S. S Jain Subodh P.G. (Autonomous) College

SUBJECT - ARTIFICIAL INTELLIGENCE

TITLE – KNOWLEDE REPRESENTATION AND REASONINGBY Dr. VIPIN KUMAR JAIN

# Knowledge Representation and Reasoning

# Introduction

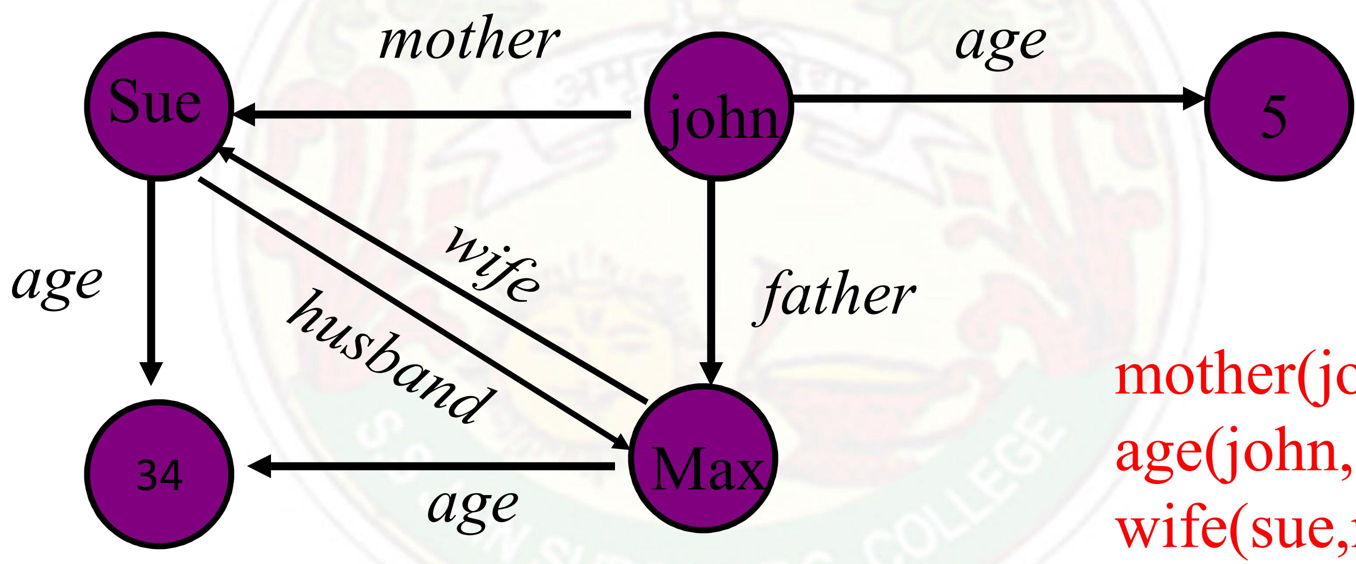
- Real knowledge representation and reasoning systems come in several major varieties.
- These differ in their intended use, expressivity, features,…
- Some major families are
  - Logic programming languages
  - Theorem provers
  - Rule-based or production systems
  - Semantic networks
  - Frame-based representation languages
  - Databases (deductive, relational, object-oriented, etc.)
  - Constraint reasoning systems
  - Description logics
  - Bayesian networks
  - Evidential reasoning

# Semantic Networks

- A semantic network is a simple representation scheme that uses a graph of labeled nodes and labeled, directed arcs to encode knowledge.
  - Usually used to represent static, taxonomic, concept dictionaries
- Semantic networks are typically used with a special set of accessing procedures that perform “reasoning”
  - e.g., inheritance of values and relationships
- Semantic networks were very popular in the ‘60s and ‘70s but are less frequently used today.
  - Often much less expressive than other KR formalisms
- The **graphical depiction** associated with a semantic network is a significant reason for their popularity.

