Integrating explanation-based & generalisation-based reasoning for scientific discovery

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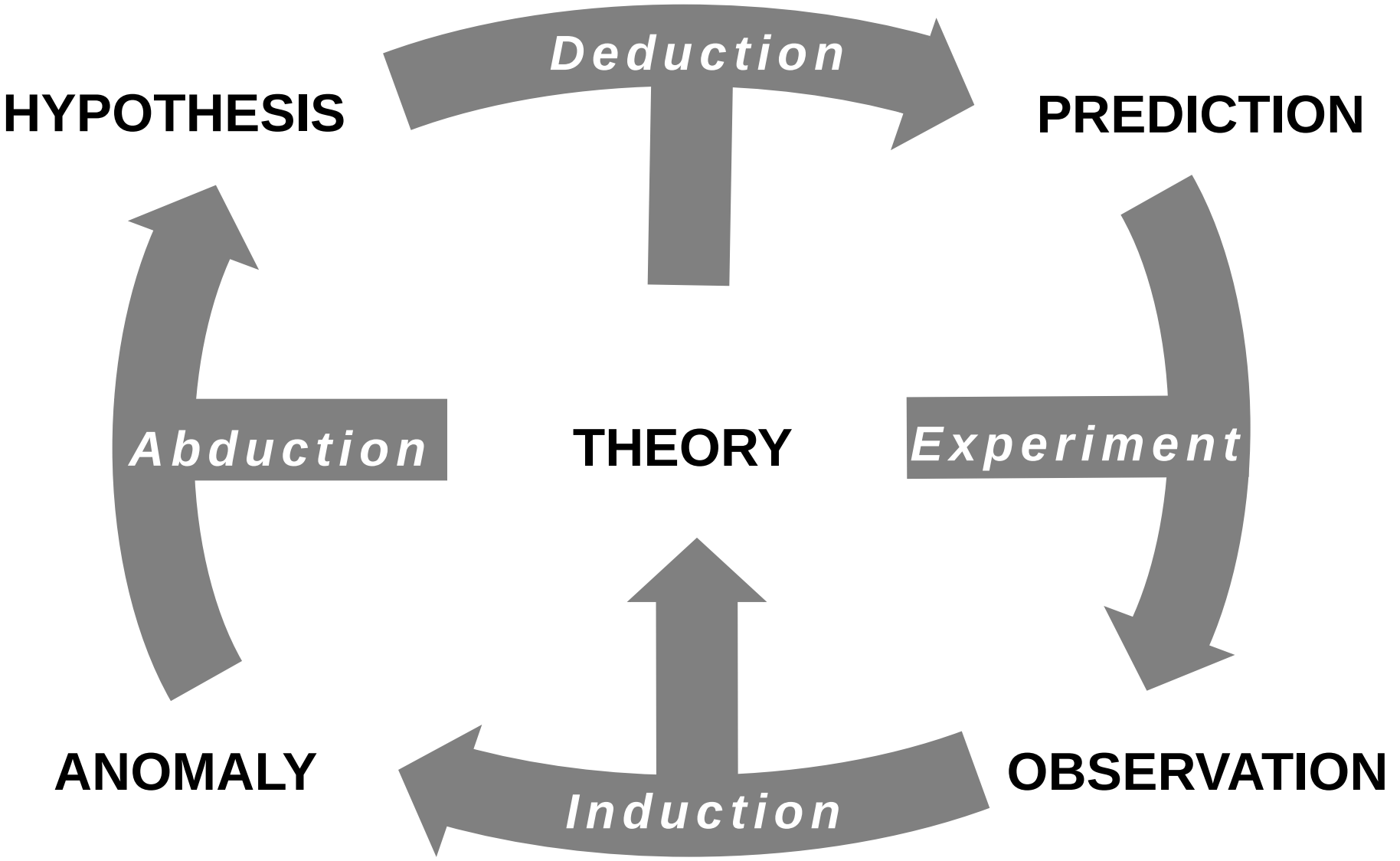
Outline

- **Scientific Method, Reasoning, and Creativity**
- **Abductive and Inductive Logic Programming**
- **Hybrid Abductive Inductive Learning**
- **Temporal Domain Modelling**

