Knowledge Representation

LESSON 10

Reading

Chapter 10

Outline

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

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

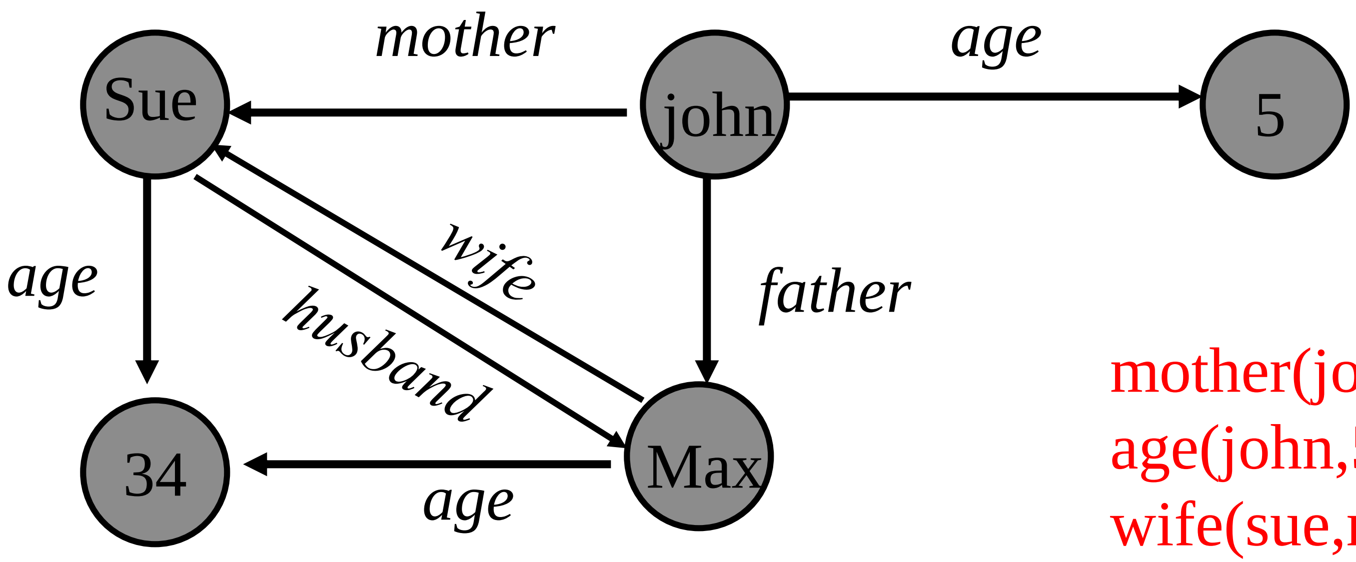
Semantic networks were very popular in the ‘60s and ‘70s but are less frequently used today.

- 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)
...

