仮説を立てて考えてみよう
Let’s Hypothesize and Reason!

井上 克巳 Katsumi Inoue
宋 剛秀 Takehide Soh
山本 泰生 Yoshitaka Yamamoto
ゴヴァン ブルニュ Gauvain Bourgne

何がわかるか？
- Intelligent machines:
  Thinking like human being.
- Automated discovery of scientific knowledge, in particular biological knowledge.

どんな研究か？
- Automated hypothesis-finding through deductively complete methods.
- Induction of causal laws in action theories, and applications to systems biology.
- Web-based ILP system.

Background

How Human Beings Think?

Observation

Induction

Hypothesizing and Reasoning

Abduction

Deduction

Prediction

How Intelligent Machines Think?

Induction

Abduction

Deduction

Diagnosis

Design

Characterization

Discovery

Verification

The genius people are able to mix these three fundamental modes of reasoning.

Combination of induction and abduction

One of the most powerful theoretical answers for the next generation of Intelligent Machine (Inoue 2001, 2004)

Logic and Computation

Abduction and Induction: Logic

Input:

B: background theory
E: examples / observations

Output:

H: hypothesis satisfying that
1. B ∧ H ⊨ E
2. B ∧ H is consistent

IE for Abduction

SOLAR

(Nabeshima, Iwanuma and Inoue 2003)
(Nabeshima, Iwanuma, Inoue and Ray 2010)

B: full clausal theory, E: conjunction of literals
H: conjunction of literals

IE for Induction

CF-induction

(Inoue 2004: Yamamoto, Ray and Inoue 2007)

B: full clausal theory, E: full clausal theory
H: full clausal theory

Example: graph completion problem - pathway finding

Find an arc which enables a path from a to d.

Axioms:

node(X), node(Y), arc(X, Y) → path(X, Y).
node(X), node(Y), node(Z), arc(X, Y), path(Y, Z) → path(X, Z).
node(a), node(b), node(c), node(d), arc(a, b), arc(c, d).

Observation: path(a, d).

Abducibles: arc(a, d)

SOLAR outputs four hypotheses.

arc(a, d), arc(a, c), arc(b, d), arc(b, c).

Distributed Abduction

Learner-Critic Protocol

(Bourgne, Maudet and Inoue 2010)

N agents a0, ..., an, each having his own knowledge (B0, E0)

B = ∪Bi, E = ∪Ei: conjunction of literals

H: conjunction of literals

Learner:

1. Compute local hypothesis (and context)
2. Interact with critics (propose)

Critic:

1. Consistency check (context computation)
2. Explainability check (uncovered examples)
3. Admissibility check
Inference-based Hypothesis-Finding for Systems Biology

Katsumi Inoue, Gauvain Bourgne, Takehide Soh, Yoshitaka Yamamoto, Andrei Doncescu (LAAS-CNRS), Taisuke Sato (Tokyo Inst. Tech)

- Discover hidden rules in systems biology.
- Explain the relationships between causes and effects from genotype to phenotype.
- Build generic models in biology, Saccharomyces Cerevisiae and E. coli.

Closed-loop Architecture for Biological Inference

- Development of a framework for knowledge discovery from biological databases using logic-based AI.
- Clarification of the principles of hypothesis formation and hypothesis evaluation and their efficient implementation.
- Bridge between biologists and computer scientists.

Research Goals
- Modeling, explaining and predicting metabolic pathways

Target Problems
1. Predicting the inhibitory effect of toxins including hydrazine with qualitative modeling
2. Explaining dynamic behavior of E. coli pathways with kinetic modeling

Approaches
- Hypothesis generation by SOLAR
- Hypothesis evaluation by an EM algorithm on BDDs
- Modeling with discretization and the Michaelis-Menten equation

Identifying Necessary Reactions in Large Metabolic Pathways

- Identifying necessary reactions in metabolic pathways

Example.
Source condition $m_{1,0}, \neg m_{2,0}$
Target condition $m_{2,2}$

Reaction Laws
$m_{1,0} \rightarrow m_{1,1}, m_{1,1} \rightarrow m_{1,2}, m_{1,2} \rightarrow m_{2,1}, m_{2,1} \rightarrow m_{2,2}$
$f_{1,1} \rightarrow m_{1,0}, f_{1,1} \rightarrow m_{2,1}, f_{1,1} \rightarrow m_{3,2}, f_{1,1} \rightarrow m_{4,3}$
$f_{2,2} \rightarrow m_{1,0}, f_{2,2} \rightarrow m_{2,1}, m_{2,2} \rightarrow m_{2,3}, m_{2,2} \rightarrow m_{2,4}$

Source and Target Metabolites

Necessary Reactions

Reaction Database (EcoCyc)

Definitive Model Generator

Pathway Model (Qualitative / Kinetic)
Pathway Data (from lab + KEGG)

Background Knowledge

Observations

SOLAR

Hypotheses $B \land H \Rightarrow E$

BDD-EM

Pathway Model Analysis
The best hypothesis selected by BDD-EM

Best Hypotheses

Initials: PROTON, WATER, ATP, ADP, $|pi|$ and NAD.
Source: GLC-6-P. Target: PYRUVATE.