Knowledge Representation and Reasoning

Chapter 12

Some material adopted from notes by
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Overview

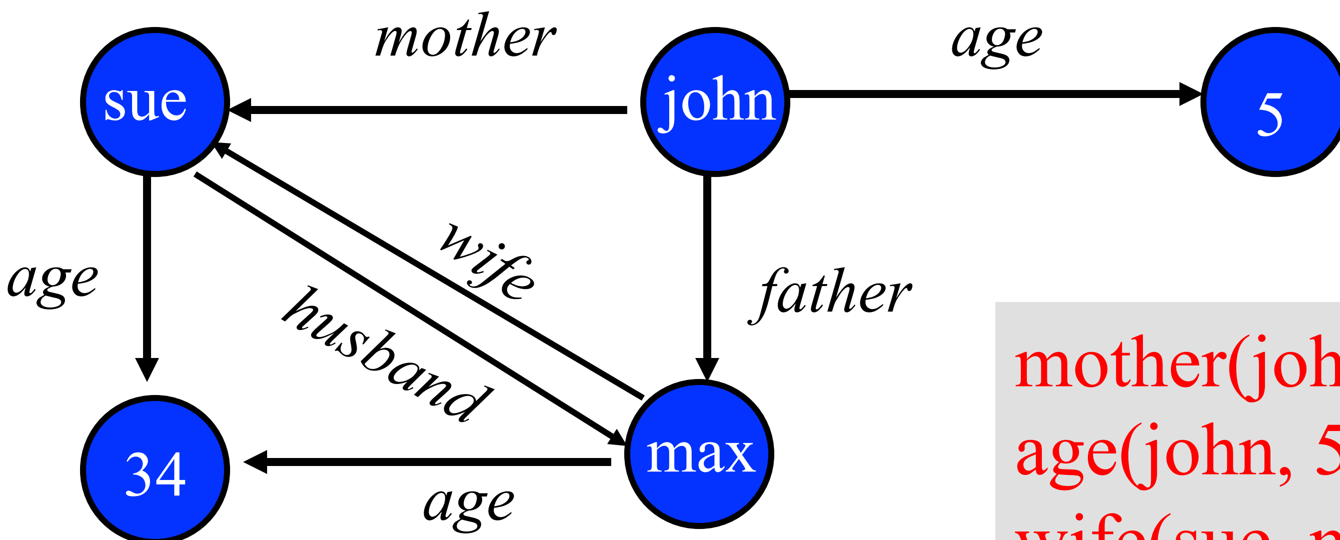
- Approaches to knowledge representation
- Deductive/logical methods
  - Forward-chaining production rule systems
  - Semantic networks
  - Frame-based systems
  - Description logics
- Abductive/uncertain methods
  - What's abduction?
  - Why do we need uncertainty?
  - Bayesian reasoning
  - Other methods: Default reasoning, rule-based methods, Dempster-Shafer theory, fuzzy reasoning

