SYSTEM DYNAMICS MODELING IN FLUIDS, ELECTRICITY, HEAT, AND MOTION

Examples, Practical Experience, and Philosophy

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Invited Talk at the
2006 GIREP Conference on Modeling in Physics and Physics Education
AMSTEL Institute of the University of Amsterdam, August 20–25, 2006

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System Dynamics Modeling

How it is done, what kind of models it leads to, how simple it is, how easily it is integrated with experiments, and how it supports creativity

I want to show how easy and how practical it is to do SD modeling…

Part 2

Creativity and basic forms of thought

A theory of creativity in science, the gestalt of physical processes, imaginative structures and figurative thought, and analogical reasoning

I want to argue that SD modeling makes use of some fundamental human thought processes that correspond to how humans “see” nature…

Part 1

System Dynamics Modeling

How it is done, what kind of models it leads to, how simple it is, how easily it is integrated with experiments, and how it supports creativity

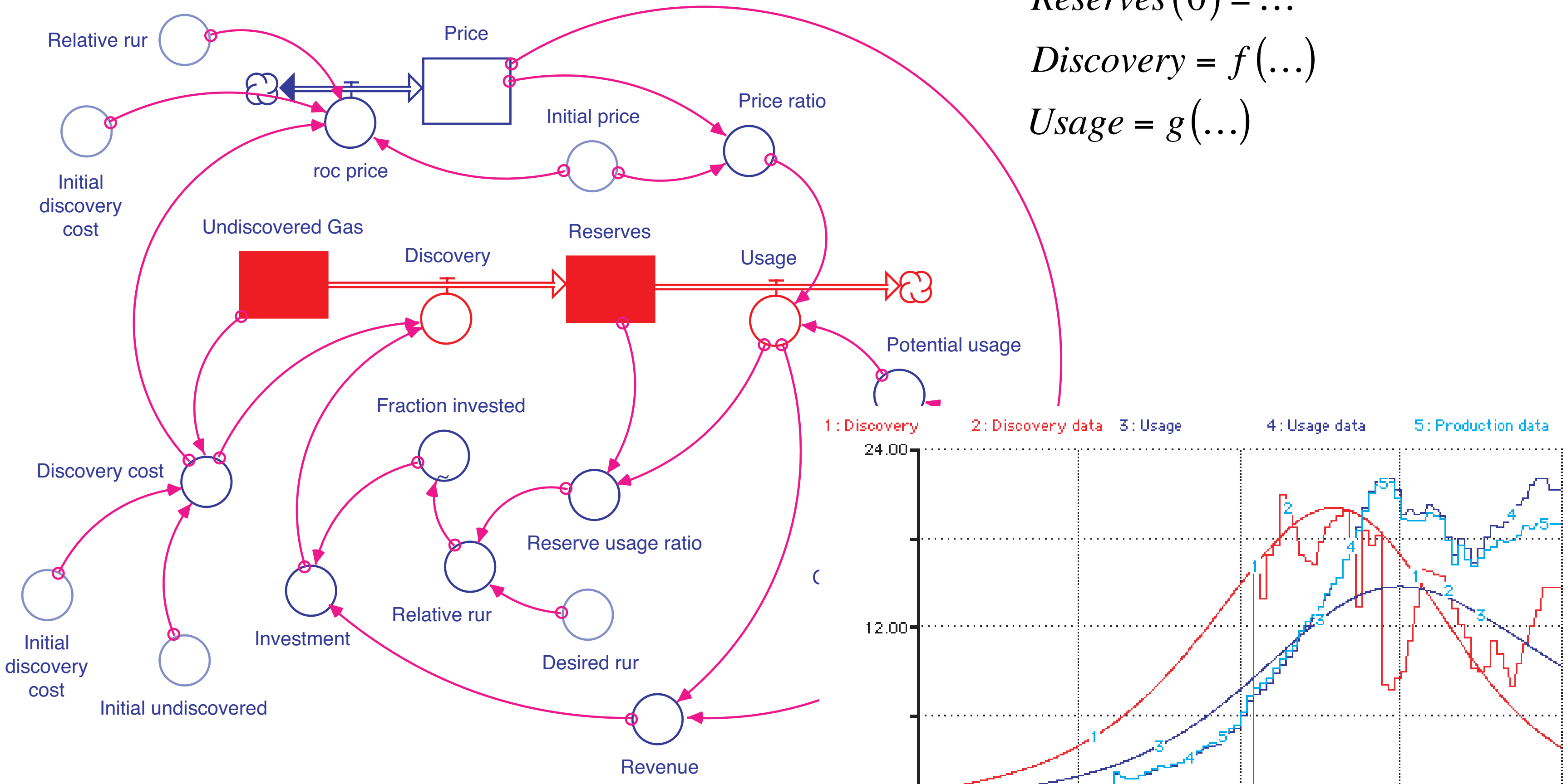
SD Modeling — Outside of physics

$$\frac{d}{dt} Reserves = Discovery - Usage$$

$$Reserves(0) = \ldots$$

$$Discovery = f(\ldots)$$

$$Usage = g(\ldots)$$



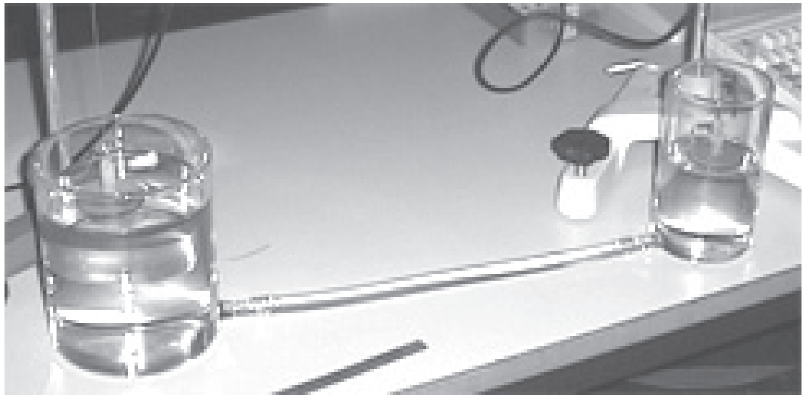
SD Modeling

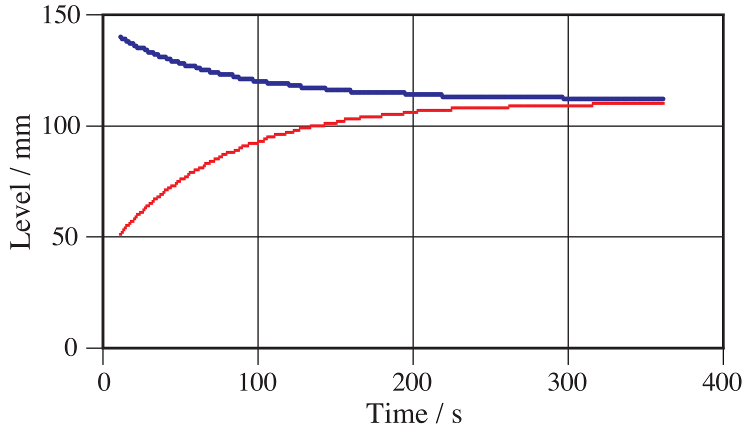
A graphical approach to building models of dynamical systems by combining the relations we perceive to hold in such systems. It makes use of a very few structures which are projected onto virtually any type of dynamical system and its processes, i.e., it makes strong use of analogical reasoning.

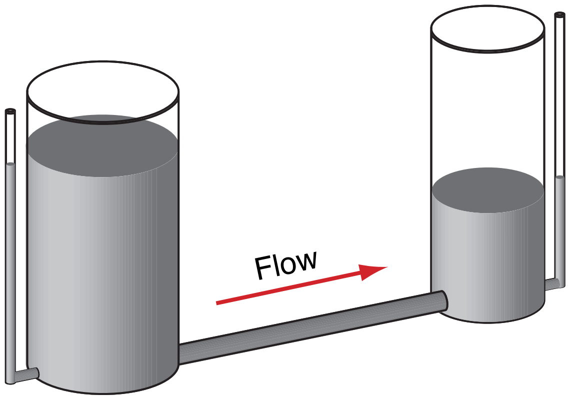
Mathematically speaking, the models created are initial value problems of spatially uniform elements.