# Nodes and Arcs

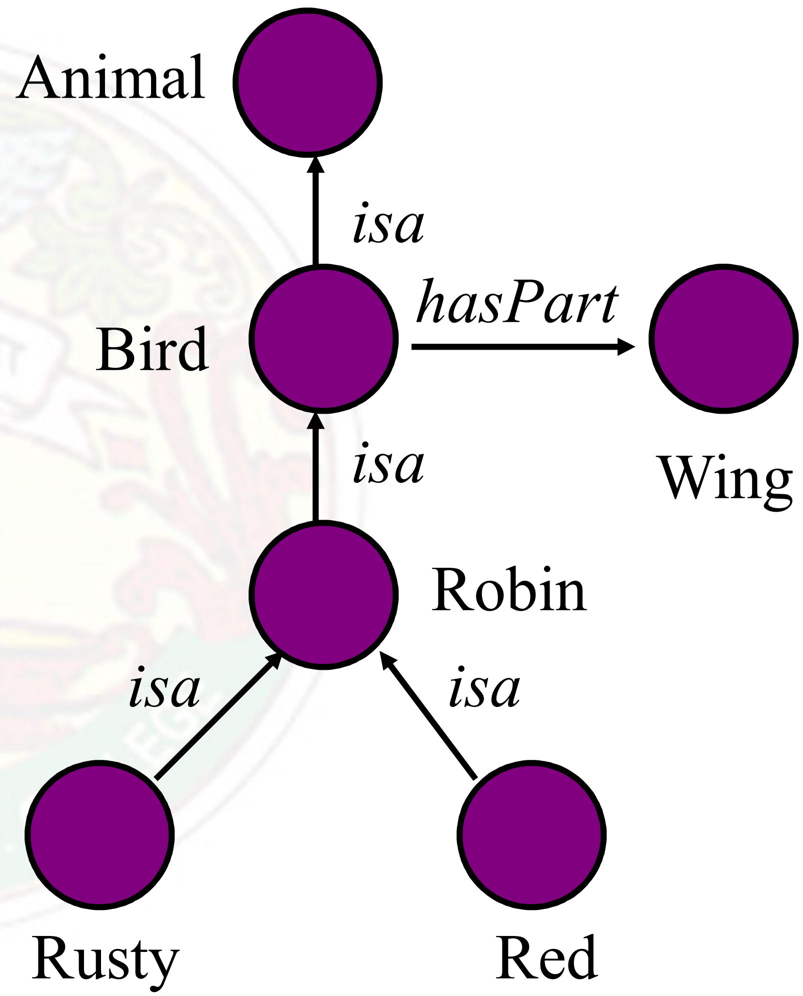
- Arcs define binary relationships that hold between objects denoted by the nodes.




mother(john,sue)
age(john,5)
wife(sue,max)
age(max,34)
...

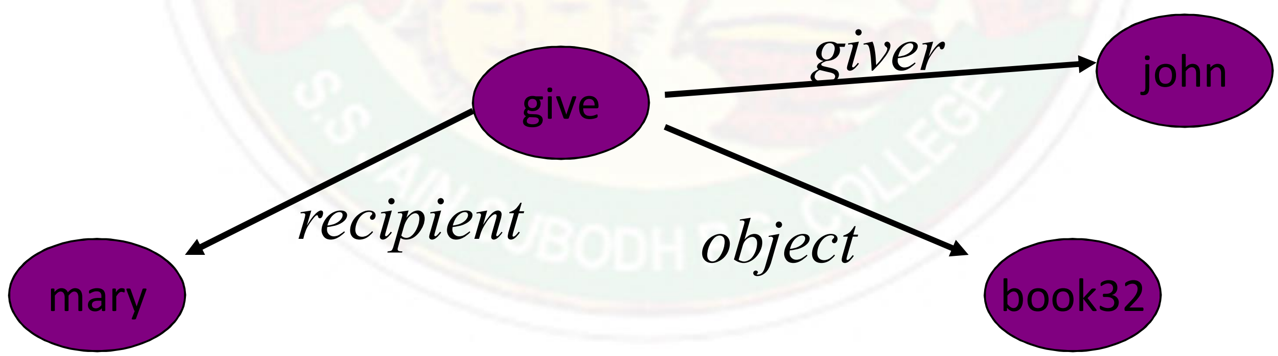
# Semantic Networks

- The ISA (is-a) or AKO (a-kind-of) relation is often used to link instances to classes, classes to superclasses
- Some links (e.g. hasPart) are inherited along ISA paths.
- The semantics of a semantic net can be relatively informal or very formal
  - often defined at the implementation level