Semantic Networks

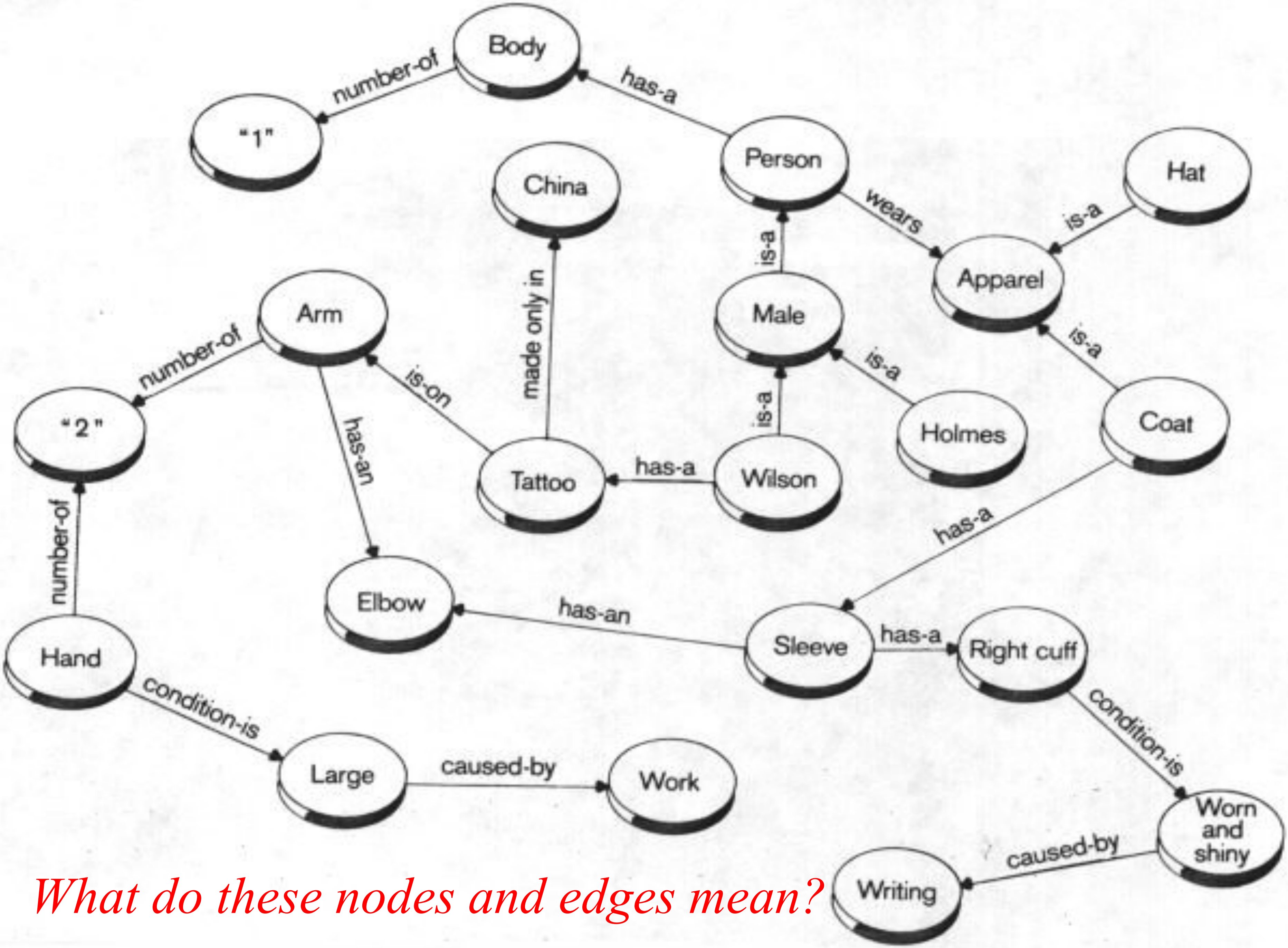
- Simple representation scheme: a graph of labeled nodes and labeled, directed arcs to encode knowledge
  - often used for static, taxonomic, concept dictionaries
- Typically used with a special set of accessing procedures that perform "reasoning"
  - e.g., inheritance of values and relationships
- Semantic networks popular in 60s & 70s, less used in '80s &'90s, back since '00s as RDF
  - less expressive than other formalisms: both a feature & bug!
- 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