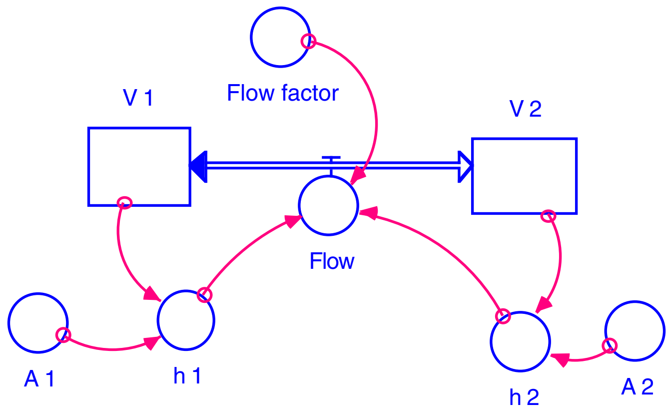
There are several programs available that implement the SD approach. Here, I shall use Stella as an example.

Two communicating oil containers

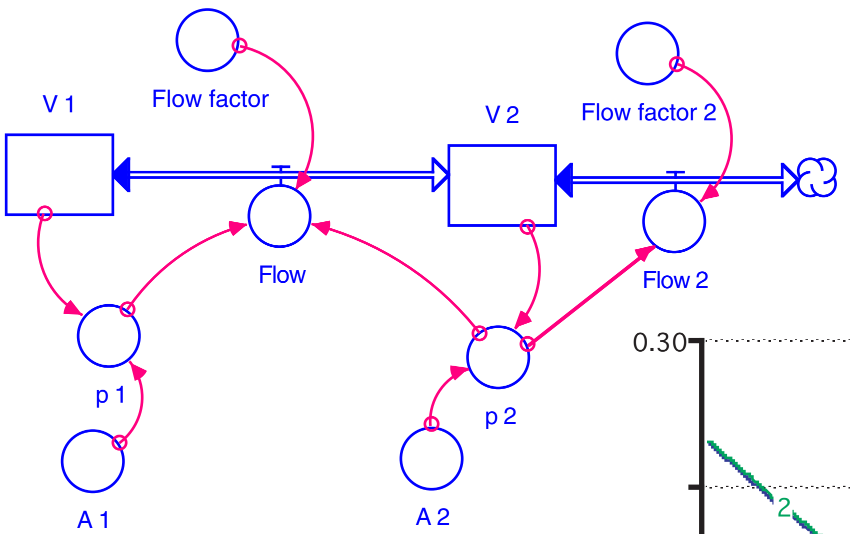








