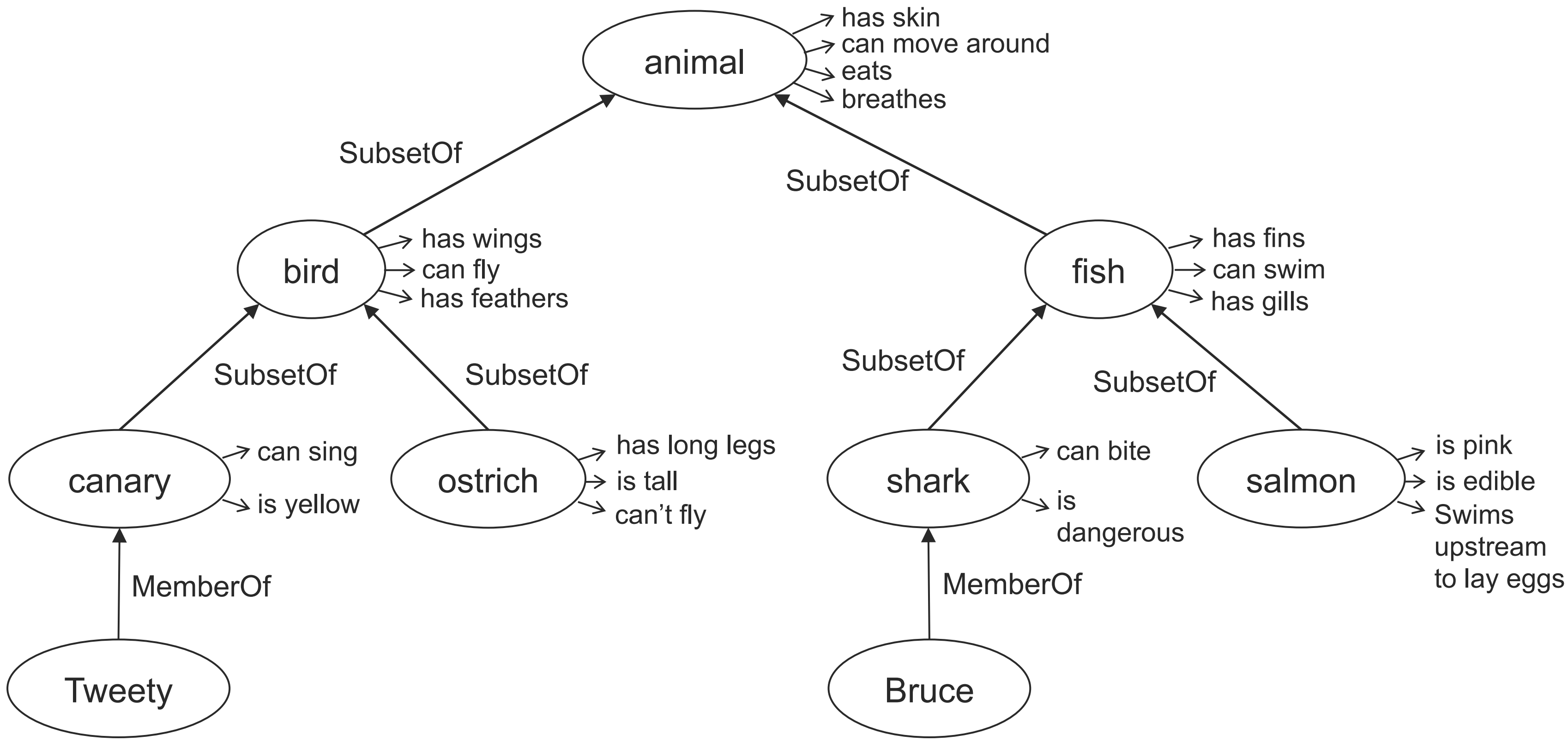
Members of a subset inherit properties associated with its superset

- Animals have skin $\Rightarrow$ Birds have skin

- Representation by FOL is cumbersome and not very transparent

Semantic Nets

Example: Graph structure for representing the same taxonomy



Semantic Nets

- Nodes:
  - Represent sets and entities
- Three types of edges:
  - Edge from a subset to a superset
  - Edge from an entity to the set of which it is a member
  - Edge from an entity or set to one of its properties
- Inheritance:
  - Properties are inherited through the *Subset* and *Member* links
  - A node inherits properties unless it has the property value specified otherwise