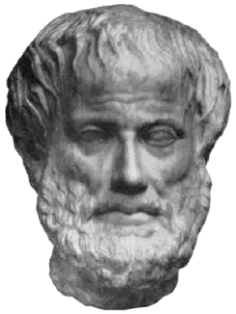
Scientific Method



Scientific Reasoning

Deduction

consequence:
from *given knowledge*
to *necessary implications*



Induction

generalisation:
from *particular cases*
to *general laws*

Abduction

explanation:
from *observed effects*
to *underlying causes*

Syllogistic Motivation

Deduction

All the beans from this bag are white

These beans are from this bag

$\therefore$ These beans are white

Induction

These beans are white

These beans are from this bag

$\therefore$ All the beans from this bag are white

Abduction

All the beans from this bag are white

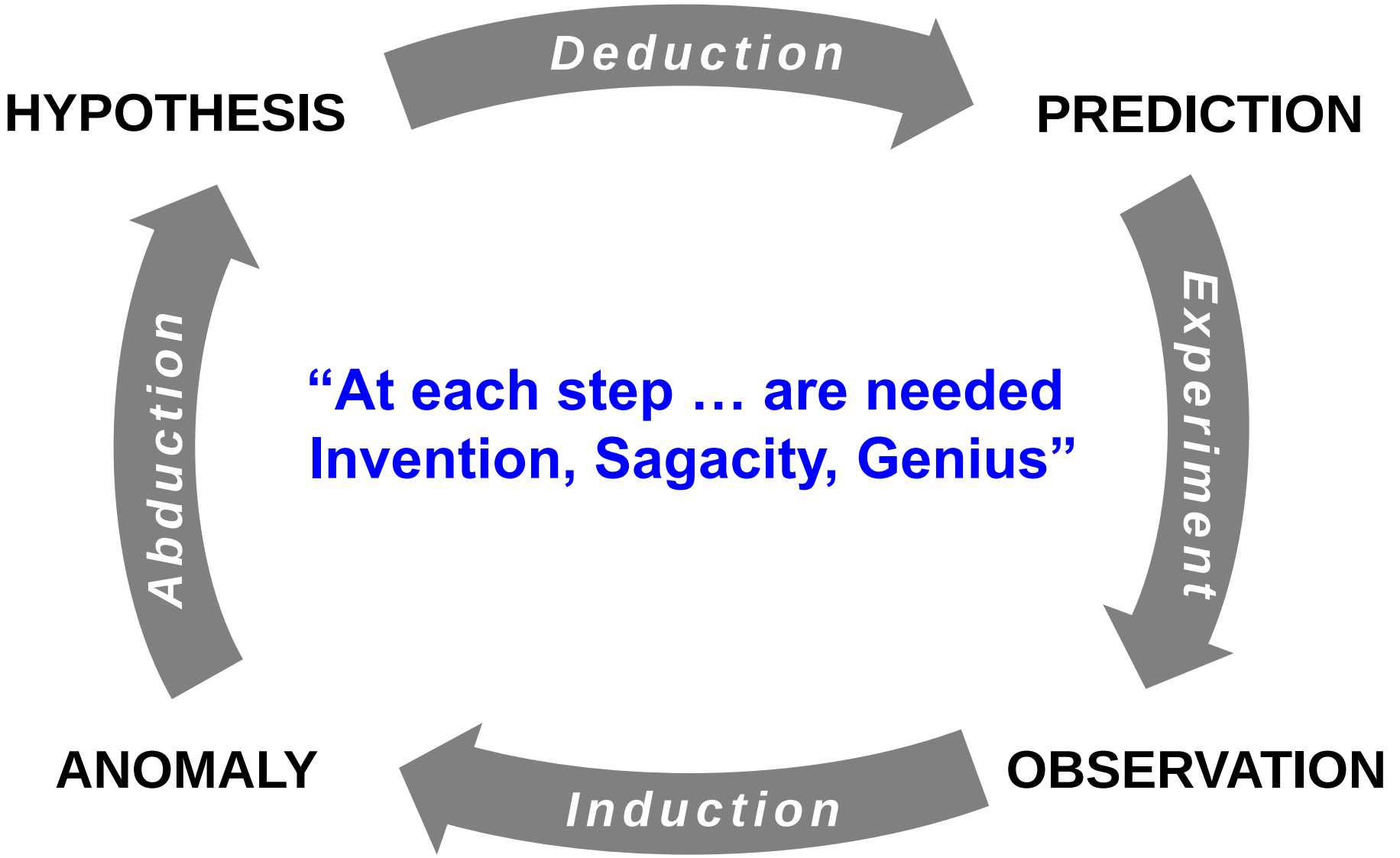
These beans are white

$\therefore$ These beans are from this bag

Computational Formalisation

Given	**T**	**Theory**
	G	**Goals**
Find	**H**	**Hypothesis**
Where	**T** $\cup$ **H** $\models$ **G**	
And	**T** is a set of **clauses**	
	G is a set of **literals**	
	H is a set of **literals**	**Abduction /**
	or a set of **clauses**	**Induction**
	satisfying …	**Bias**

