Qualitative Causal Analysis of Empirical Knowledge for Ontology Evolution in Physics

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GALILEO project and Ontology Evolution in Physics

- Aim: solving contradictions between multiple ontologies.
  - Canonical case: contradictions in physics between theoretical expectations and experimental observations.
- Main results: Ontology Repair Plans (ORPs).
  - Trigger: detects contradiction between ontologies.
  - Repair: changes ontology axioms or signature.
  - Create New Axioms: propagates changes as needed.
- Methodology: turn case studies in physics history into ORPs.
  - Extract ORP's conceptual backbone from case study.
  - Represent ORP in higher-order logic.
  - Implement ORP (λProlog and beyond).
- Some ORPs and their state of development.
  - Developed and tested: Where's My Stuff? (WMS), Inconstancy, Unite.
  - Being tested: Open Structure, Close Structure.
  - Under development: Unify.

The case of latent heat

(until the 1750s)

$$\Delta T \equiv Q = m \times \Delta t$$

$$\swarrow \dashrightarrow \dashrightarrow \searrow$$

(1759)

$$Q = m \times \Delta T \times c$$

(1761)

$$Q = m \times \Delta T + m \times L$$

$$\searrow \quad \swarrow$$

(1763)

$$Q = m \times \Delta T \times c + m \times L$$

- Q, the heat, measured by temperature (before evolution), or heat put into or taken out of a body (after evolution).
- Δt, the flow of heat, measured by time, from the hotter to the cooler object.
- ΔT, change in temperature.
- m, mass of the body.
- c, specific heat capacity of the substance,
- L, specific latent heat capacity of a substance during phase transitions.

Evolution

- *From Equation 1750s to 1759*:

  (i) temperature change depends on substance-specific constant c

  (ii) heat distinguished from temperature

  Experimental evidence: depending on substance, changes in Q need a longer or shorter Δt (assuming Δt has constant rate)

- *From Equation 1750s to 1761*:

  (i) latent heat added to equation

  (ii) heat distinguished from temperature.

  Experimental evidence: during phase-changes a change in Q takes a greater Δt than within phases.

- *From equation 1759 and 1761 to 1763*: unify above results.

WMS's job

(until the 1750s)

$$\Delta T \equiv Q = m \times \Delta t$$

$$\searrow$$

WMS's step: $Q = m \times \Delta t + Q_{invis}$

$$\searrow$$

(1761)

$$Q = m \times \Delta T + m \times L$$

Application of Where's My Stuff?

Suppose ontology O_t represents the 1750s theory of heat and is contradicted by experimental evidence represented in O_s:

$$O_t \vdash Heat(H_2O, Melt) = Heat(H_2O, Melt)$$
$$O_s \vdash Heat(H_2O, Melt) = 0$$
$$O_t \vdash Heat(H_2O, Melt) > 0$$

Trigger and substitution:

$$O_t \vdash stuff(\vec{s}) = v_1, \quad O_s \vdash stuff(\vec{s}) = v_2, \quad O_t \vdash v_1 > v_2$$

$$\{Heat(H_2O, Melt)/v_1, 0/v_2, \langle H_2O, Melt\rangle/\vec{s}, \; Heat/stuff\}$$

Split Stuff:

$$\forall \vec{s} : \vec{\tau}.\ stuff\sigma_{invis}(\vec{s}) ::= stuff(\vec{s}) - stuff\sigma_{vis}(\vec{s})$$

Create New Axioms:

$$\begin{aligned} Ax(\nu(O_t)) &::= \{\forall \vec{s} : \vec{\tau}.\ stuff\sigma_{invis}(\vec{s}) ::= stuff(\vec{s}) - stuff\sigma_{vis}(\vec{s})\} \cup Ax(O_t) \\ Ax(\nu(O_s)) &::= \{\phi\{stuff/stuff\sigma_{vis}\} \mid \phi \in Ax(O_s)\} \end{aligned}$$

Result of application of Where's My Stuff?

$$Q_{vis} = (m \times \Delta t)$$
$$Q = Q_{vis} + Q_{invis}$$

Such addition-strategy is found in other cases in physics, e.g. the postulation of dark matter or of planets to account for unpredictable yet observed gravitational behaviour in galaxies or, resp., in planetary sytems.