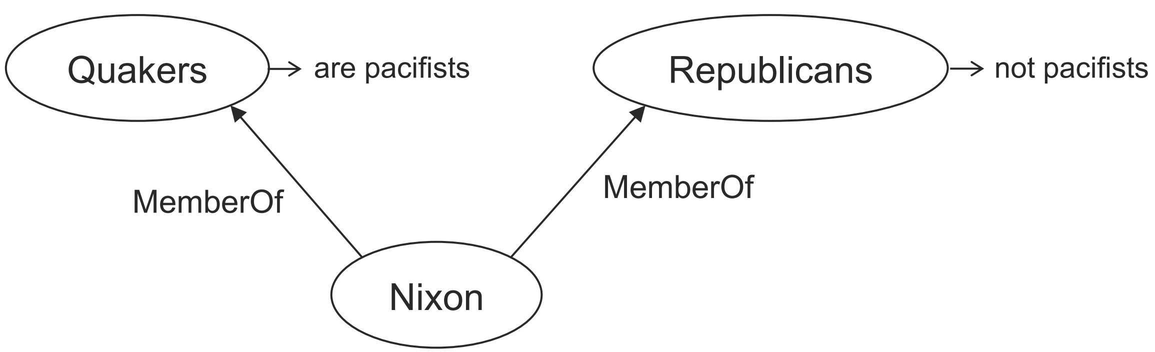
Example:

Can canaries fly? Yes Can ostriches fly? No

Semantic Nets

- Multiple inheritance:
  - An object can belong to more than one category and can inherit properties along several different paths
  - It is possible for two inheritance paths to produce conflicting answers
  - Conflicts can be resolved by using prioritization

Example: Nixon is a pacifist and is not a pacifist



Semantic Nets

- Advantages of semantic nets:
  - Capture inheritance information in a modular way
  - Easy to handle exceptions
  - Simple and easy to understand
  - Efficient

- Used in natural language processing applications
  - Semantic parsing: conversion of a natural language utterance to a machine-understandable logical form
  - Word-sense disambiguation

Expressiveness of Semantic Nets

- Semantic nets cannot easily represent
  - Negation
    - E.g., Bald people do not belong to hairy people
    - Membership in one class precludes membership in another
      $\rightarrow$ Easy in logic: $\forall x\ [Bald(x) \rightarrow \neg Hairy(x)]$
  - Disjunction
    - E.g., Opus appears in either the Times or the Newsweek
  - Quantification
    - E.g., All of Opus' friends are cartoon characters
- Uses procedural attachment to fill in the gap
  - A procedure can be stored as the value of some relation

Frames

- Data structure that can represent the knowledge in a semantic net

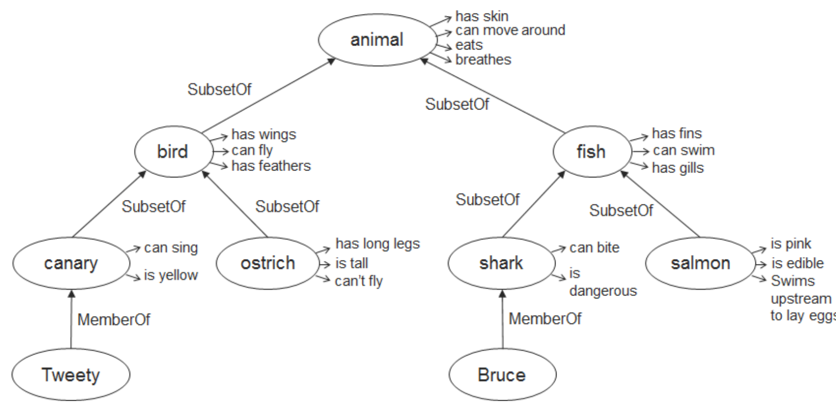
(frame-name

slot-name1: filler1;

slot-name2: filler2;

. . . . . .

