Integrated Commonsense Reasoning and Learning Using Non-axiomatic Logic

Pei Wang
Temple University
Philadelphia, USA

"Intelligence" as a Whole

- Mainstream AI treats "Intelligence" as a collection of problem-specific and domain-specific functions
- Artificial General Intelligence (AGI) takes "Intelligence" as a general-purpose and holistic/integrated capability
- AGI research still includes different objectives and techniques

Basic Assumption

"Intelligence" is *the capability of a system to adapt to its environment and to work with insufficient knowledge and resources*

Assumption of Insufficient Knowledge and Resources (AIKR):

- To rely on *finite* processing capacity
- To work in *real time*
- To *open* to unexpected tasks

Non-Axiomatic Logic (NAL)

NAL consists of

- a *language* for representation
- a *semantic theory* of the language
- a set of formal *inference rules*

NAL is the logic part of NARS (Non-Axiomatic Reasoning System), an AGI project designed under AIKR

NARS is open source, with demonstrations and working examples

Representation Language

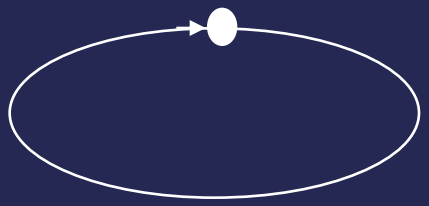
Term: identifier of concept

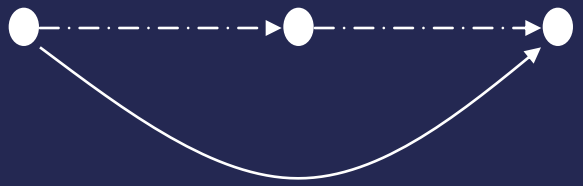
Statement: subject-copula-predicate

$S \rightarrow P$

as specialization-generalization

Copula *inheritance* is reflexive and transitive





Idealized Evidence

Positive evidence of $S \rightarrow P$:

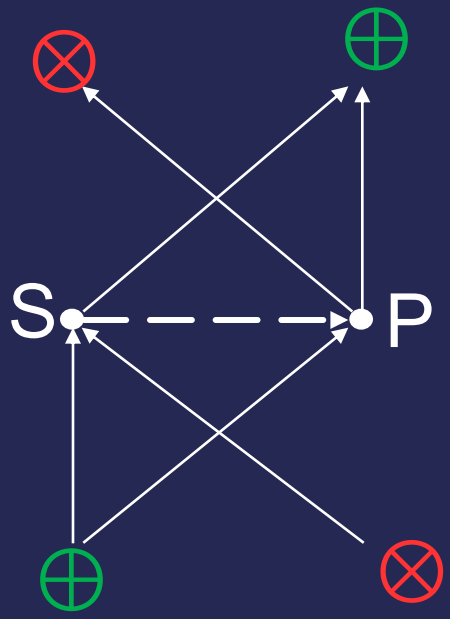
$\{x \mid ((x \rightarrow S) \wedge (x \rightarrow P))$

$\vee ((P \rightarrow x) \wedge (S \rightarrow x))\}$

Negative evidence of $S \rightarrow P$:

$\{x \mid ((x \rightarrow S) \wedge \neg(x \rightarrow P))$

$\vee ((P \rightarrow x) \wedge \neg(S \rightarrow x))\}$



Amount of evidence:

positive (w^+) , negative (w^-), total ($w = w^+ + w^-$)

Truth-Value Defined

In NAL, the truth-value of a statement is a pair of real numbers in [0, 1], and measures the evidential support to the statement

$S \rightarrow P \langle f, c \rangle$

frequency: $f = w^+ / w$

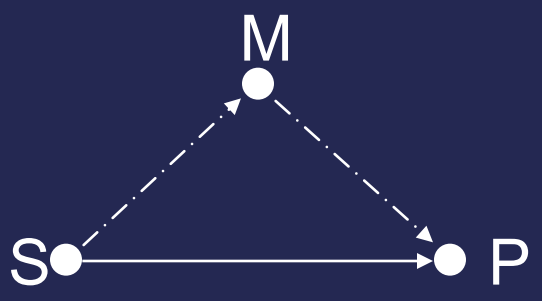
confidence: $c = w / (w + 1)$

Deduction

$M \rightarrow P\ [f_1, c_1]$
$S \rightarrow M\ [f_2, c_2]$

$S \rightarrow P\ [f, c]$

$f = and(f_1, f_2)$
$c = and(f_1, f_2, c_1, c_2)$



bird $\rightarrow$ *animal* [1.00, 0.90]
robin $\rightarrow$ *bird* [1.00, 0.90]