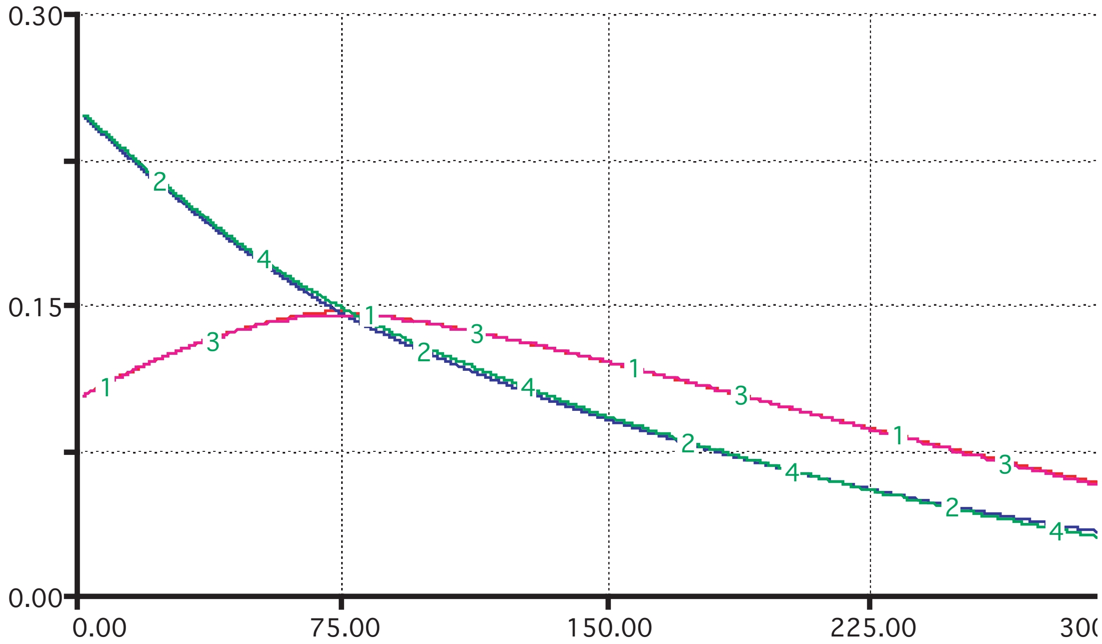
Two communicating water containers with outflow



Flow =

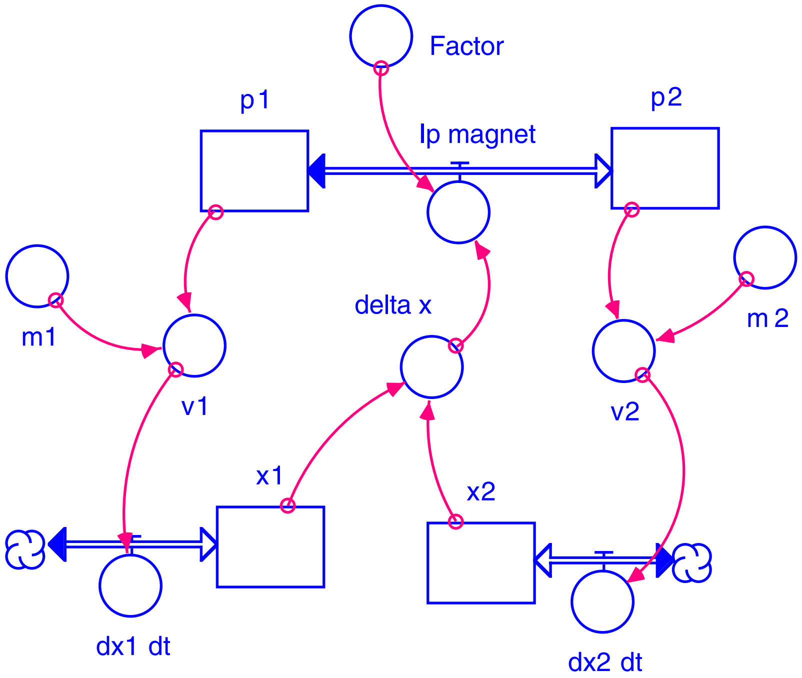
IF ((P1-P2) > 0) THEN SQRT((P1-P2)/k1)

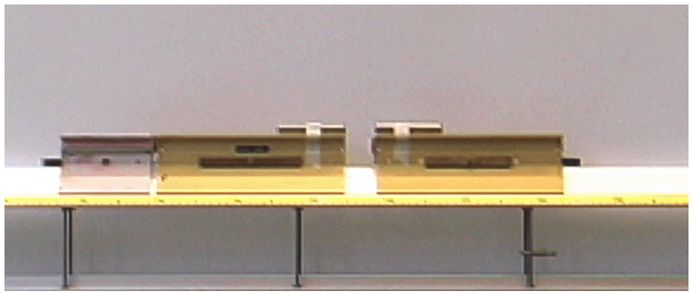
ELSE -SQRT(-(P1-P2)/k1)



