Cognitive Logic vs. Mathematical Logic

& the Way to Artificial General Intelligence

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Artificial General Intelligence

Artificial General Intelligence (AGI): a small research community in AI that believes

- "Intelligence" is a general-purpose capability
- "Intelligence" should be studied as a whole
- It is possible to build "machine intelligence" comparable to human intelligence

AI and Logic

"Intelligence" can be understood as "rationality" and "validity" — "to do the right thing".

"Logic" studies valid reasoning, or the "Law of Thought".

Therefore, an AI system may be built as a reasoning system following a logic.

Traditional Theories

Systems following "Mathematical logic"

- Language and inference rules: *first-order predicate calculus*
- Semantics: *model theory*
- Memory: *database or knowledge base*
- Control: *theory of computation and algorithm*

Traditional Problems (1)

- Uncertainty: *fuzzy concepts, changing meanings and truth-values, fallible results, conflicting evidence, nondeterministic inference process, …*
- Semantic justification of non-deductive inference: *induction, abduction, analogy, …*

Traditional Problems (2)

- Counter-intuitive results: *sorites paradox, implication paradox, Hempel's confirmation paradox, Wason's selection task, …*
- Computability and complexity: *termination problem, combinatorial explosion, unanticipated problem, …*

Proposed Solutions

- non-monotonic logic
- paraconsistent logic
- relevance logic
- probabilistic logic
- fuzzy logic
- inductive logic
- temporal logic
- modal logic
- situation calculus
- possible-world theory
- mental logic
- mental model
- case-based reasoning
- Bayesian network
- neural network
- genetic algorithm
- heuristic algorithm
- learning algorithm
- anytime algorithm
- … …

Common Root of the Problems

The traditional theories were developed in the study of the foundation of mathematics, while the problems appear outside mathematics.

The *logic of mathematics* is different from the *logic of cognition and intelligence …*

… in their assumptions on the knowledge and resources of the system involved.

Different Types of Systems

Pure-axiomatic: the system's knowledge and resources are sufficient (with respect to the problems to be solved).

Semi-axiomatic: some (but not all) aspects of the knowledge and resources are sufficient.

Non-axiomatic: the knowledge and resources of the system are insufficient.

What is NARS

NARS (Non-Axiomatic Reasoning System) is a reasoning system that is fully based on the *Assumption of Insufficient Knowledge and Resources*.

NARS is a *finite, real time, open*, and *adaptive* system.

NARS is different from the traditional systems in all major components.

Categorical Language

- A typical sentence:

  bird → animal [1.0, 0.9]
- *Term*: "bird" and "animal" are names of concepts
- *Inheritance* ("→"): a copula for specialization-generalization relation
- Truth-value: [*frequency*, *confidence*]

Experience-Grounded Semantics

- The truth-value of a sentence is determined by the available evidence from the experience of the system:

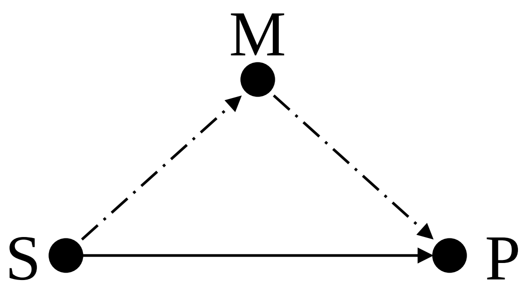
  $$f = w^{+}/w, \quad c = w/(w+1)$$

  where w^{+} and w are the amounts of positive and total evidence, respectively.
- The meaning of a term is defined by its experienced relations with other terms.

Deduction

$$\frac{\begin{array}{l} M \rightarrow P\ [f_1, c_1] \\ S \rightarrow M\ [f_2, c_2] \end{array}}{S \rightarrow P\ [f, c]}$$

$$f = f_1 * f_2$$
$$c = c_1 * c_2 * f_1 * f_2$$



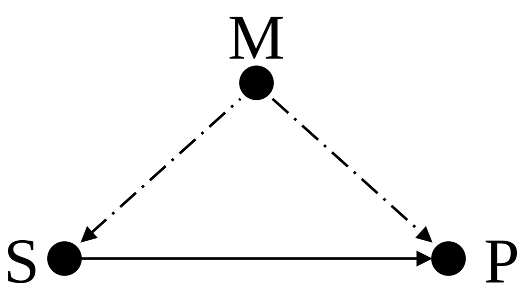
$$\frac{\begin{array}{l} \text{bird} \rightarrow \text{animal}\ [1.00, 0.90] \\ \text{robin} \rightarrow \text{bird}\ \ [1.00, 0.90] \end{array}}{\text{robin} \rightarrow \text{animal}\ [1.00, 0.81]}$$