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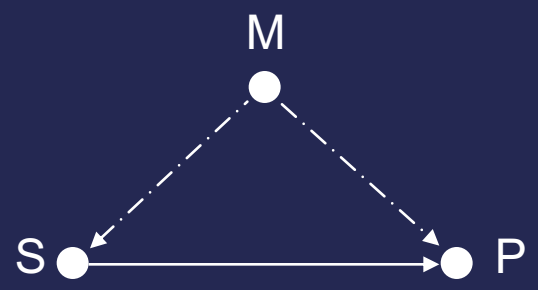
robin $\rightarrow$ *animal* [1.00, 0.81]

Induction

$M \rightarrow P\ [f_1, c_1]$
$M \rightarrow S\ [f_2, c_2]$

$S \rightarrow P\ [f, c]$

$\boldsymbol{w}^+ = \text{and}(f_1, f_2, c_1, c_2)$
$\boldsymbol{w} = \text{and}(f_2, c_1, c_2)$



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

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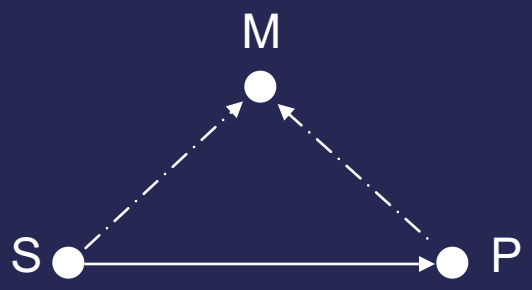
bird → *swimmer* [1.00, 0.45]

Abduction

$P \rightarrow M\ [f_1, c_1]$
$S \rightarrow M\ [f_2, c_2]$

$S \rightarrow P\ [f, c]$

$\boldsymbol{w}^+ = \text{and}(f_1, f_2, c_1, c_2)$
$\boldsymbol{w} = \text{and}(f_1, c_1, c_2)$



seabird $\rightarrow$ *swimmer* [1.00, 0.90]
gull $\rightarrow$ *swimmer* [1.00, 0.90]

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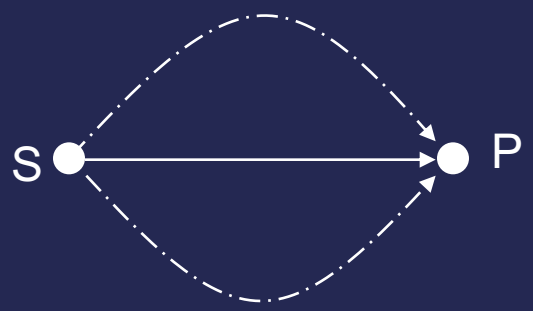
gull $\rightarrow$ *seabird* [1.00, 0.45]

Revision

$S \longrightarrow P\ [f_1, c_1]$
$S \longrightarrow P\ [f_2, c_2]$

$S \longrightarrow P\ [f, c]$

$$w^+ = w^+_1 + w^+_2$$
$$w = w_1 + w_2$$



bird ⟶ *swimmer* [1.00, 0.62]
bird ⟶ *swimmer* [0.00, 0.45]