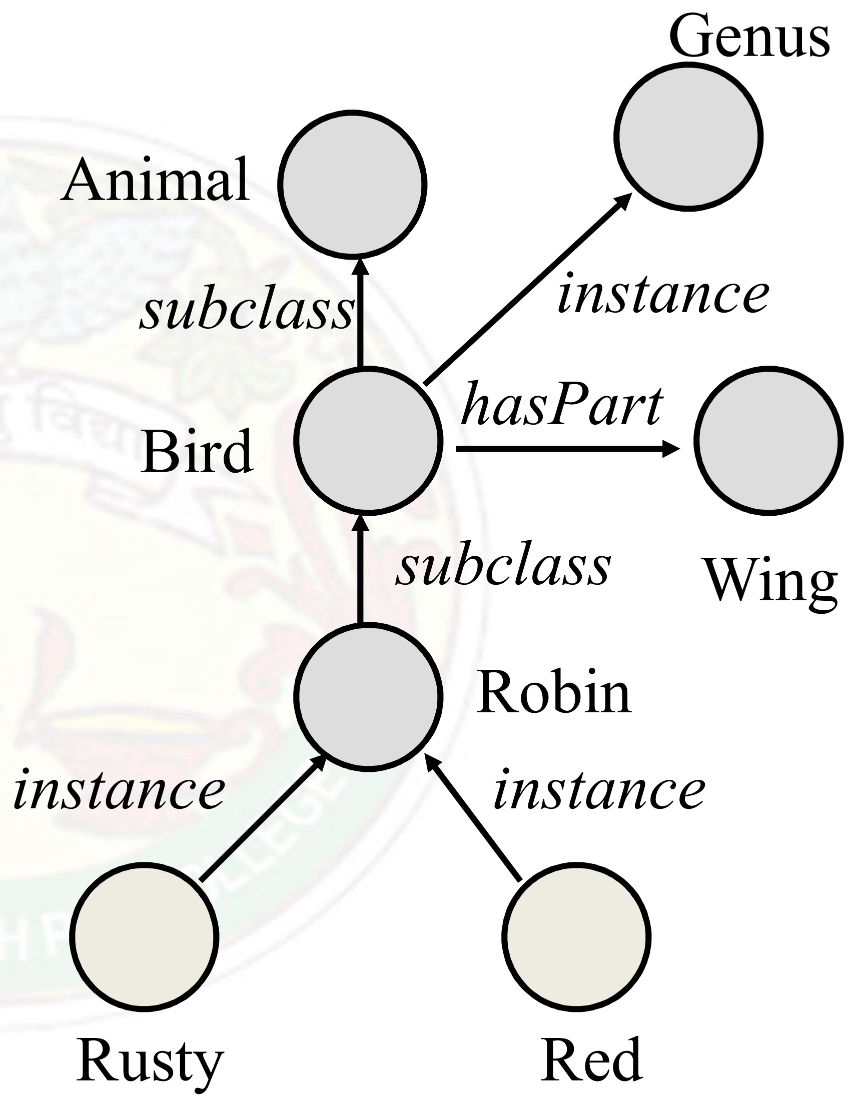
# Reification

- Non-binary relationships can be represented by "turning the relationship into an object"
- This is an example of what logicians call "reification"
  - reify v : consider an abstract concept to be real
- We might want to represent the generic give event as a relation involving three things: a giver, a recipient and an object, give(john,mary,book32)



# Individuals and Classes

- Many semantic networks distinguish
  - –nodes representing individuals and those representing classes
  - –the "subclass" relation from the "instance-of" relation



