

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

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何がわかる？

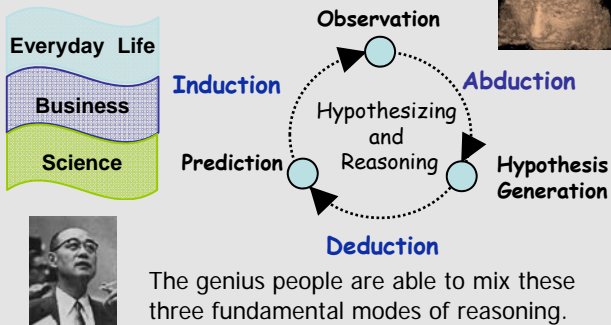
- Intelligent machines:
Thinking like human being.
- Automated discovery of scientific knowledge, in particular biological knowledge.

どんな研究？

- 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 ?



How Intelligent Machines Think ?



- Induction
 - Abduction
 - Deduction
- Diagnosis
Design
Characterization
Discovery
Verification

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

$$1. B \wedge H \models E,$$

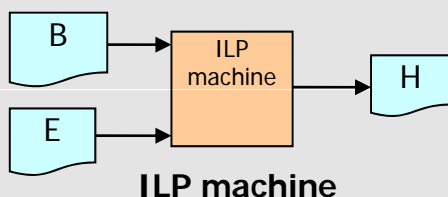
$$2. B \wedge H \text{ is consistent.}$$

Inverse Entailment (IE)

Computing a hypothesis H can be done **deductively** by:

$$B \wedge \neg E \models \neg H$$

We have good tools for this inverse computation.



IE for Abduction

- **SOLAR** (Nabeshima, Iwanuma & Inoue 2003)

B : full clausal theory

E : conjunction of literals ($\neg E$ is a clause)

H : conjunctions of literals ($\neg H$ is a clause)

Example: graph completion problem – pathway finding

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

Axioms: $[\neg \text{node}(X), \neg \text{node}(Y), \neg \text{arc}(X,Y), \text{path}(X,Y)].$

$[\neg \text{node}(X), \neg \text{node}(Y), \neg \text{node}(Z), \neg \text{arc}(X,Y), \neg \text{path}(Y,Z), \text{path}(X,Z)].$

$[\text{node}(a)]. [\text{node}(b)]. [\text{node}(c)]. [\text{node}(d)].$

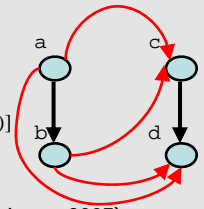
$[\text{arc}(a,b)]. [\text{arc}(c,d)].$

Negated Observation: $[\neg \text{path}(a,d)].$

Production_field: $[\neg \text{arc}(_,_)].$

SOLAR outputs four consequences:

$[\neg \text{arc}(a, d)], [\neg \text{arc}(a, c)], [\neg \text{arc}(b, d)], [\neg \text{arc}(b, c)]$



IE for Induction

- **CF-induction** (Inoue 2004; Yamamoto, Ray & Inoue 2007)

CF-induction is the only existing ILP system that is complete for full clausal theories.

SAT-based Approach for Pathway Finding

This approach transforms pathways and biological rules into CNF formulas. We can identify probable paths by finding minimal models.

推論による仮説発見とシステム生物学への応用 Inference-based Hypothesis-Finding for System Biology

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何がわかる？

- 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*.

どんな研究？

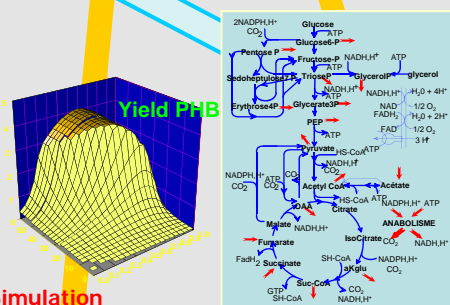
- Development of a framework for knowledge discovery from biological databases using logic-based AI.
- Clarification of the principles of hypothesis formation and hypothesis evaluation and their efficient implementation.
- Bridge between biologists and computer scientists

Modeling

Phenomenological models

METABOLIC Analyzer

INTRACELLULARE pools



Genomic Response

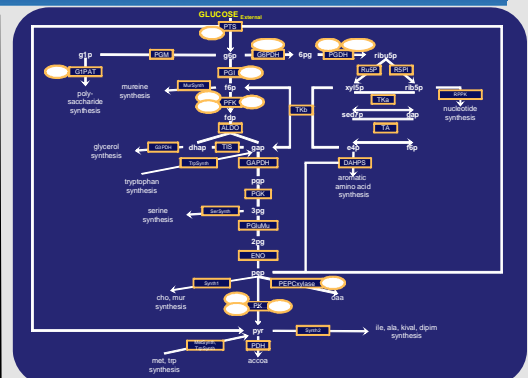
Structural Models

Simulation

Metabolic Constraints

Optimization

Stoichiometric Modeling



Metabolic pathway: sequences of enzyme-catalyzed reaction steps, converting substrates to a variety of products to meet the needs of the cell.

Flux: the rate at which a material is processed through a metabolic pathway.

Approach

Goals

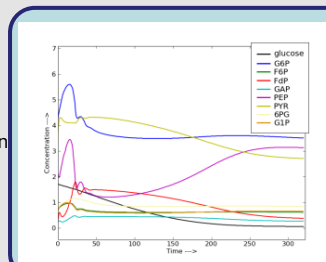
- Explaining and predicting metabolic pathways

Approaches

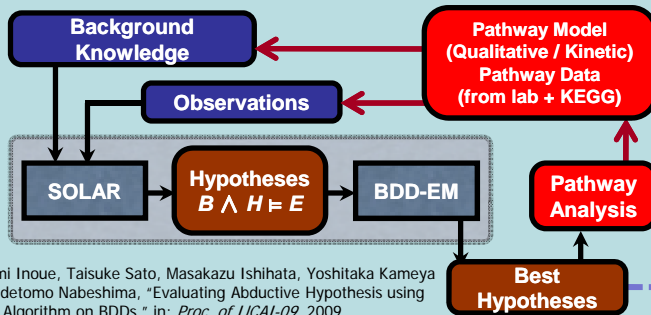
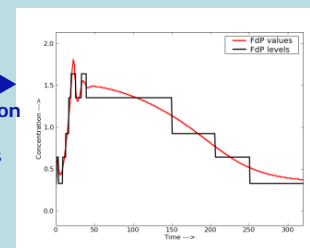
- Hypothesis generation by SOLAR
- Hypothesis evaluation by an EM algorithm on BDDs
- Modeling with discretization and the Michaelis-Menten equation

Problem Settings

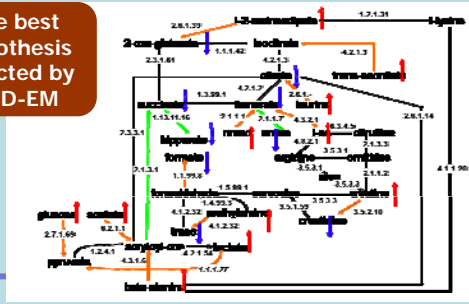
1. Predicting the inhibitory effect of toxins including hydrazine with qualitative modeling
2. Explaining dynamic behavior of *E. coli* pathways with kinetic modeling



Discretization with continuous HMMs



The best hypothesis selected by BDD-EM



Katsumi Inoue, Taisuke Sato, Masakazu Ishihata, Yoshitaka Kameya and Hidetomo Nabeshima, "Evaluating Abductive Hypothesis using an EM Algorithm on BDDs," in: *Proc. of IJCAI-09*, 2009.