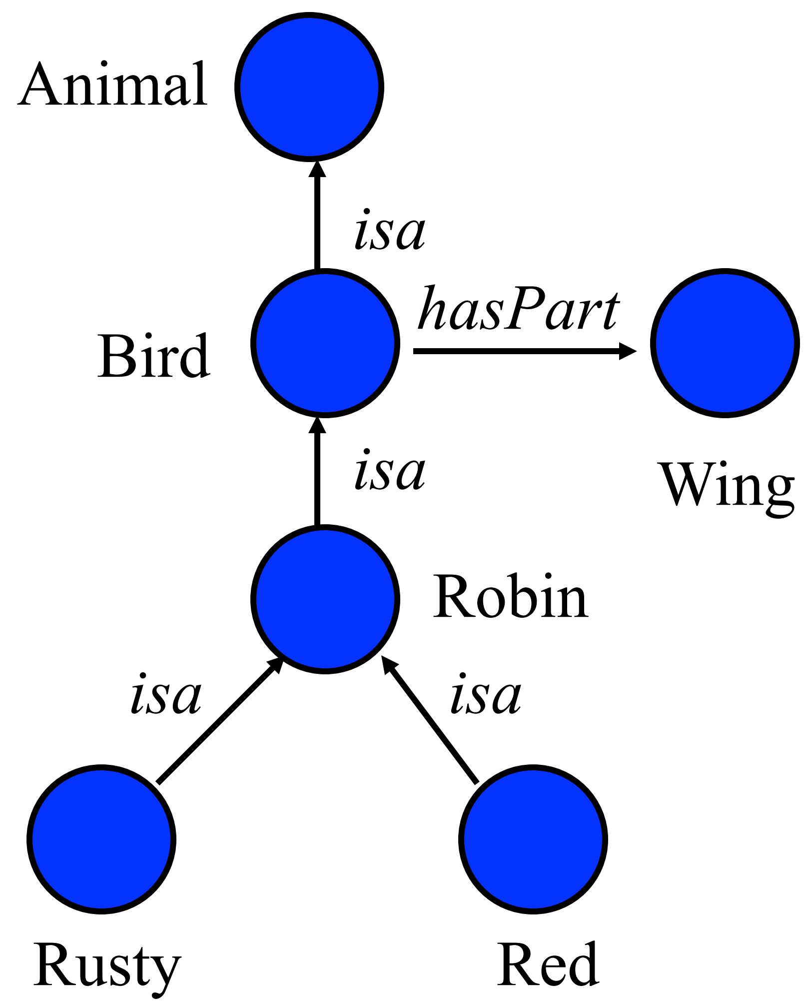
mother(john, sue)
age(john, 5)
wife(sue, max)
age(max, 34)
...



What do these nodes and edges mean?

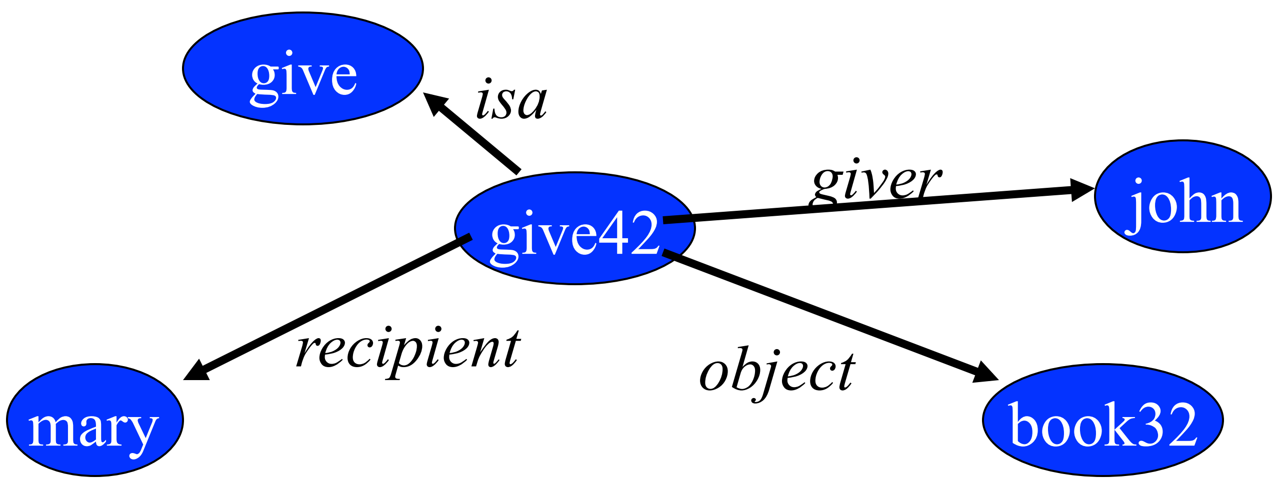
Semantic Networks

- ISA (is-a) or AKO (a-kind-of) relations often used to link instances to classes and classes to super-classes
- Some links (e.g. hasPart) are inherited along ISA paths
- Meaning of a semantic net can be relatively informal or very formal
  - often defined by implementation
  - See W. Woods, What's in a Link, 1975.



