Knowledge Sharing Among Heterogeneous Agents

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Facts of Life: Diversity and Heterogeneity

Open-ended variety of systems connected to the Internet:

- **The great majority are legacy systems with no formal semantics.**
- **Some use SQL databases with the closed-world assumption.**
- **Others use SQL or SPARQL with the open-world assumption.**
- **Some knowledge bases use a version of classical logic.**
- **But most knowledge bases use a version of nonmonotonic logic.**

How can these systems interoperate effectively?

Some logicians claim that true interoperability is impossible unless all agents adopt exactly the same logic and ontology.

But in practice, independently developed computer systems have been interoperating successfully since the 1960s.

Example: The billions of systems connected to the WWW.

How can these views be reconciled?

Solution: First-Order Logic

Use classical FOL semantics for message passing:

- **Every system of any kind – classical, nonmonotonic, or legacy – can accept and use statements in FOL or some subset of FOL.**
- **Every system can generate statements in FOL – at least the subset used for the data in SQL and SPARQL databases.**
- **Any qualifications about the FOL content can be expressed in metadata, which are also statements in FOL or some subset.**

Observation by Alan Robinson, *

FOL can be used to set up, as first order theories, the many "other logics" such as modal logic, higher order logic, temporal logic, dynamic logic, concurrency logic, epistemic logic, nonmonotonic logic, relevance logic, linear logic, fuzzy logic, intuitionistic logic, causal logic, quantum logic; and so on and so on. The idea that FOL is just one among many "other logics" is an unfortunate source of confusion and apparent complexity. The "other logics" are simply notations reflecting syntactically sugared definitions of notions or limitations which can be formalized within FOL.

*** See http://ssdi.di.fct.unl.pt/masters/mcl/content/downloads/Robinson-CL2000.pdf**

Question

If all methods of reasoning about the physical world must be nonmonotonic, why should we relate them to classical logic?

Can't we just adopt one general method of nonmonotonic logic as the standard?

Answer: There is no ideal method of nonclassical reasoning.

- **There is an open-ended variety of nonmonotonic reasoning methods that have different advantages and disadvantages.**
- **There are also many different methods of heuristic, probable, statistical, approximate, case-based, and fuzzy reasoning.**
- **They have only one thing in common: Every nonclassical method is defined in terms of some version of classical FOL.**
- **The only general way to relate conclusions derived by different nonclassical methods is to relate them via classical semantics.**

Classical FOL is an island of stability in an ocean of nonclassical methods of reasoning.