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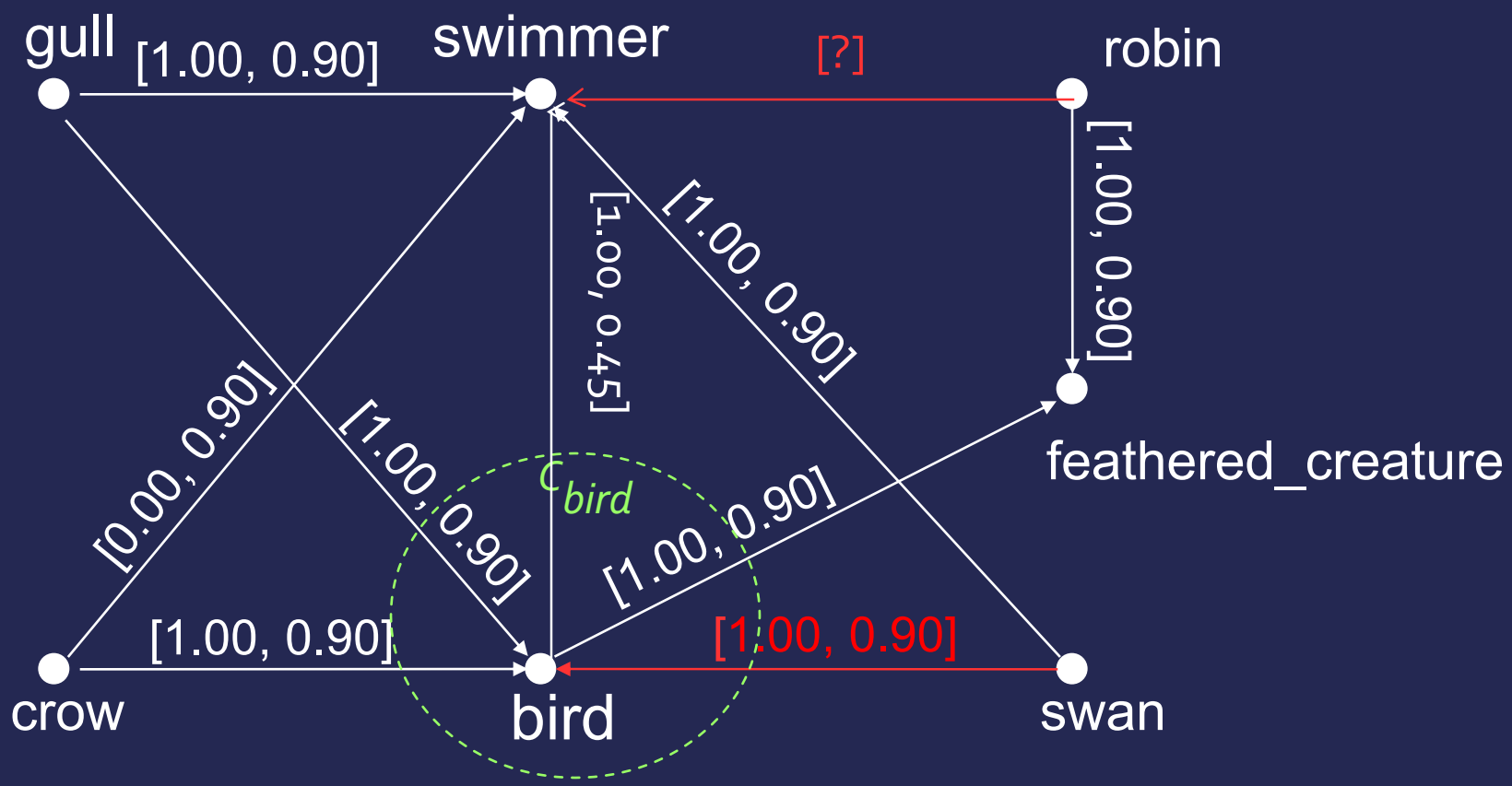
bird ⟶ *swimmer* [0.67, 0.71]

Memory as a Network



Expressing Power

- Terms can be composed from other terms to express patterns in experience
- Statements can correspond to *sensation*, *perception*, *event*, and *operation*
- Copulas include *inheritance*, *similarity*, *implication*, and *equivalence*
- The meaning of a term is its experienced relations with the other terms

Inferential Power

- Syllogistic rules also include *choice*, *analogy*, *comparison*, etc.
- Compositional rules generate new terms and concepts
- *Backward inference* uses the rules to derive questions and goals
- Inference tasks: *observation digesting*, *question answering*, and *goal achieving*

Learning as Reasoning

- Learning (adaptation) is the long-term effects of the inference processes
- Task processing does not follow any fixed algorithm, but is data-driven, real-time, lifelong, context-sensitive, and incremental
- The system uses whatever knowledge and resources available, and provides justifiable solutions with numerical evaluation

Application Potential

- Customized version of the system can be built for a specific application
- Such a system can be used as a coordinator of various special-purpose tools
- The system allows various forms of run-time user/system interaction
- Ideal for situations where the insufficiency of knowledge/resource cannot be ignored

Publications & demonstrations:
http://www.cis.temple.edu/~pwang/

Thanks for your attention!