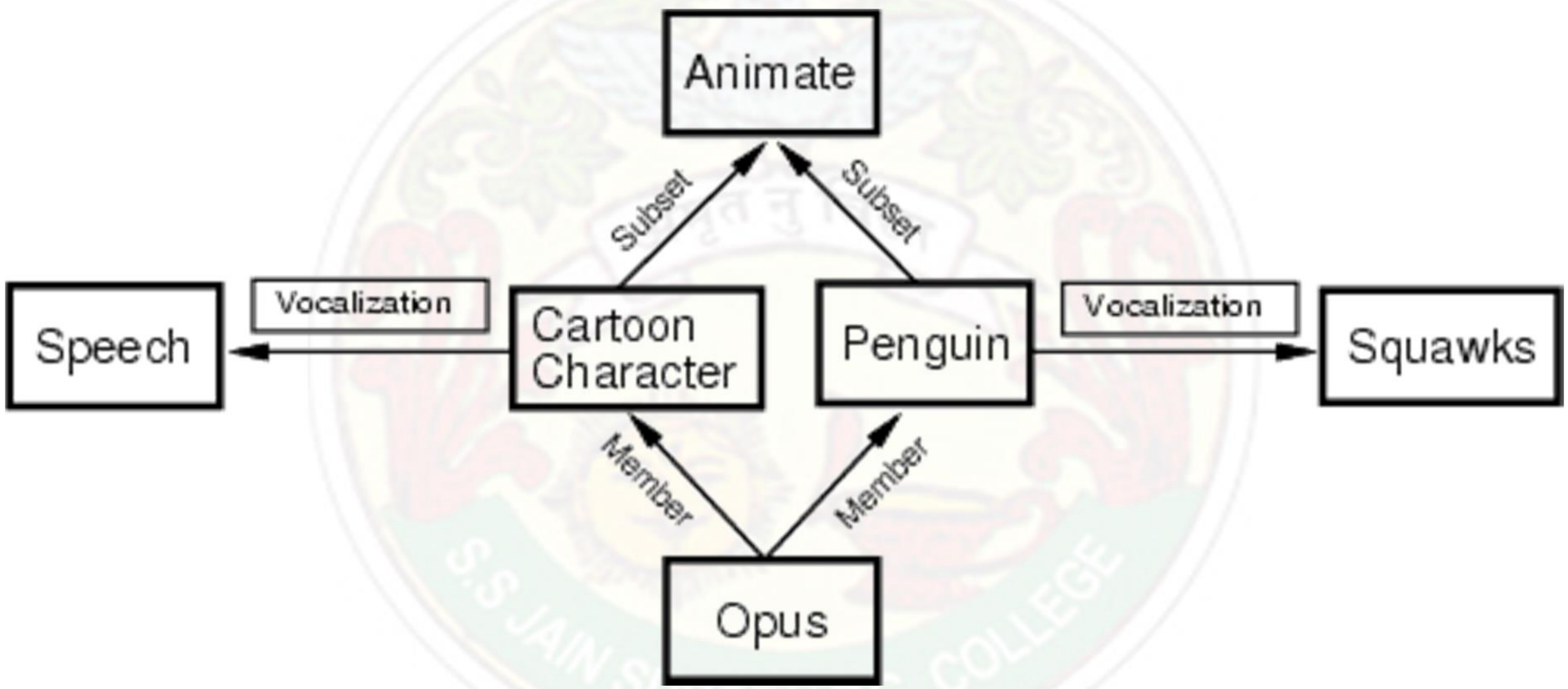
# Link types

| Link Type | Semantics | Example |
|---|---|---|
| $A \xrightarrow{\text{Subset}} B$ | $A \subset B$ | $Cats \subset Mammals$ |
| $A \xrightarrow{\text{Member}} B$ | $A \in B$ | $Bill \in Cats$ |
| $A \xrightarrow{R} B$ | $R(A,B)$ | $Bill \xrightarrow{\text{Age}} 12$ |
| $A \xrightarrow{\boxed{R}} B$ | $\forall x \; x \in A \Rightarrow R(x,B)$ | $Birds \xrightarrow{\boxed{\text{Legs}}} 2$ |
| $A \xrightarrow{\boxed{\boxed{R}}} B$ | $\forall x \; \exists y \; x \in A \Rightarrow y \in B \wedge R(x,y)$ | $Birds \xrightarrow{\boxed{\boxed{\text{Parent}}}} Birds$ |