Proposal by Tim Berners-Lee

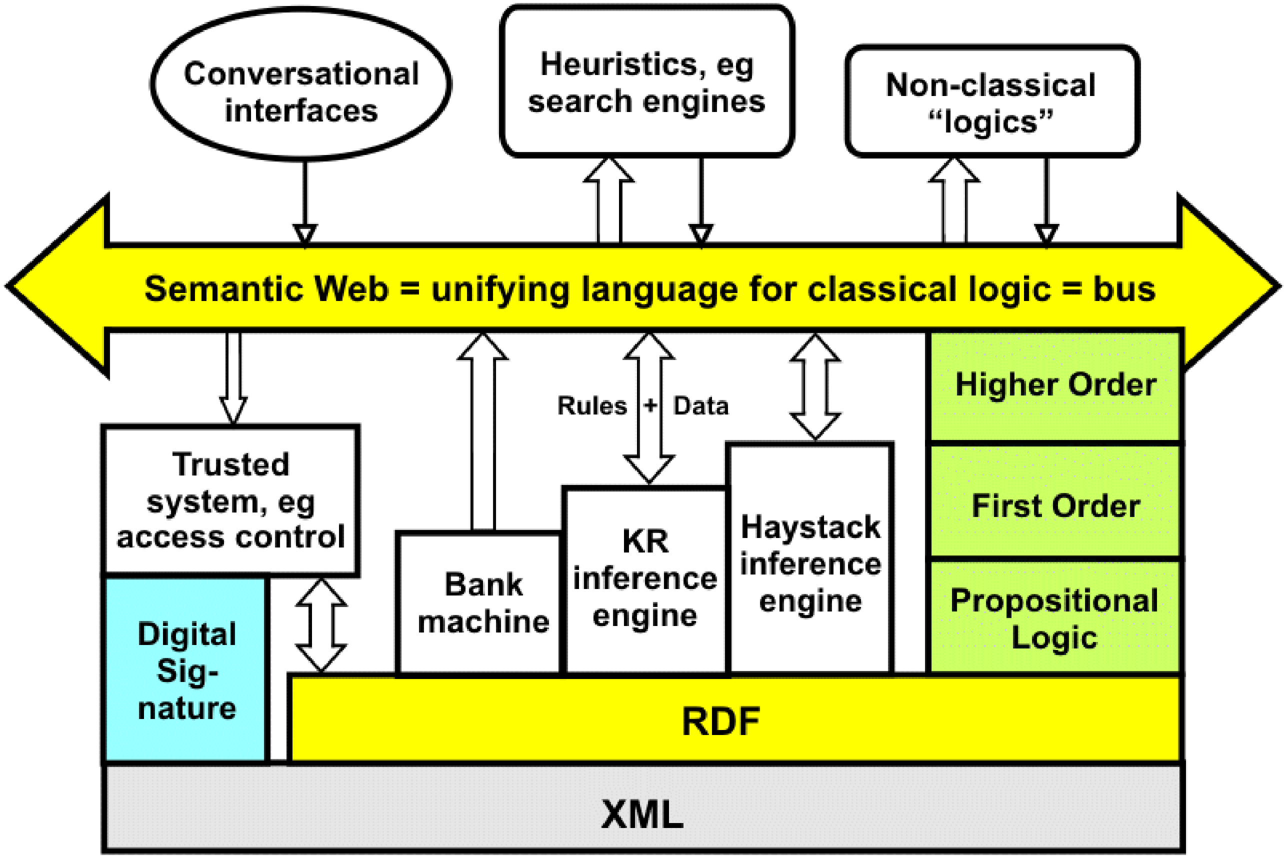


Diagram from the DAML proposal of February 2000, *

- Semantic Web Logic Language (SweLL) is a superset of FOL.
- Designed to support diversity, heterogeneity, and interoperability.
- But the DAML project implemented a tiny subset of the proposal.

* See http://www.w3.org/2000/01/sw/DevelopmentProposal

Goal: Finish Tim's Project

The unifying language in the double arrow is the foundation:

- **Superset of higher-order, first-order, and propositional logic.**
- **Supports message passing among heterogeneous systems.**
- **Those systems may use any heuristics or nonclassical logics.**

Common Logic was designed to meet those requirements:

- **Guha and Hayes used the CL semantics to define a logic base (LBase) for RDF and other SW notations. ***
- **But the DAML implementers chose a limited subset for OWL.**
- **It is too limited to support the requirements in the proposal.**
- **The final DAML report in 2006 ignored many of the requirements.**

Goal: Determine how a unifying language based on CL can meet the requirements of diversity, heterogeneity, and interoperability.

*** See http://www.w3.org/TR/lbase/**

Foundation of Formal Semantics

Summary of Wittgenstein's *Tractatus Logico-Philosophicus*:

1 The world is everything that is the case.

1.1 The world is the totality of facts, not of things.

3.25 There is one and only one complete analysis of the proposition.

4.001 The totality of propositions is the language.

4.116 Everything that can be said can be said clearly.

5 Propositions are truth-functions of elementary propositions.

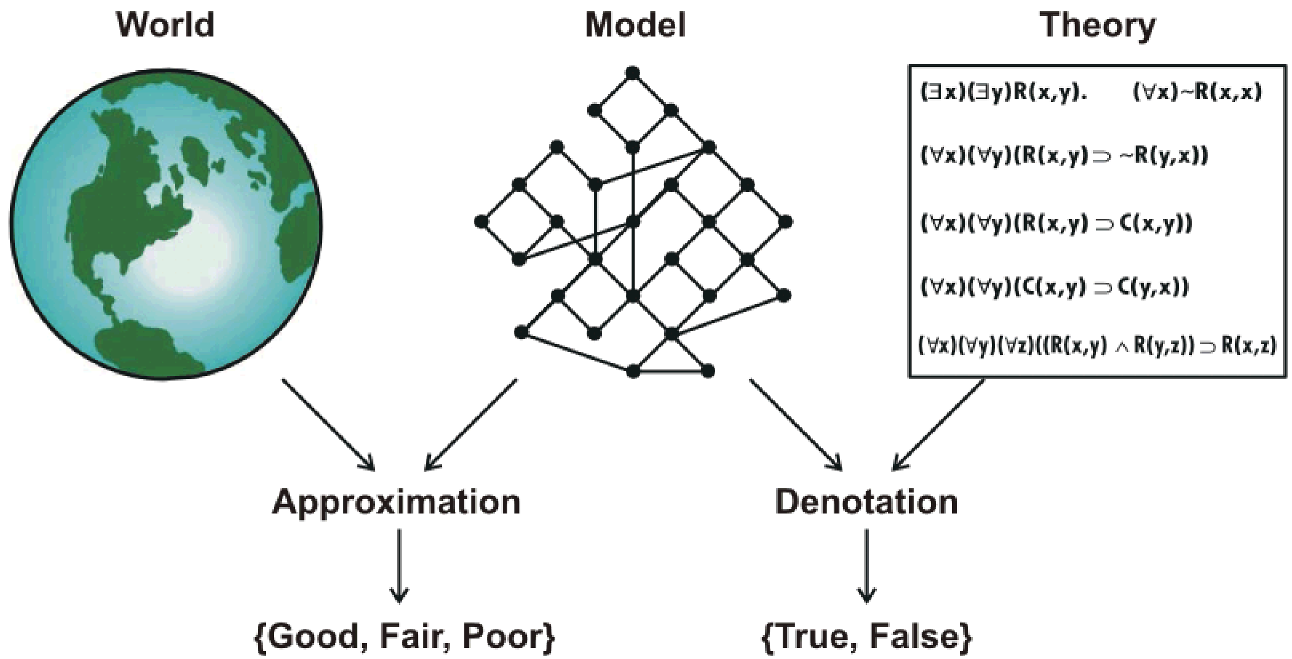
6.13 Logic is not a theory but a reflexion of the world.

7 Whereof one cannot speak, thereof one must be silent.

This book set the agenda for formal semantics in the 20th century.

It assumes that the world is a fixed model that determines the truth or falsity of any sentence in language or logic.

Model-Theoretic Semantics



In the *Tractatus*, Wittgenstein assumed that the world is the model.

If there is exactly one world, there is exactly one model, there is exactly one ontology, and any approximation is false.

Engineers are cynical, but realistic:

"All models are wrong. Some are useful."

Syntax, Semantics, and Pragmatics

For any formal logic L,

- Syntax is defined by a grammar that determines which patterns of symbols are sentences of L.
- Semantics is defined by an evaluation function $\Phi(s,M)$, which maps any sentence s and model M to the denotation T or F.
- Pragmatics consists of an open-ended family of methods for using the syntax and semantics of the sentences in L.

Examples of pragmatics:

- Methods of deduction, induction, and abduction based on Φ.
- Methods of theory revision based on Φ.
- Nonclassical proof procedures based on Φ.
- All methods of analysis, planning, communication, learning, logic programming, and question answering based on Φ.

Learning a New Theory

Observations generate facts:

```
Tweety is a bird.    Tweety flies.
Daffy is a bird.     Daffy flies.
Hooty is a bird.     Hooty flies.
```

Induction derives general axioms from multiple facts:

```
Every bird flies.
Every flying thing is a bird.
For every x, x is a bird if and only if x flies.
```

Any one of these axioms can be added to a subset of the facts to generate the other facts.