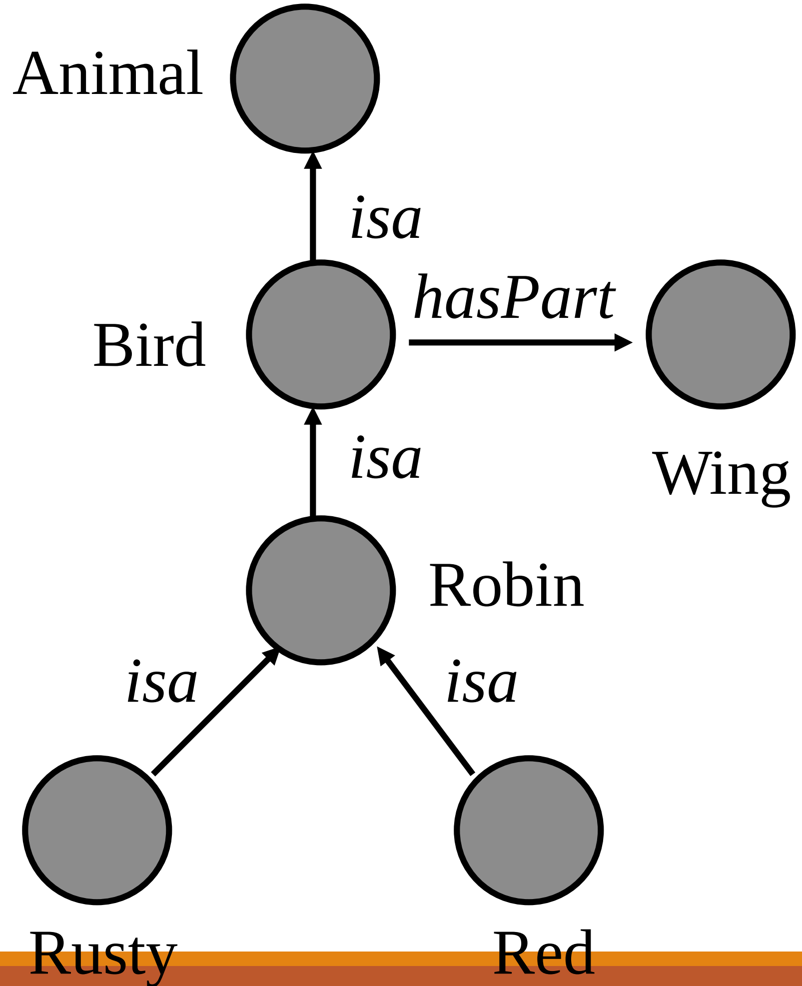
Semantic Networks

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



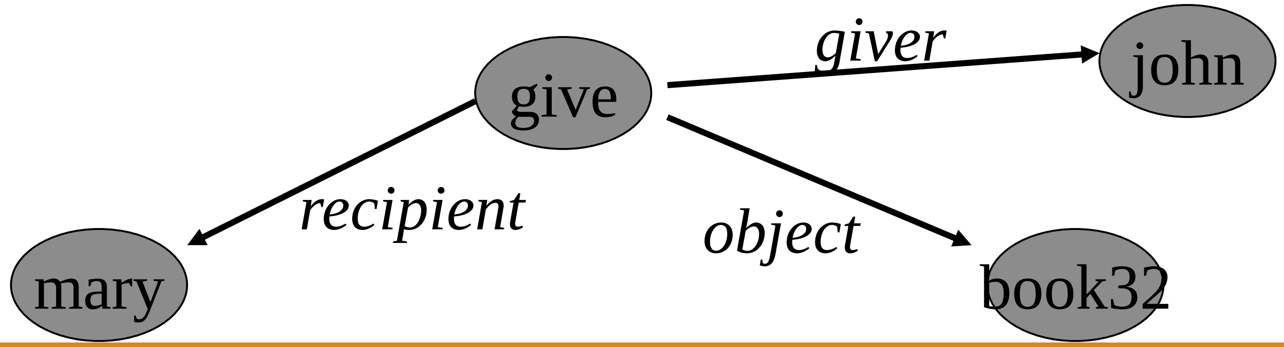
Reification

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

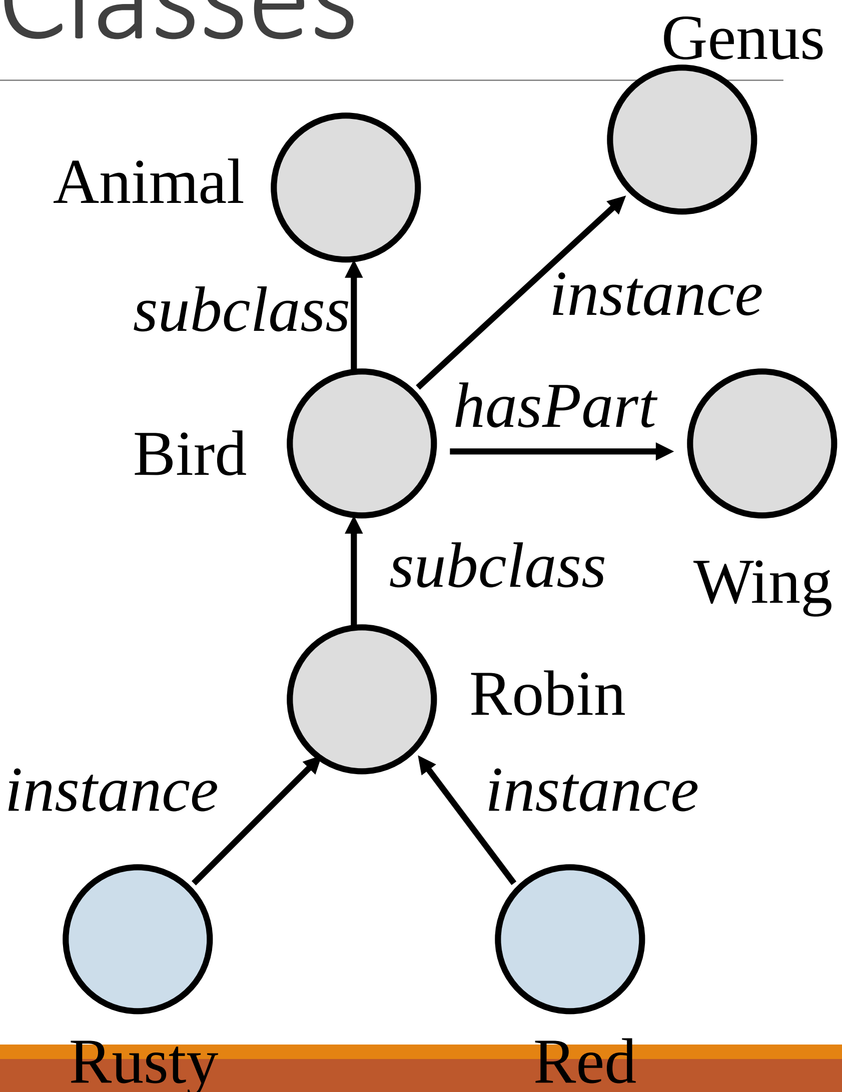
We might want to represent the generic give event as a relation involving three things: a giver, a recipient and an object, give(john,mary,book32)