# Inference by Inheritance

- One of the main kinds of reasoning done in a semantic net is the inheritance of values along the subclass and instance links.
- Semantic networks differ in how they handle the case of inheriting multiple different values.
  - All possible values are inherited, ***or***
  - Only the “lowest” value or values are inherited

# Conflicting inherited values

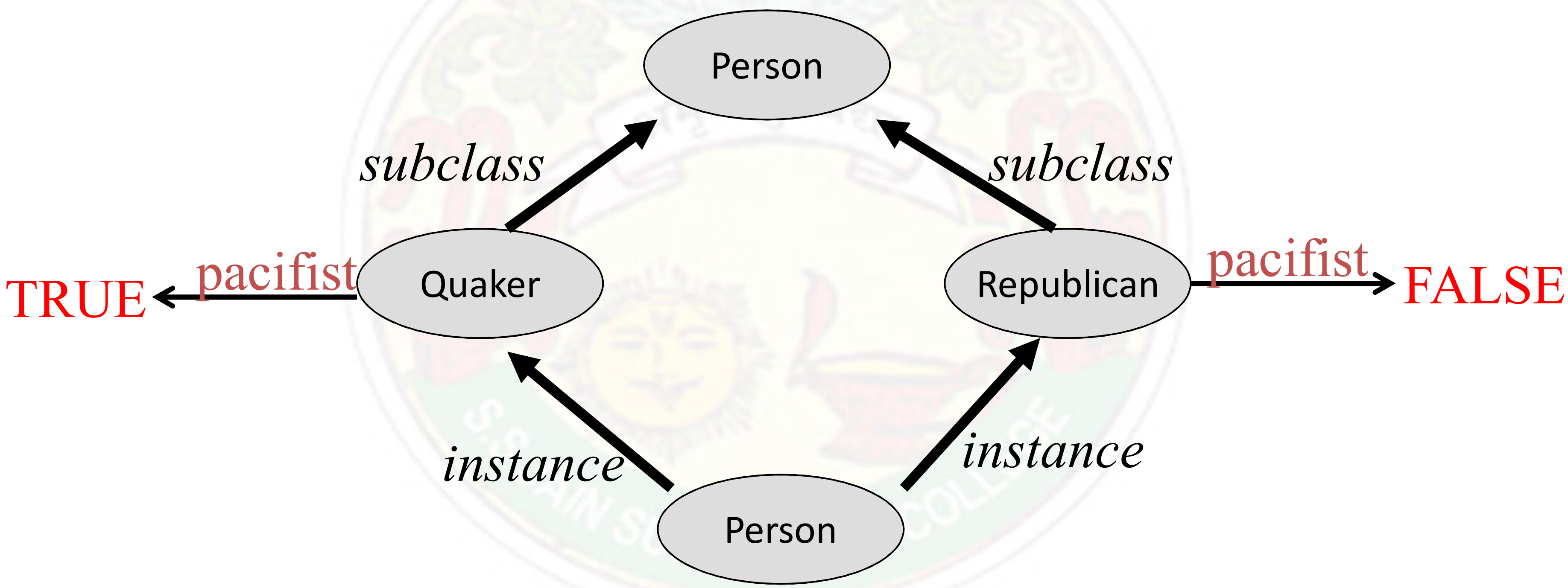


# Multiple inheritance

- A node can have any number of superclasses that contain it, enabling a node to inherit properties from multiple "parent" nodes and their ancestors in the network.
- These rules are often used to determine inheritance in such "tangled" networks where multiple inheritance is allowed:
  - If X<A<B and both A and B have property P, then X inherits A's property.
  - If X<A and X<B but neither A<B nor B<Z, and A and B have property P with different and inconsistent values, then X does not inherit property P at all.