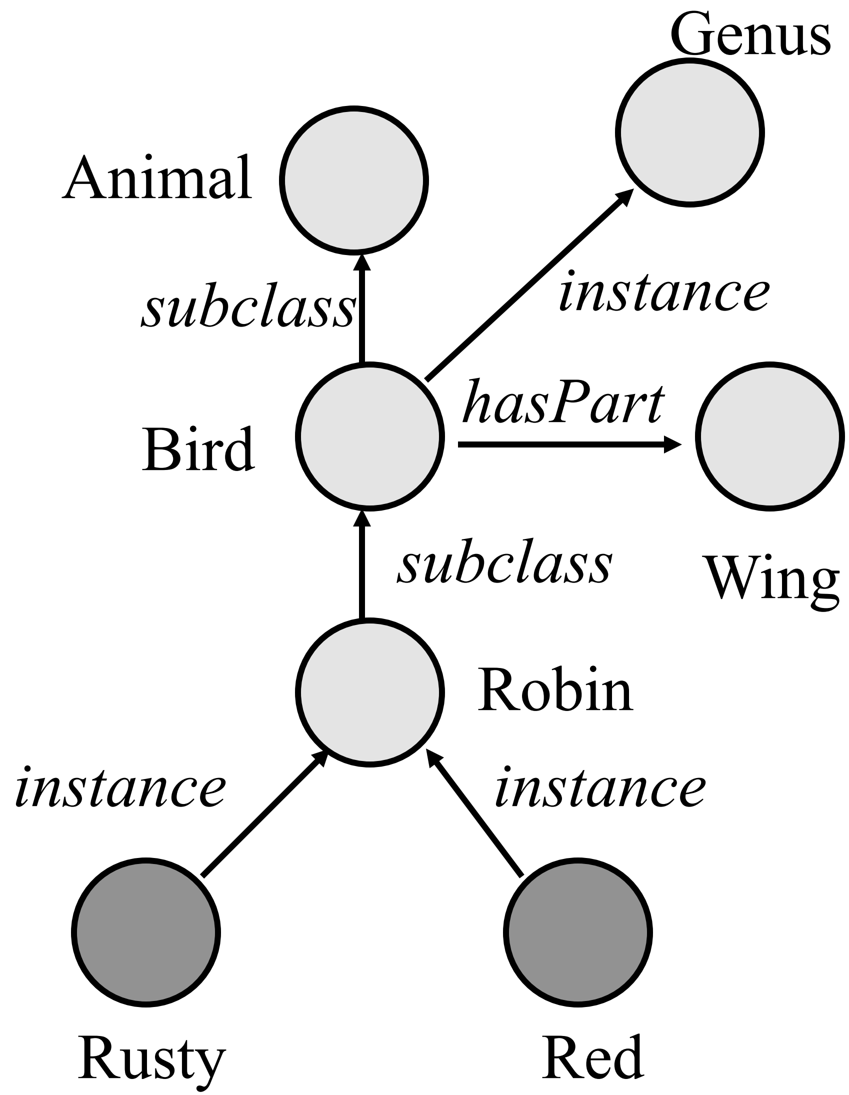
Reification

- Non-binary relationships can be represented by "turning the relationship into an object"
- Logicians and philosophers call this 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 & those representing classes
  - E.g., subclass from instance_of relation
- Formalization must deal with nodes like *Bird*
  - OWL uses punning