Heuristics give a slight preference for "`Every bird flies.`"

But the other axioms cannot be ruled out.

New Information Triggers Belief Revision

New observation:

```
Vampy is not a bird. Vampy flies.
```

This observation rules out two options, leaving just one:

```
Every bird flies.
```

Another observation:

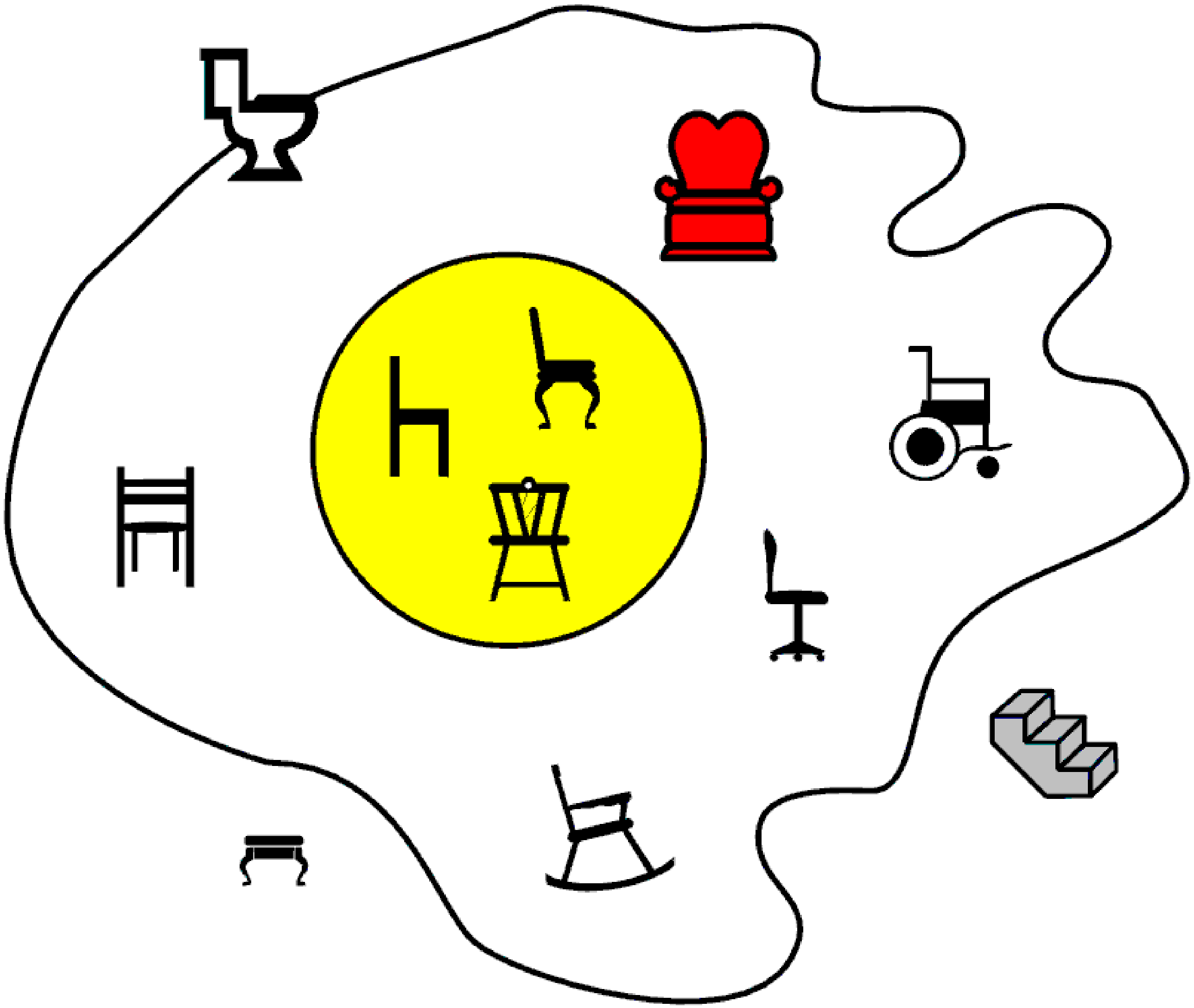
```
Tux is a penguin. Tux is a bird. Tux does not fly.
```