Creativity and the Knowledge Soup



Ab/Inductive Logic Programming

- **Facts** a
- **Rules** $a \leftarrow b_1, \ldots b_m \text{ not } c_1, \ldots \text{not } c_n$
- **Constraints** $\leftarrow b_1, \ldots b_m \text{ not } c_1, \ldots \text{not } c_n$
- **ALP** Backward Chaining, Contrapositive Reasoning, Abductive Switch, …
- **ILP** Inverse resolution, Least Generalisation, Inverse Entailment, …

ALP and ILP

`	ALP	ILP
non-observation predicate learning	√	X progo5, Alecto, Inthelex
non-monotonic reasoning	√	X Sakam,a Otero
non-ground hypotheses	X Theorest, ASLDNFA	√
non-unit hypotheses	X	√

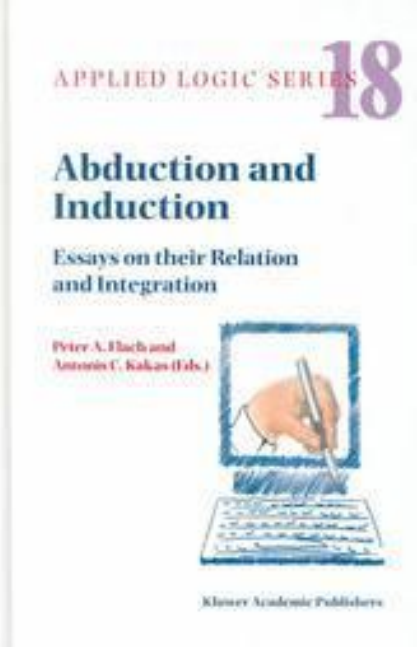
ALP and ILP

`	ALP	ILP
non-observation predicate learning **(Theoretical Concepts)**	√	X progo5, Alecto, Inthelex
non-monotonic reasoning **(Closed World)**	√	X Sakam,a Otero
non-ground hypotheses **(General Laws)**	X Theorest, ASLDNFA	√
non-unit hypotheses	X	√