# Nixon Diamond

- This was the classic example circa 1980.

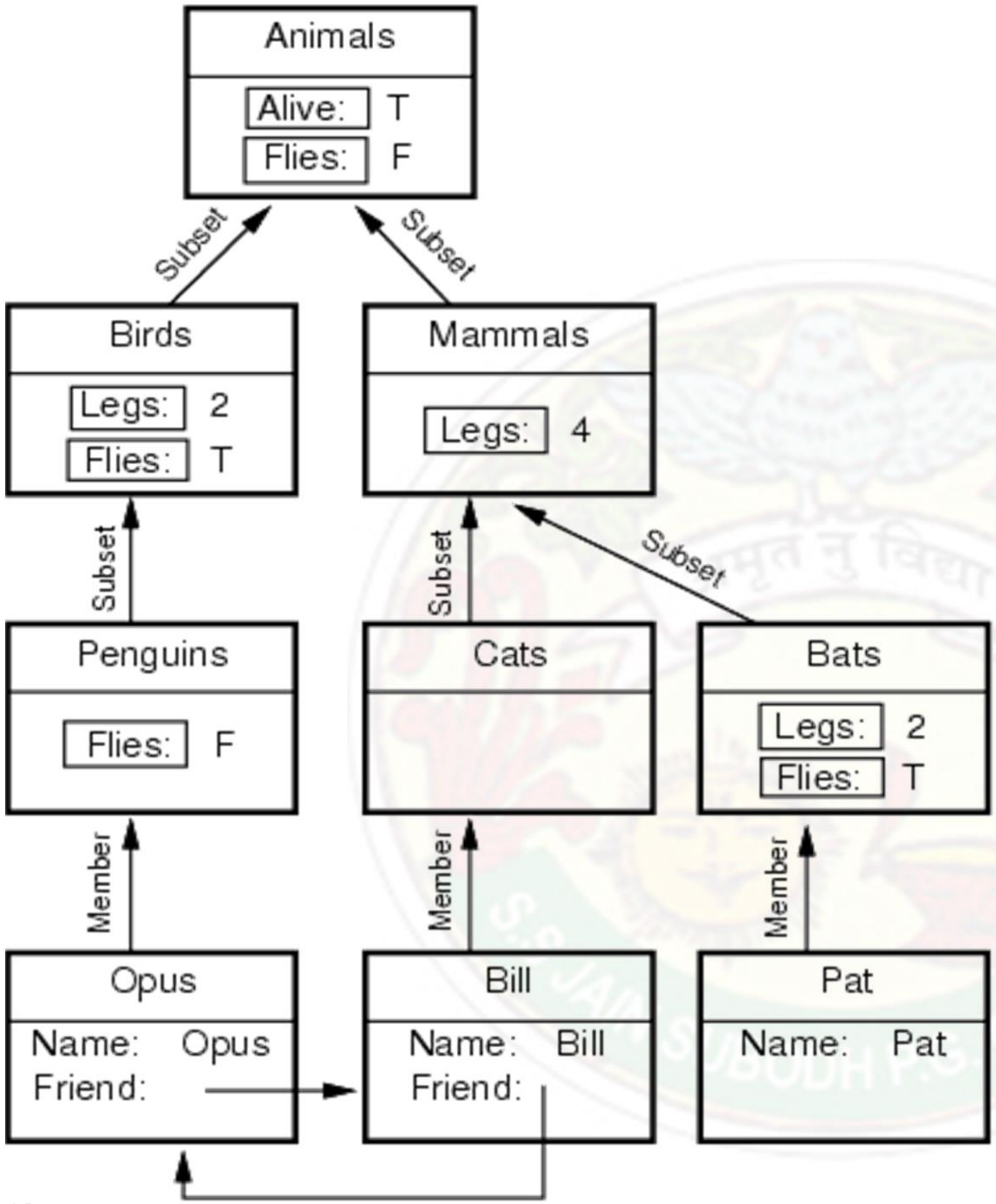


# From Semantic Nets to Frames

- Semantic networks morphed into Frame Representation Languages in the ‘70s and ‘80s.
- A frame is a lot like the notion of an object in OOP, but has more meta-data.
- A **frame** has a set of **slots**.
- A **slot** represents a relation to another frame (or value).
- A slot has one or more **facets.**
- A **facet** represents some aspect of the relation.