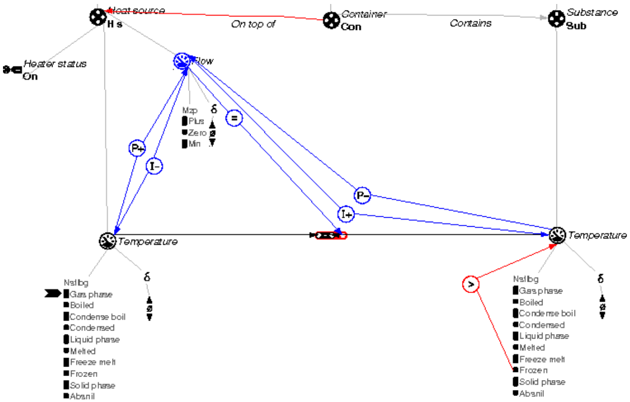
Causal analysis of experiment in QPT

How does the experimental set-up represented by the sensory ontology come to produce evidence that contradicts the expectations of the theoretical ontology?

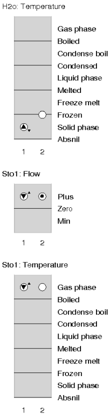
In the following, an attempt at addressing this question using Qualitative Process Theory (QPT) (Forbus, 1984)

QPT model of experimental set-up for Equation 1750s

Model



Unique Simulation



Process *Heat flow*

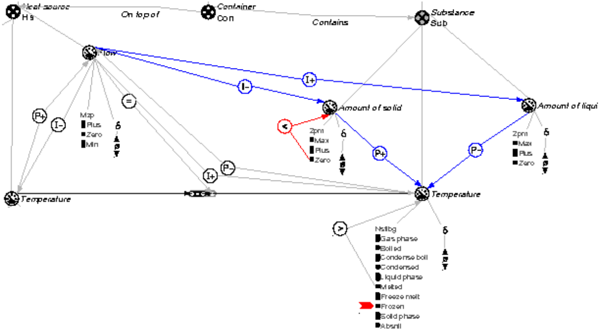
Modification principles

The phenomenological quantities (i.e. *Amount of solid* and *Amount of liquid*), not included in the equation 1750s, and their causal role in the modified model *should be neutral from an energetic viewpoint*, their insertion in the model should be based on the following three principles:

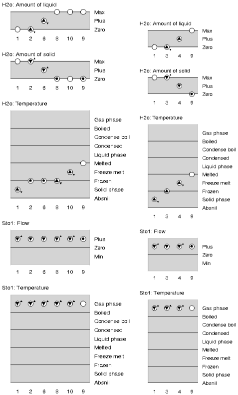
1. changes in their values should be direct effects of the cause quantity (i.e. *Flow*);
2. they should indirectly affect the effect quantity (i.e. *Temperature*);
3. they should exert an opposite indirect causal influence on the cause quantity with respect to the influence exerted on it by the effect quantity.

Modified QPT model of experimental set-up

Modified Model



Alternative simulations



Process *Melting*

Lesson learnt

These changes to the process *Heat_flow* create an ambiguity in the model for the quantity *Temperature*, which during the process *Melting* is at the same time positively directly influenced by *Flow* and indirectly negatively proportional to it. Such ambiguity is reflected in the two alternative simulations produced by the modified model. The first simulation envisions an interruption of the temperature rise, whereas the second matches the prediction based on Equation 1750s. The very creation of the ambiguity through the modification steps 1 to 3 above sheds light on how the contradiction between the theoretical and the sensory ontology is generated.

Future work

- Find other cases of the causal analysis for WMS.
- Extend causal analysis to other ontology repair plans.