Inference by Inheritance

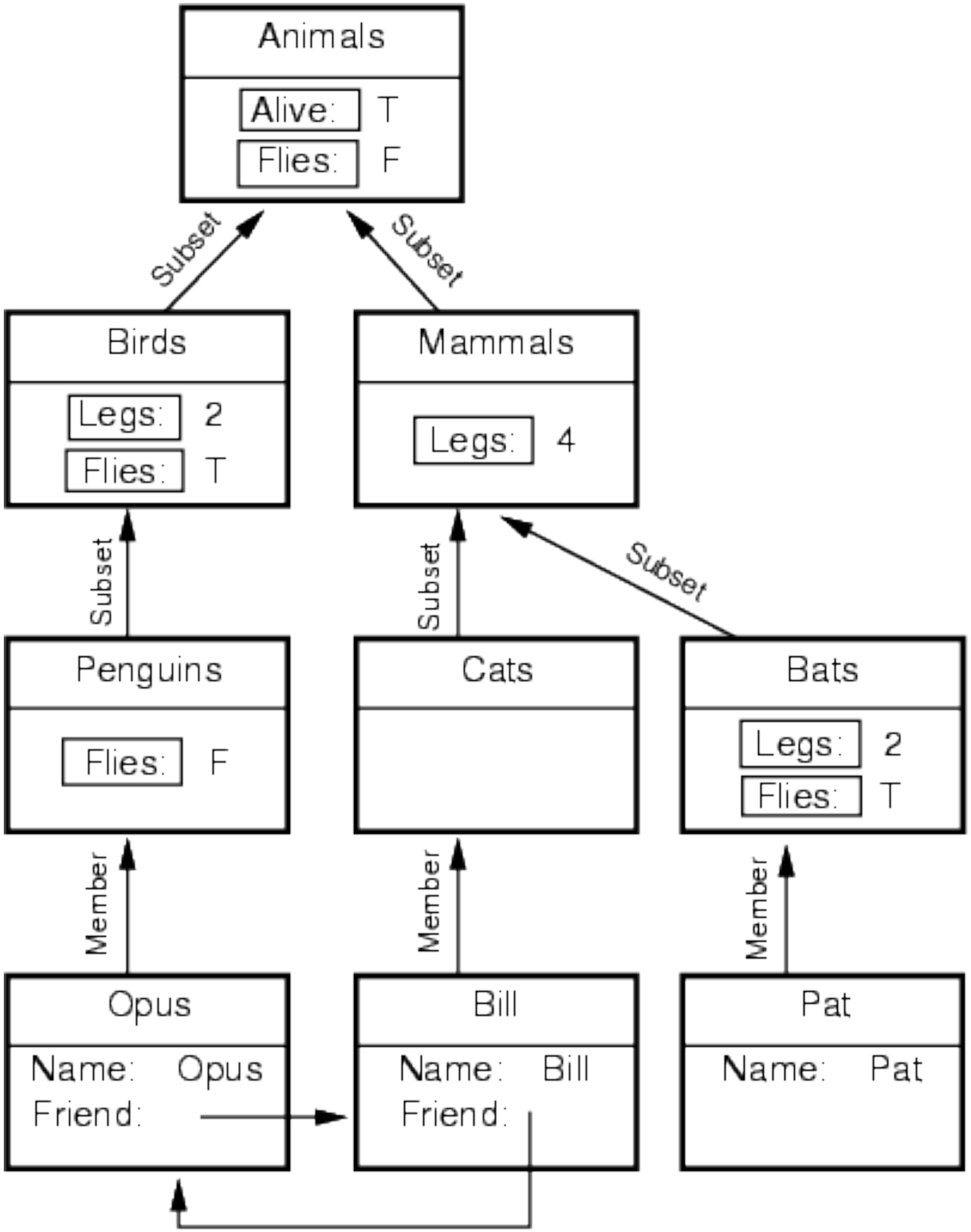
- One kind of reasoning done in semantic nets is inheritance along subclass & instance links
  - It's like inheritance in object-oriented languages
- Semantic networks differ in details of
  - Inheriting along subclass or instance links, e.g
    - Only inherit values on instance links
  - inheriting multiple different values, e.g.
    - All possible values are inherited, ***or***
    - Only the "closest" value or values are inherited

From Semantic Nets to Frames

- Semantic networks evolved into frame representation languages in the 70s and 80s
- Frames like a OO classes with more meta-data
  - Cf. AI's focus on *knowledge* over *data*
- A **frame** has a set of **slots**
- **Slots** represents relations to other frame or literal values (e.g., number or string)
- A slot has one or more **facets**
- A **facet** represents some aspect of the relation