Level versus time

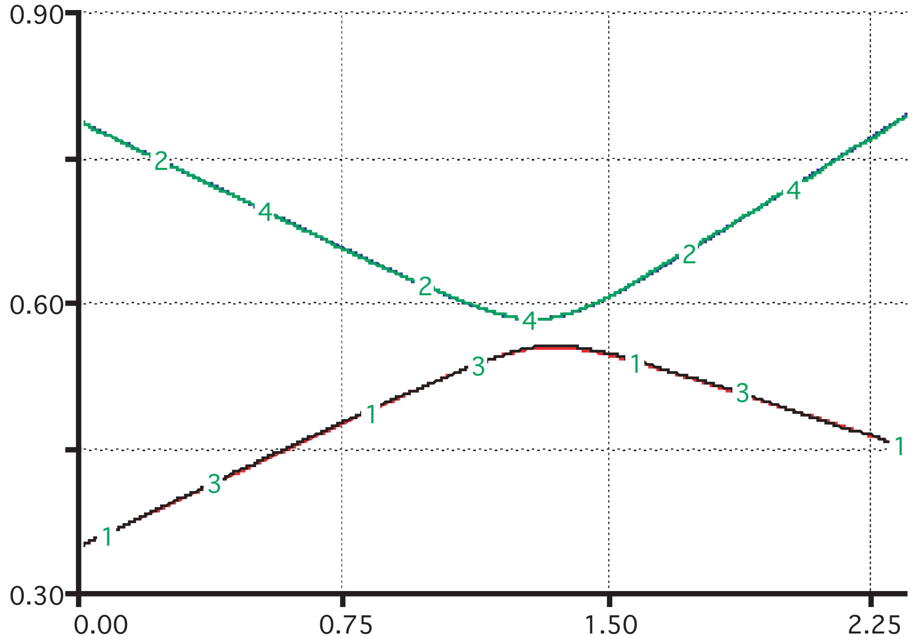
Two gliders with magnets



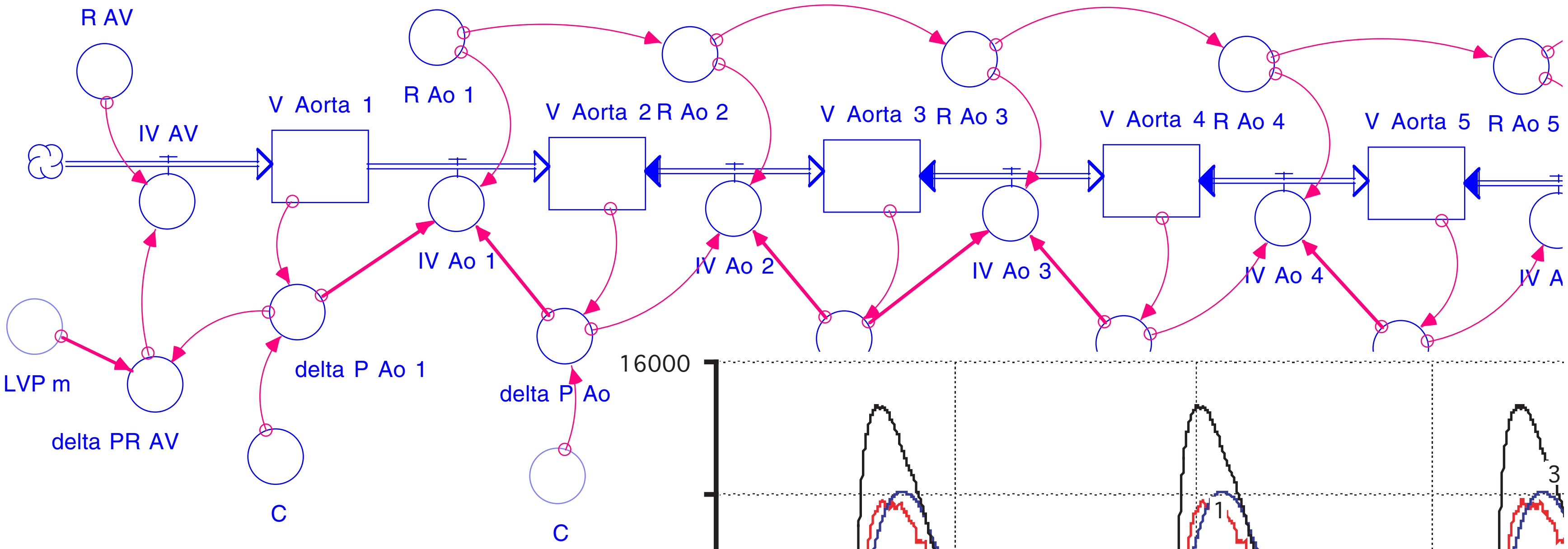