# Facets

- A slot in a frame holds more than a value.
- Other facets might include:
  - current fillers (e.g., values)
  - default fillers
  - minimum and maximum number of fillers
  - type restriction on fillers (usually expressed as another frame object)
  - attached procedures (if-needed, if-added, if-removed)
  - salience measure
  - attached constraints or axioms
- In some systems, the slots themselves are instances of frames.




(a) A frame-based knowledge base

Rel(Alive,Animals,T)
Rel(Flies,Animals,F)

Birds ⊂ Animals
Mammals ⊂ Animals

Rel(Flies,Birds,T)
Rel(Legs,Birds,2)
Rel(Legs,Mammals,4)

Penguins ⊂ Birds
Cats ⊂ Mammals
Bats ⊂ Mammals
Rel(Flies,Penguins,F)
Rel(Legs,Bats,2)
Rel(Flies,Bats,T)

Opus ∈ Penguins
Bill ∈ Cats
Pat ∈ Bats
Name(Opus,"Opus")
Name(Bill,"Bill")
Friend(Opus,Bill)
Friend(Bill,Opus)
Name(Pat,"Pat")

(b) Translation into first-order logic

# Description Logics

- Description logics provide a family of frame-like KR systems with a formal semantics.
  - E.g., KL-ONE, LOOM, Classic, …
- An additional kind of inference done by these systems is automatic **classification**
  - finding the right place in a hierarchy of objects for a new description
- Current systems take care to keep the languages simple, so that all inference can be done in polynomial time (in the number of objects)
  - ensuring tractability of inference

# Abduction

- **Abduction** is a reasoning process that tries to form plausible explanations for abnormal observations
  - Abduction is distinctly different from deduction and induction
  - Abduction is inherently uncertain
- Uncertainty is an important issue in abductive reasoning
- Some major formalisms for representing and reasoning about uncertainty
  - Mycin's certainty factors (an early representative)
  - **Probability theory (esp. Bayesian belief networks)**
  - Dempster-Shafer theory
  - Fuzzy logic
  - Truth maintenance systems
  - Nonmonotonic reasoning

# Abduction

- **Definition** (Encyclopedia Britannica): reasoning that derives an explanatory hypothesis from a given set of facts
  - The inference result is a **hypothesis** that, if true, could **explain** the occurrence of the given facts
- **Examples**
  - Dendral, an expert system to construct 3D structure of chemical compounds
    - Fact: mass spectrometer data of the compound and its chemical formula
    - KB: chemistry, esp. strength of different types of bounds
    - Reasoning: form a hypothetical 3D structure that satisfies the chemical formula, and that would most likely produce the given mass spectrum

# Abduction examples (cont.)

- Medical diagnosis
  - Facts: symptoms, lab test results, and other observed findings (called manifestations)
  - KB: causal associations between diseases and manifestations
  - Reasoning: one or more diseases whose presence would causally explain the occurrence of the given manifestations
- Many other reasoning processes (e.g., word sense disambiguation in natural language process, image understanding, criminal investigation) can also been seen as abductive reasoning

# Comparing abduction, deduction, and induction

**Deduction:** major premise: All balls in the box are black
minor premise: These balls are from the box
conclusion: These balls are black

A => B
A
---------
B

**Abduction:** rule: All balls in the box are black
observation: These balls are black
explanation: These balls are from the box

A => B
B
-------------
Possibly A

**Induction:** case: These balls are from the box
observation: These balls are black
hypothesized rule: All ball in the box are black