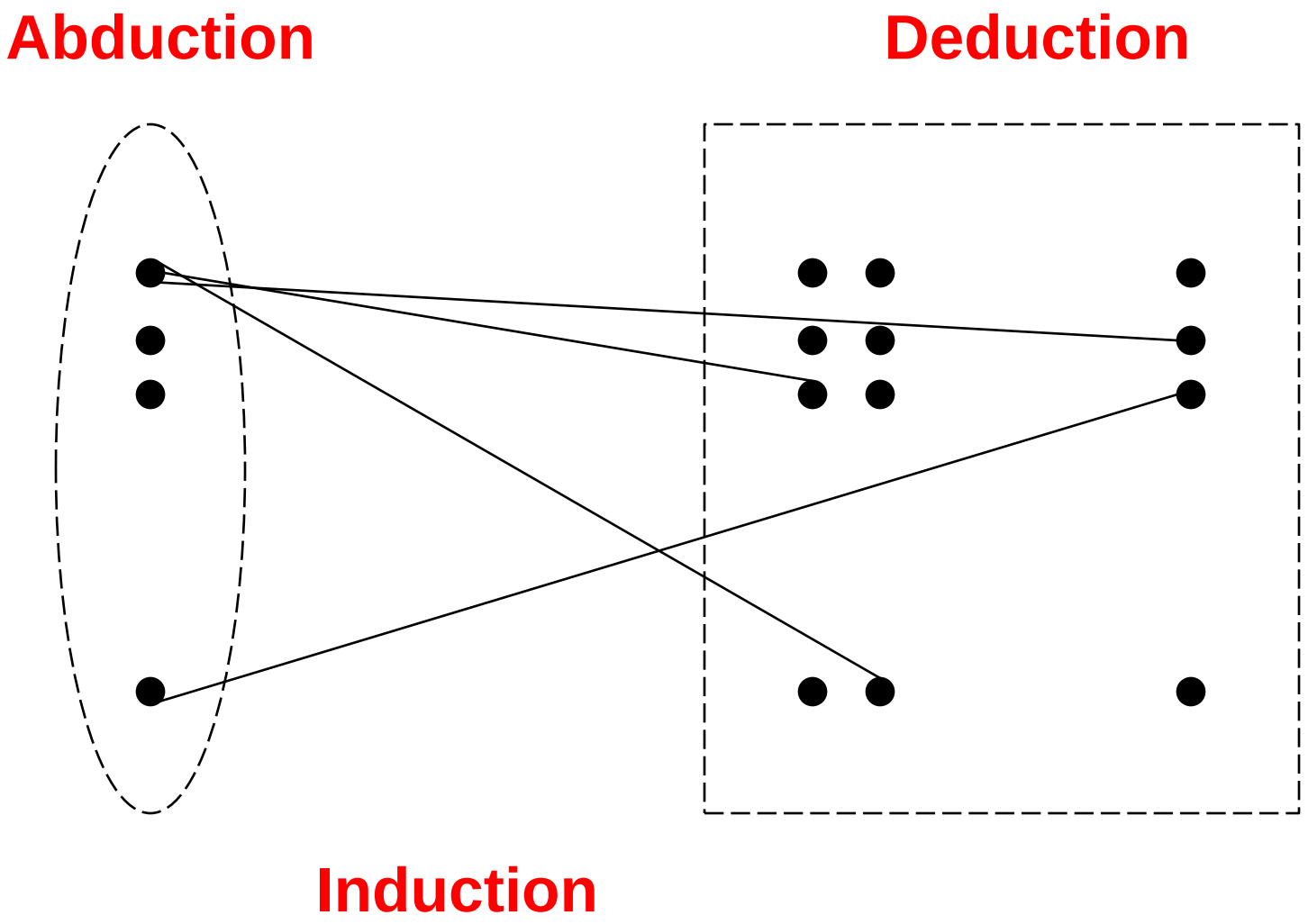
Integration of ALP and ILP

- **inductive learning presupposes incompleteness. abduction can hypothesise missing information**

- **Flach & Kakas 2000**
  - **Two Phase Learning**
    - Extraction case
    - Identification case
  - **Multi-strategy Learning**
  - **Theory Revision**
  - **Abductive Concept Learning**



Hybrid Abductive Inductive Learning



Temporal Domain Modelling

- **Given** T Knowledge
  N Narrative
  S Scenario

ontology
structure
behaviour

- **Find**: M Domain Model

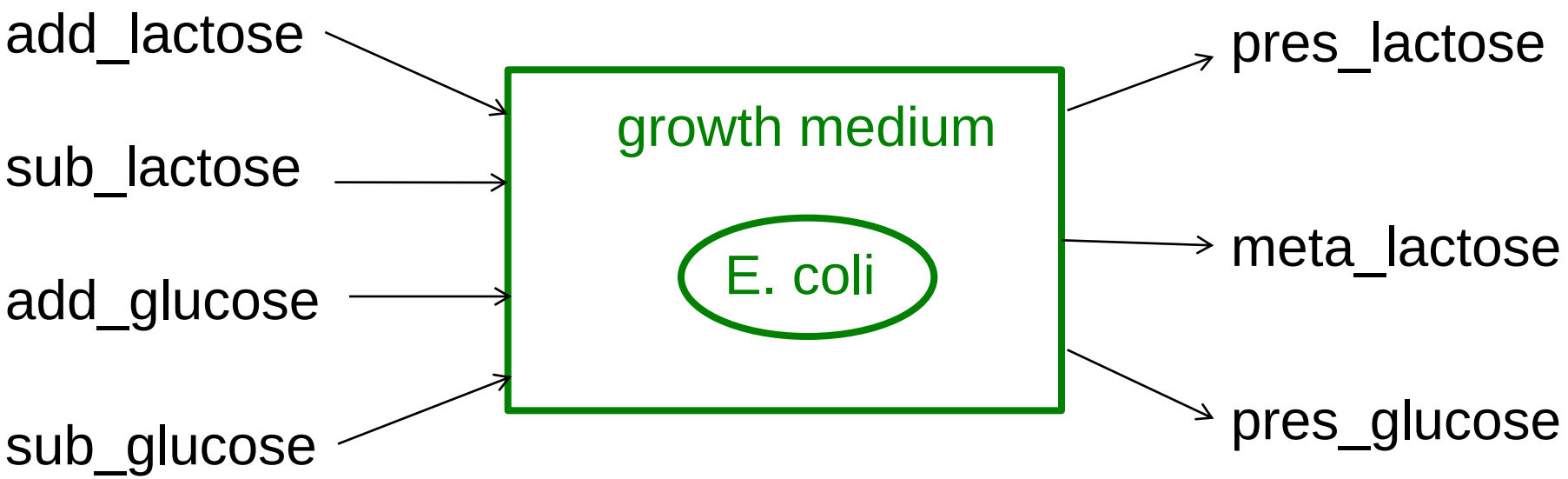
- **Where** $T \cup M \models N \rightarrow S$
  $T \cup M \cup N \models S$