Induction

$$\frac{M \rightarrow P\ [f_1, c_1] \qquad M \rightarrow S\ [f_2, c_2]}{S \rightarrow P\ [f, c]}$$

$$f = f_1$$

$$c = f_2 * c_1 * c_2 \,/\, (f_2 * c_1 * c_2 + 1)$$



swan → bird [1.00, 0.90]
swan → swimmer [1.00, 0.90]

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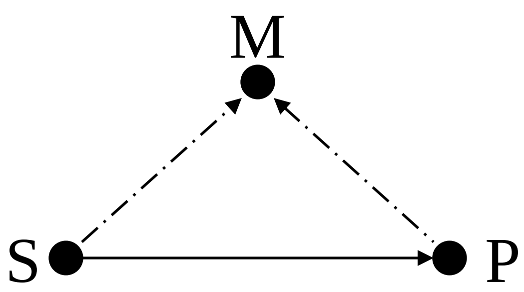
bird → swimmer [1.00, 0.45]

Abduction

$$\frac{P \to M\ [f_1, c_1] \quad S \to M\ [f_2, c_2]}{S \to P\ [f, c]}$$

$f = f_2$

$c = f_1 * c_1 * c_2 \,/\, (f_1 * c_1 * c_2 + 1)$



seabird → swimmer [1.00, 0.90]
gull → swimmer [1.00, 0.90]

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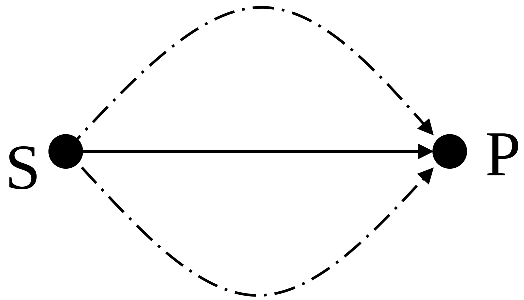
gull → seabird [1.00, 0.45]

Revision

$$\frac{S \rightarrow P\ [f_1, c_1] \quad S \rightarrow P\ [f_2, c_2]}{S \rightarrow P\ [f, c]}$$