)



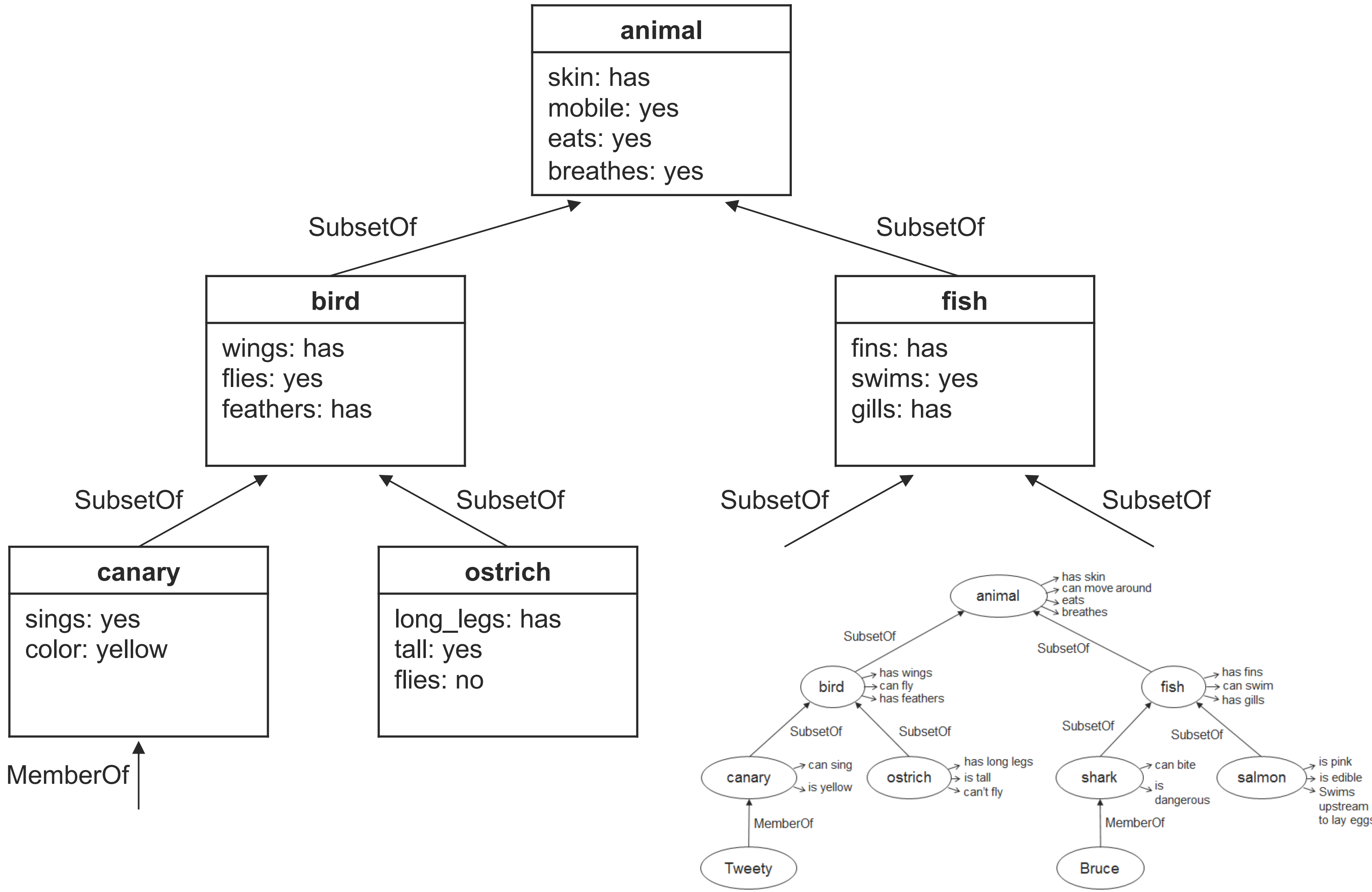
<u>Example</u>: Frames that represent the previous semantic net

(**animal**
SupersetOf: **bird**;
SupersetOf: **fish**;
skin: has;
mobile: yes;
eats: yes;
breathes: yes;
)

(**bird**
SubsetOf: **animal**;
SupersetOf: **canary**;
SupersetOf: **ostrich**;
wings: has;
flies: yes;
feathers: has;
)