E. coli Lactose Metabolism

ACTIONS (Events)

.....TIME.....(Integers)

EFFECTS (Fluents)



Knowledge

% temporal axioms

holdsAt(F,T_2) ← happens(E,T_1), T_1<T_2, initiates(E,F,T_1), not clipped(T_1,F,T_2).

holdsAt(F,T_2) ← initially(F), not clipped(0,F,T_2).

clipped(T_1,F,T_2) ← happens(E,T), T_1<T, T<T_2, terminates(E,F,T).

% ontology

time(0..9).

event(add_gluc ; add_lact ; sub_gluc).

fluent(pres_lact ; pres_gluc ; meta_lact).

% behaviour

initiates(add_gluc, pres_gluc, T).

initiates(add_lact, pres_lact, T).

terminates(sub_gluc, pres_gluc, T).

terminates(sub_lact, pres_lact, T).

Narrative, Scenario (and Bias)

% narrative

initially(pres(gluc)).
happens(add(lact),1).
happens(sub(gluc),2).
happens(sub(lact),3).
happens(add(lact),4).
happens(add(gluc),5).
happens(sub(lact),6).
happens(sub(gluc),7).

% scenario

not holdsAt(meta(lact),1),
not holdsAt(meta(lact),2),
holdsAt(meta(lact),3),
not holdsAt(meta(lact),4),
holdsAt(meta(lact),5),
not holdsAt(meta(lact),6),
not holdsAt(meta(lact),7),
not holdsAt(meta(lact),8).

% language bias

modeh(0, 2, min, initiates(#event,#fluent,+time)).
modeh(0, 2, min, terminates(#event,#fluent,+time)).

modeb(0, 3, pos, holdsAt(#fluent,+time)).
modeb(0, 3, neg, holdsAt(#fluent,+time)).

Abductive Phase

$$\Delta = \left\{ \begin{array}{l} initiates\,(sub\_gluc, meta\_lact, 2). \\ ter\ \min\ ates(sub\_lact, meta\_lact, 3). \\ initiates\,(add\_lact, meta\_lact, 4). \\ ter\ \min\ ates(add\_gluc, meta\_lact, 5). \end{array} \right\}$$

Deductive Phase

$$
K = \left\{ \begin{array}{lcl}
initiates(sub\_gluc, meta\_lact, 2) & \leftarrow & holdsAt(pres\_lact, 2), \\
 & & holdsAt(pres\_gluc, 2), \\
 & & not\_holdsAt(meta\_lact, 2). \\
ter\ \min ates(sub\_lact, meta\_lact, 3) & \leftarrow & holdsAt(pres\_lact, 3), \\
 & & not\_holdsAt(pres\_gluc, 3). \\
initiates(add\_lact, meta\_lact, 4) & \leftarrow & not\_holdsAt(pres\_lact, 4), \\
 & & not\_holdsAt(pres\_gluc, 4). \\
ter\ \min ates(add\_gluc, meta\_lact, 5) & \leftarrow & holdsAt(pres\_lact, 5), \\
 & & not\_holdsAt(pres\_gluc, 5).
\end{array} \right\}
$$

Inductive Phase

$$H = \left\{ \begin{array}{lcl} initiates(sub\_gluc, meta\_lact, T) & \leftarrow & time(T), \\ & & holdsAt(pres\_lact, T). \\ terminates(sub\_lact, meta\_lact, T) & \leftarrow & time(T). \\ initiates(add\_lact, meta\_lact, T) & \leftarrow & time(T), \\ & & not\_holdsAt(pres\_gluc, T). \\ terminates(add\_gluc, meta\_lact, T) & \leftarrow & time(T). \end{array} \right\}$$

Conclusions

- Creativity is inherent in all phases of science
- Computaional tools support (some aspects of) abductive and inductive reasonig
- Generalisation-based and explanation-based reasoning techniques can be usefully integrated
- Temporal calculi may be well suited for repres-enting and reasoning about scientific domains