This observation restricts the universal quantifier:

```
Every bird that is not a penguin flies.
```

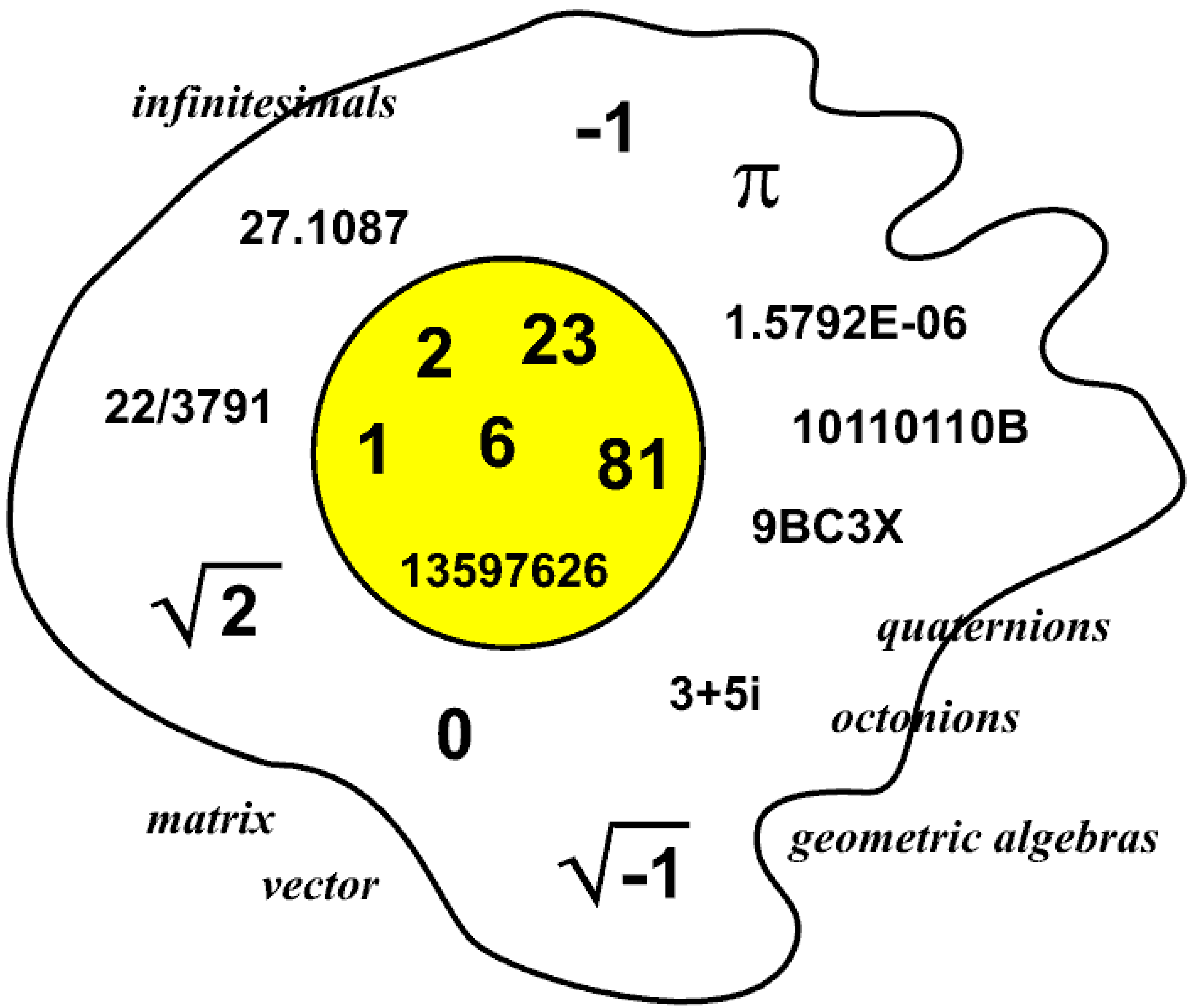
Learning and belief revision use the same semantics as classical deduction, but they make nonmonotonic revisions.