Individuals and Classes

Many semantic networks distinguish

- nodes representing individuals and those representing classes
- the “subclass” relation from the “instance-of” relation



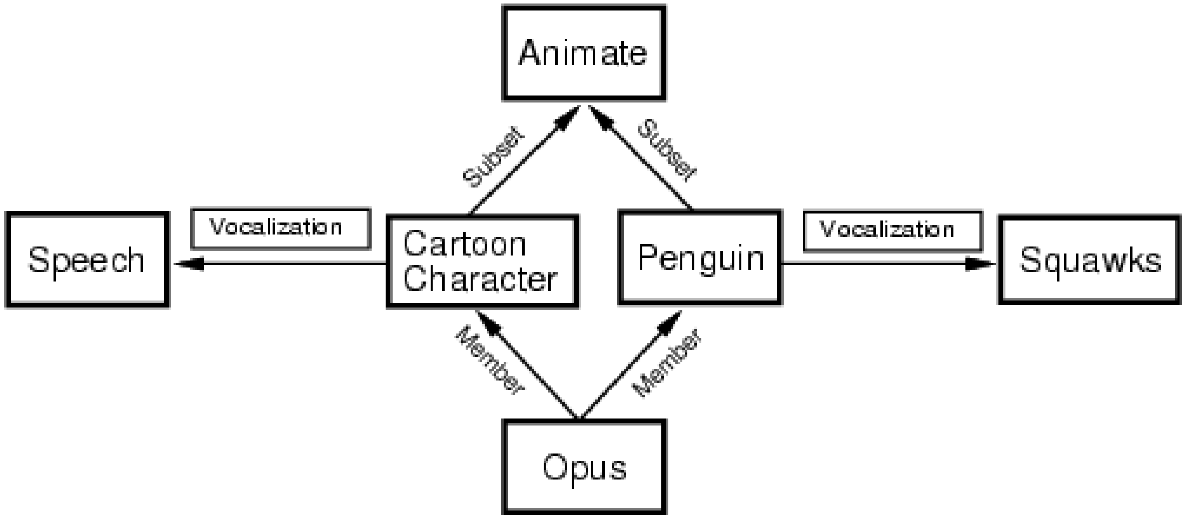
Inference by Inheritance

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.