* Frame names are in bold face

Frames



animal
skin: has
mobile: yes
eats: yes
breathes: yes
SubsetOf
SubsetOf
bird
wings: has
flies: yes
feathers: has
fish
fins: has
swims: yes
gills: has
SubsetOf
SubsetOf
SubsetOf
SubsetOf
canary
sings: yes
color: yellow
ostrich
long_legs: has
tall: yes
flies: no
MemberOf
animal
has skin
can move around
eats
breathes
SubsetOf
SubsetOf
bird
has wings
can fly
has feathers
fish
has fins
can swim
has gills
SubsetOf
SubsetOf
SubsetOf
SubsetOf
canary
can sing
is yellow
ostrich
has long legs
is tall
can't fly
shark
can bite
is dangerous
salmon
is pink
is edible
Swims upstream to lay eggs
MemberOf
MemberOf
Tweety
Bruce

Nonmonotonic Logic

- Monotonic logic (propositional logic & first-order logic) has no mechanism for withdrawing or overriding conclusions once derived

- Conclusions reached by humans are often only tentative, based on partial information, and they are retracted in the light of new evidence

  ➡ Nonmonotonic logic can systemize this reasoning

  - Circumscription
  - Default logic

Circumscription

- Circumscription assumption:

  No conditions change or are different than what is expected unless explicitly stated

Example: Logical statement for circumscription

$$\forall x\ bird(x) \wedge \neg\ abnormal(x) \rightarrow flies(x)$$

- The reasoner circumscribes the predicate *abnormal* (It is assumed to be false unless otherwise stated)
- If we only know $bird(Tweety)$, we deduce $flies(Tweety)$
- Suppose we include the following statement

$$\forall x\ ostrich(x) \rightarrow abnormal(x)$$

- If we know both $ostrich(Ralph)$ and $bird(Ralph)$, we could not conclude $flies(Ralph)$

Circumscription

<u>Example</u>:

$$\forall x\ Quaker(x) \wedge \neg\ abnormal_1(x) \rightarrow pacifist(x)$$

$$\forall x\ Republican(x) \wedge \neg\ abnormal_2(x) \rightarrow \neg\ pacifist(x)$$

$$Republican(Nixon) \wedge Quaker(Nixon)$$

- We could have the reasoner draw no conclusion about pacifism, or we could employ prioritized circumscription to give the priority to either one

Default Logic

- Default logic derives conclusions if they are consistent with the current state of the knowledge
- General form of a default rule:

$$\frac{A: B_1, B_2, \ldots, B_n}{C}$$

where A, B_i and C are formulas in first-order logic

A ⋯ prerequisite

$B_1, B_2, \ldots,$ and B_n ⋯ consistent conditions

C ⋯ consequent

- If any of the B_i can be proven false,
  then we cannot conclude C from A

  Otherwise we can

Default Logic

- A default theory is a pair (D, W)

  D $\cdots$ a set of default rules

  W $\cdots$ a set of sentences in first-order logic

- An extension of a default theory is a maximal set of consequences of the theory

Example: Extension of a default theory

$$D = \left\{ \frac{bird(x) : flies(x)}{flies(x)} \right\}$$

$$W = \{bird(Tweety)\}$$

- There is only one extension: $\{bird(Tweety), flies(Tweety)\}$

Default Logic

Example: Multiple extensions

$$D = \left\{ \frac{Quaker(x) : pacifist(x)}{pacifist(x)}, \frac{Republican(x) : \neg pacifist(x)}{\neg pacifist(x)} \right\}$$

$$W = \{Quaker(Nixon), Republican(Nixon)\}$$

- There are two possible extensions:

  $\{Quaker(Nixon), Republican(Nixon), pacifist(Nixon)\}$

  $\{Quaker(Nixon), Republican(Nixon), \neg pacifist(Nixon)\}$

- Prioritizing rules can give preference to one of these extensions

Difficulties with Nonmonotonic Logic

- A set of conclusions needs to be revised when knowledge changes
  - ➡ Truth maintenance systems (Doyle 1979, Goodwin 1982)

- It is difficult to base a decision on conclusions reached via this formalism
  - The conclusions are tentative and can be retracted in light of new evidence
  - The default conclusions are based only on the current evidence
  - However, we do not know how likely they are
  - ➡ Probability theory