What is a Chair?



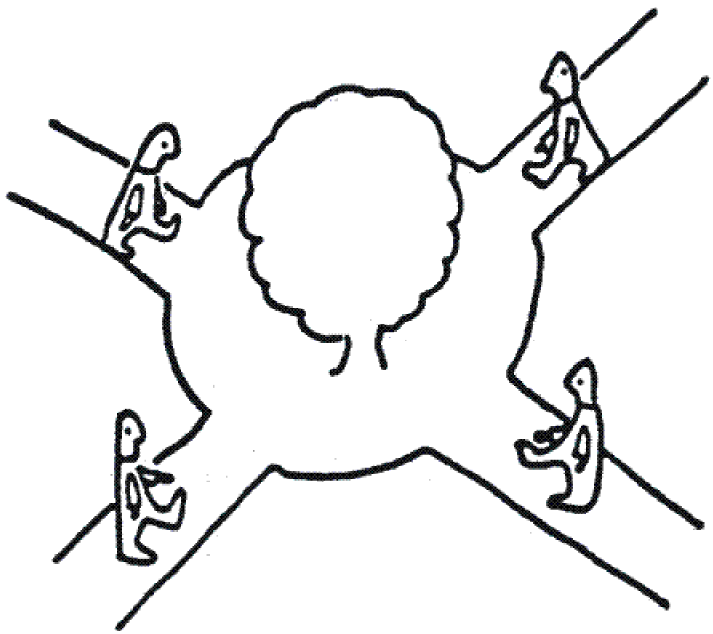
The egg-yolk theory puts typical examples in the yolk and unusual examples in the egg white (Lehmann & Cohn 1994).

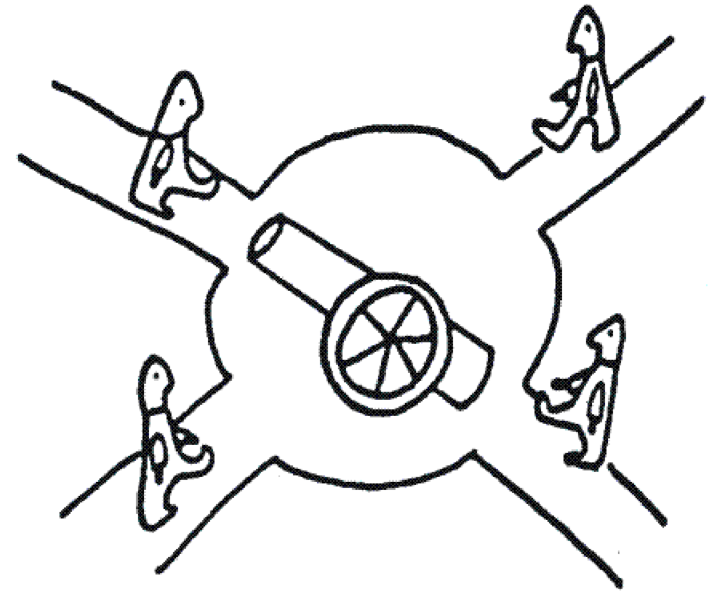
What is a Number?



Concepts in science and mathematics grow and change.

Issues about Orientation





les présidents sont devant l'arbre
the presidents are in front of the tree

?les présidents sont devant le canon
the presidents are in front of the cannon

For a tree, any side could be could be considered the front.

But a cannon has distinct front, back, and sides.

Issues about Motion

le curé est avant le ministre
the priest is before the minister

le chêne est avant le peuplier
the oak is before the poplar

For stationary objects, such as trees, the speaker's viewpoint determines the choice of preposition.