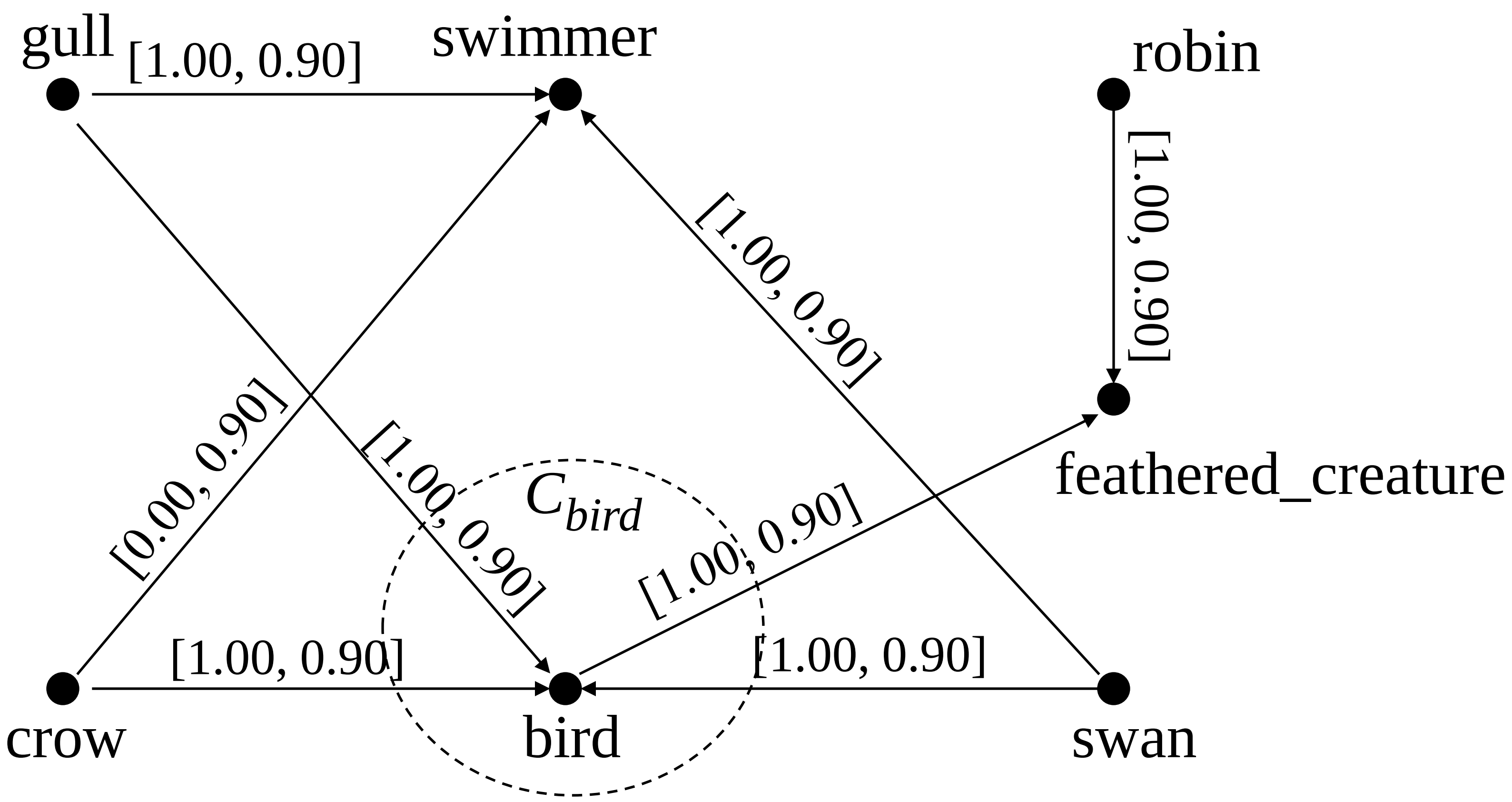
$$f = \frac{f_1 * c_1 * (1 - c_2) + f_2 * c_2 * (1 - c_1)}{c_1 * (1 - c_2) + c_2 * (1 - c_1)}$$

$$c = \frac{c_1 * (1 - c_2) + c_2 * (1 - c_1)}{c_1 * (1 - c_2) + c_2 * (1 - c_1) + (1 - c_2) * (1 - c_1)}$$



$$\frac{\text{bird} \rightarrow \text{swimmer}\ [1.00, 0.62] \quad \text{bird} \rightarrow \text{swimmer}\ [0.00, 0.45]}{\text{bird} \rightarrow \text{swimmer}\ [0.67, 0.71]}$$

Memory as a Network



Control Strategy

- In each step, a task is processed by interacting with a belief within the same concept, according to applicable rules.
- The concept, task, and belief are selected probabilistically, according to priority distributions among tasks and beliefs.
- Factors influencing the priority of an item: quality, usefulness in history, relevance to the current context, etc.

First-Order Reasoning

- Compound terms: *sets*, *intersections*, *differences*, *products*, and *images*.
- Variants of the *inheritance* copula: *similarity*, *instance*, and *property*.
- New inference rules for *comparison*, *analogy*, plus compound-term *composition* and *decomposition*.
- Related changes in memory and control.

Higher-Order Reasoning

- *Implication* and *equivalence*, are higher-order copulas between statements.
- Compound statements: *negations*, *conjunctions*, and *disjunctions*.
- The implication relation is used to carry out *conditional and hypothetical inferences*.
- Variable terms are used to carry out *general and abstract inferences*.

Procedural Reasoning

- *Events* as statements with temporal relations (*sequential* and *parallel*). *Prediction* as temporal inference.
- *Operations* as statements with procedural interpretation. *Skill learning* and *planning* as procedural inferences.
- *Goals* as statements to be realized. *Decision making* as committing to candidate goals.

Summary

- It is possible to build a reasoning system that adapts to environment, and works with insufficient knowledge and resources.
- Such a system provides a unified solution to many problems in AI and cognitive sciences, and may lead to AGI.

THANKS!

Further information:

http://www.cis.temple.edu/~pwang/