Whenever A then B
-------------
Possibly A => B

**Deduction** reasons from causes to effects
**Abduction** reasons from effects to causes
**Induction** reasons from specific cases to general rules

# Characteristics of abductive reasoning

- “Conclusions” are **hypotheses**, not theorems (may be false *even if* rules and facts are true)
  - E.g., misdiagnosis in medicine

- There may be multiple plausible hypotheses
  - Given rules A => B and C => B, and fact B, both A and C are plausible hypotheses
  - Abduction is inherently uncertain
  - Hypotheses can be ranked by their plausibility (if it can be determined)

# Characteristics of abductive reasoning (cont.)

- Reasoning is often a hypothesize-and-test cycle
  - **Hypothesize**: Postulate possible hypotheses, any of which would explain the given facts (or at least most of the important facts)
  - **Test**: Test the plausibility of all or some of these hypotheses
  - One way to test a hypothesis H is to ask whether something that is currently unknown–but can be predicted from H–is actually true
    - If we also know A => D and C => E, then ask if D and E are true
    - If D is true and E is false, then hypothesis A becomes more plausible (**support** for A is increased; **support** for C is decreased)

# Characteristics of abductive reasoning (cont.)

- Reasoning is **non-monotonic**
  - That is, the plausibility of hypotheses can increase/decrease as new facts are collected
  - In contrast, deductive inference is **monotonic:** it never change a sentence's truth value, once known
  - In abductive (and inductive) reasoning, some hypotheses may be discarded, and new ones formed, when new observations are made

# Sources of uncertainty

- Uncertain **inputs**
  - Missing data
  - Noisy data
- Uncertain **knowledge**
  - Multiple causes lead to multiple effects
  - Incomplete enumeration of conditions or effects
  - Incomplete knowledge of causality in the domain
  - Probabilistic/stochastic effects
- Uncertain **outputs**
  - Abduction and induction are inherently uncertain
  - Default reasoning, even in deductive fashion, is uncertain
  - Incomplete deductive inference may be uncertain

▸ Probabilistic reasoning only gives probabilistic results (summarizes uncertainty from various sources)

# Decision making with uncertainty

- **Rational** behavior:
  - For each possible action, identify the possible outcomes
  - Compute the **probability** of each outcome
  - Compute the **utility** of each outcome
  - Compute the probability-weighted **(expected) utility** over possible outcomes for each action
  - Select the action with the highest expected utility (principle of **Maximum Expected Utility**)

# Bayesian reasoning

- Probability theory
- Bayesian inference
  - Use probability theory and information about independence
  - Reason diagnostically (from evidence (effects) to conclusions (causes)) or causally (from causes to effects)
- Bayesian networks
  - Compact representation of probability distribution over a set of propositional random variables
  - Take advantage of independence relationships

# Other uncertainty representations

- Default reasoning
  - Nonmonotonic logic: Allow the retraction of default beliefs if they prove to be false
- Rule-based methods
  - Certainty factors (Mycin): propagate simple models of belief through causal or diagnostic rules
- Evidential reasoning
  - Dempster-Shafer theory: Bel(P) is a measure of the evidence for P; Bel($\neg$P) is a measure of the evidence against P; together they define a belief interval (lower and upper bounds on confidence)
- Fuzzy reasoning
  - Fuzzy sets: How well does an object satisfy a vague property?
  - Fuzzy logic: "How true" is a logical statement?

# Uncertainty tradeoffs

- **Bayesian networks:** Nice theoretical properties combined with efficient reasoning make BNs very popular; limited expressiveness, knowledge engineering challenges may limit uses
- **Nonmonotonic logic:** Represent commonsense reasoning, but can be computationally very expensive
- **Certainty factors:** Not semantically well founded
- **Dempster-Shafer theory:** Has nice formal properties, but can be computationally expensive, and intervals tend to grow towards [0,1] (not a very useful conclusion)
- **Fuzzy reasoning:** Semantics are unclear (fuzzy!), but has proved very useful for commercial applications