Facets

- A slot in a frame can hold more than a value
- Other facets might include:
  - **Value**: current fillers
  - **Default:** default fillers
  - **Cardinality:** minimum and maximum number of fillers
  - **Type:** type restriction on fillers, e.g another frame
  - **Procedures:** if-needed, if-added, if-removed
  - **Salience:** measure on the slot's importance
  - **Constraints:** 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 are a family of frame-like KR systems with a formal semantics
  - E.g., KL-ONE, OWL
- Additional kind of inference is automatic classification of Frames and objects
  - Automatically finding right place in a hierarchy
- Many current systems limit languages to support decidably complete reasoning
- The Semantic Web language OWL based on description logic

Beyond Deduction

- Logical deduction is not the only kind of reasoning that's useful

Deduction, Abduction, 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: from causes to effects

Abduction: from effects to causes

Induction: from specific cases to general rules

Abduction

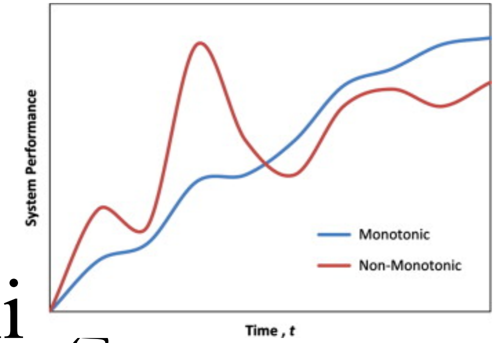
Abduction: reasoning that derives an explanatory hypothesis from a given set of facts

- Inference result is a **hypothesis** that, if true, could **explain** the occurrence of the given facts
- Inherently unsound and uncertain

Example: Medical diagnosis

- Facts: symptoms, test results, other observed findings
- KB: causal associations between diseases & symptoms
- Reasoning: diseases whose presence would causally explain the occurrence of the given manifestations

Non-monotonic reasoning



- Abduction is *non-monotonic* reasoning
- Monotonic: your knowledge only increases
  - Propositions don't change their truth value
  - You never *unknow* things
- In abduction: plausibility of hypotheses can increase/decrease as new facts are collected
- Deductive inference is **monotonic:** it never change a sentence's truth value, once known
- In abductive and inductive reasoning, hypotheses may be discarded and new ones formed when new observations are made

Default logic

- Default reasoning is another kind of non-monotonic reasoning
- We know many facts which are *mostly* true, *typically* true, or good default *assumptions*
  - E.g., birds can fly, dogs have four legs, etc.
- Sometimes these facts are wrong however
  - Ostriches are birds, but can not fly
  - A dead bird can not fly
  - Uruguay President José Mujica had a 3-legged dog

Negation as Failure

- Prolog introduced the notion of *negation as failure*, which is widely used in logic programming languages and many KR systems
- Proving P in classical logic can have three outcomes: true, false, unknown *(+ still thinking)*
- Sometimes being unable to prove something can be used as evidence that it is not true
- This is typically the case in a database context
  - Is John registered for CMSC 671?
  - If there's no record for John in the registrar's database, assume he's not registered

Default Logic

- There are several models for default reasoning
  - All have advantages and disadvantages, supporters and detractors
- Implementations often use negation as failure

```
canfly(x) :- bird(x), \+ cannotfly(X).
cannotfly(X) :- ostritch(X); dead(X).
```

- Autoepistemic reasoning (reasoning about what you know) is useful also
  - Does President Obama have a wooden leg?

Dealing with Uncertain Knowledge

- The world is not a well-defined place
- There is uncertainty in the facts we know:
  - What's the temperature? Imprecise measures
  - Is Obama tall? Imprecise definitions
  - Where is the pit? Imprecise knowledge
- There is uncertainty in our inferences
  - If I have a blistery, itchy rash and was gardening all weekend I probably have poison ivy
- People make successful decisions all the time anyhow

Sources of Uncertainty

- Uncertain **inputs --** missing and/or 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 deductive, is uncertain
  - Incomplete deductive inference may be uncertain

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

Reasoning Under Uncertainty

How can we reason under uncertainty and with inexact knowledge?

- Heuristics
  - mimic expert's heuristic knowledge processing methods
- Empirical associations
  - experiential reasoning
  - based on limited observations
- Fuzzy sets and fuzzy logic
- Probabilities
  - objective (frequency counting)
  - subjective (human experience)

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 action with the highest expected utility (principle of **Maximum Expected Utility**)