For moving objects, their relative position is more significant.

But objects like snails and turtles, which move very slowly, are treated like stationary objects (unless their motion is relevant).

Issues about Function

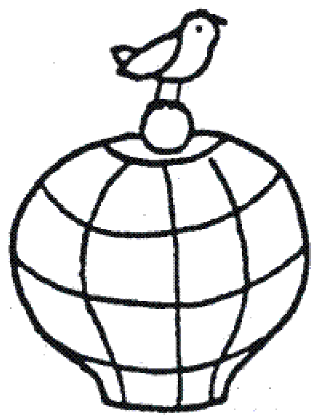
la poire est dans la coupe
the pear is in the bowl

The French preposition *dans* or the English *in* normally links something to a container.

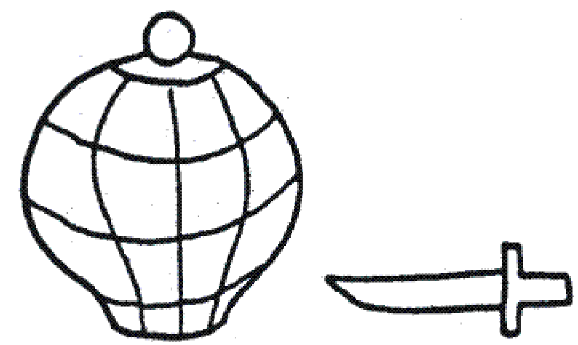
The primary function of a bowl is to serve as a container.

That function is more relevant than the question whether the bowl actually encloses the pear.

Issues about Background Knowledge



l'oiseau est à l'extérieur de la cage
the bird is outside the cage



? le couteau est à l'extérieur de la cage
the knife is outside the cage

A cage is sometimes used to enclose a bird.

But a cage is an unlikely container for a knife.

Normal comment: "The knife is to the right of the cage."

To say "The knife is outside the cage" implies that there is some reason why it might have been in the cage.

Nonmonotonic Reasoning

David Makinson (2005) defined three kinds of bridges that relate classical and nonmonotonic methods.

- Modify the set of assumptions.
- Constrain the set of permissible models.
- Use rules that make incremental changes of assumptions or models during a proof.

These three bridges enable any classical proof procedure to be used in nonmonotonic methods of belief revision.

They also enable the most widely used nonmonotonic proofs to be converted to classical proofs.

The classical proofs use the same semantics, but a modified set of axioms (assumptions and constraints).

More to Come

More slides will be added within the next week or two.

Foundation for Knowledge Sharing

Model-theoretic semantics is key to all versions of logic:

- Classical logic has a fixed set of axioms (assumptions and constraints) and a fixed set of models.
- Nonmonotonic methods may change the assumptions, constraints, and models during the reasoning process.
- Heuristics, probability, statistics, case-based reasoning, and fuzzy logic use a wider range of metalevel reasoning.
- But the semantics of every method of reasoning is based on an evaluation function that determines truth values in terms of models.

Basis for message passing among heterogeneous agents:

- All agents can reason with statements in FOL or some subset of FOL.
- All agents can assert statements in FOL.
- Messages should consist of FOL statements with FOL metadata.
- The metadata may state assumptions, constraints, and qualifications such as probabilities, error bounds, or fuzzy values.
- An agent may interpret any message by its own reasoning methods.

Related Readings

A longer set of slides that have some overlap with these:
http://www.jfsowa.com/talks/goal.pdf

Fads and Fallacies About Logic,
http://www.jfsowa.com/pubs/fflogic.pdf

Role of Logic and Ontology in Language and Reasoning,
http://www.jfsowa.com/pubs/rolelog.pdf

Slides for a tutorial about patterns of logic and ontology,
http://www.jfsowa.com/talks/kdptut.pdf

Makinson's book:
Makinson, David (2005) *Bridges from Classical to Nonmonotonic Logic*, London: King's College Publications.

For other citations in these slides, see the general bibliography,
http://www.jfsowa.com/bib.htm