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.

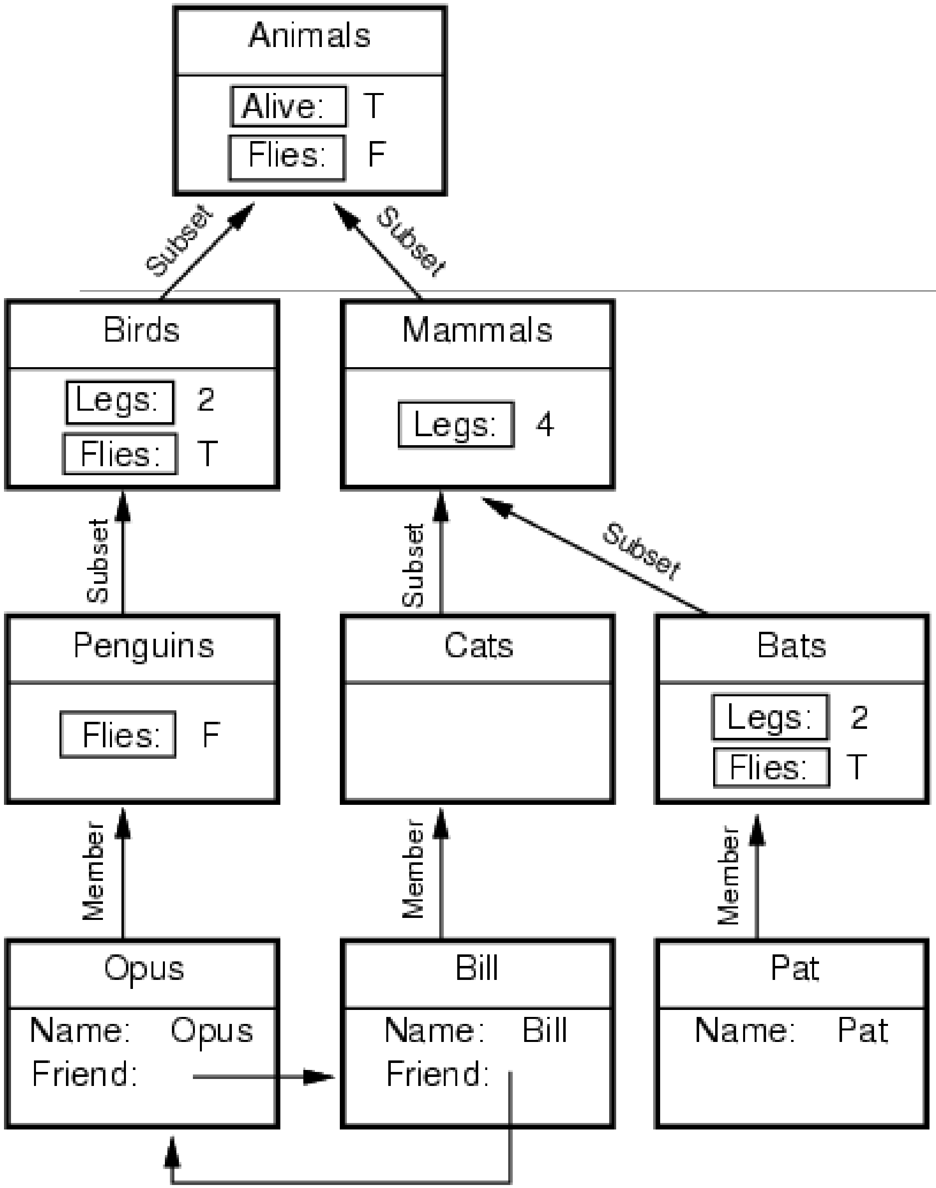
Facets

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 $\subset$ Animals
Mammals $\subset$ Animals

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

Penguins $\subset$ Birds
Cats $\subset$ Mammals
Bats $\subset$ Mammals

Rel(Flies,Penguins,F)
Rel(Legs,Bats,2)
Rel(Flies,Bats,T)

Opus $\in$ Penguins
Bill $\in$ Cats
Pat $\in$ 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