Ip_magnet = Factor / delta_x^5

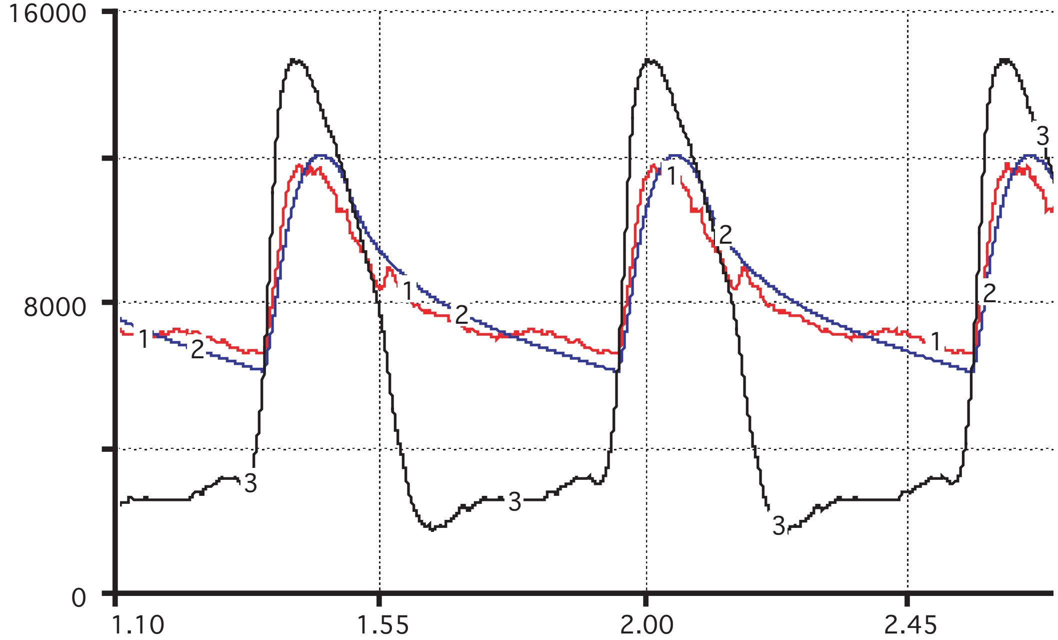
Position versus time



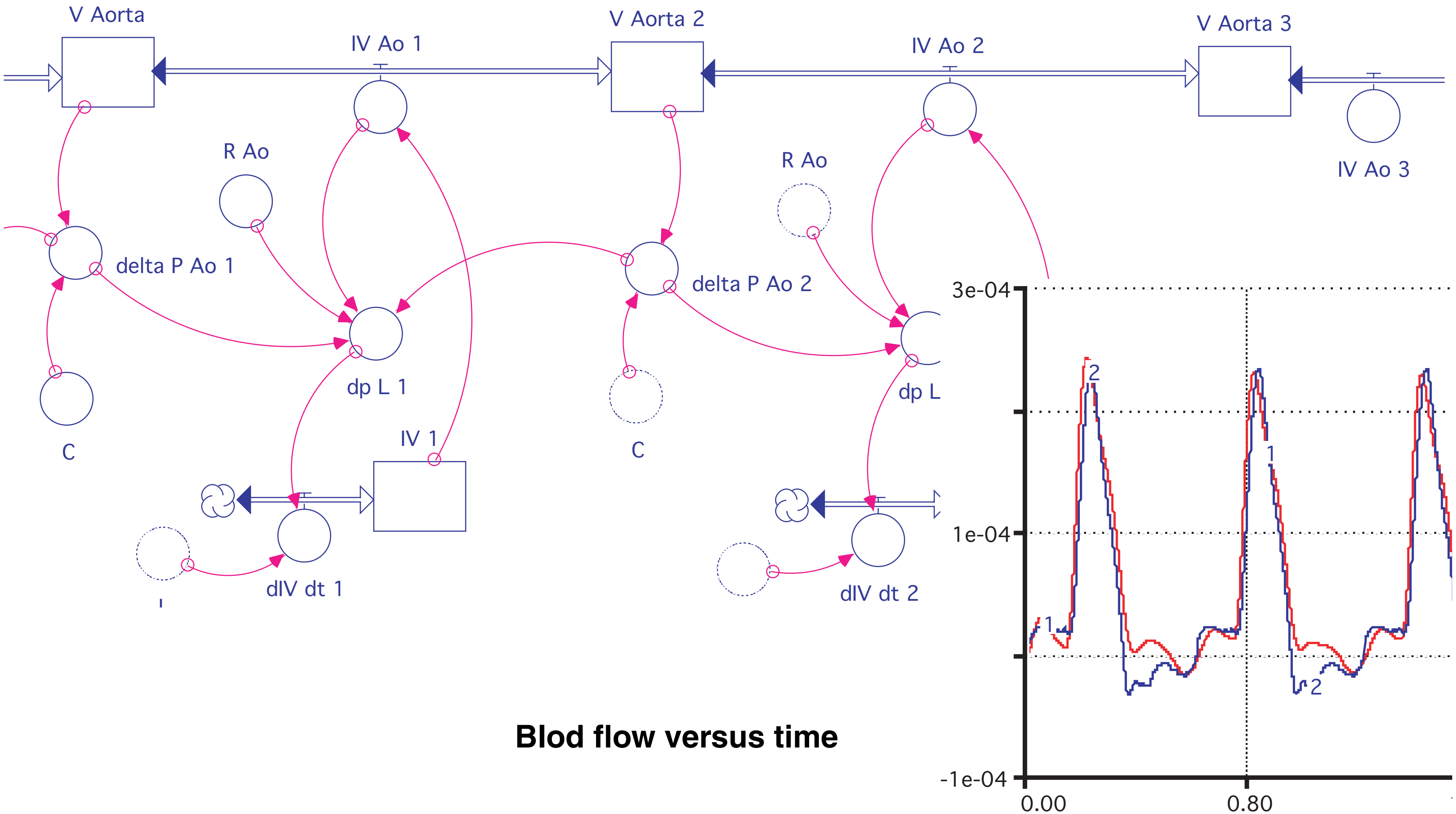
A model of a sheep's aorta



Pressure versus time

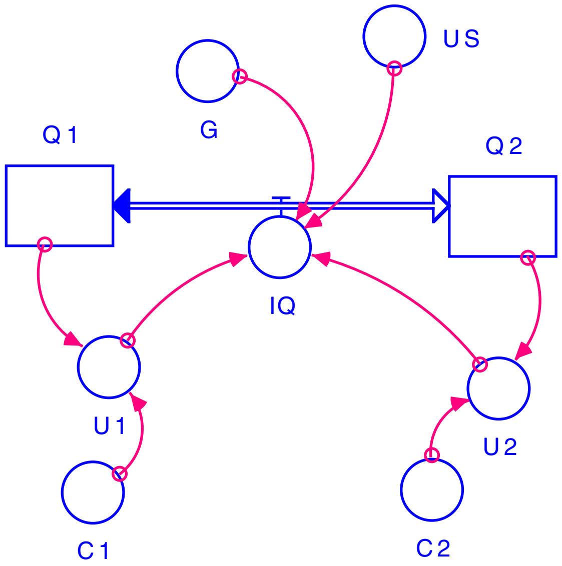


A model of a sheep's aorta with inductive effects



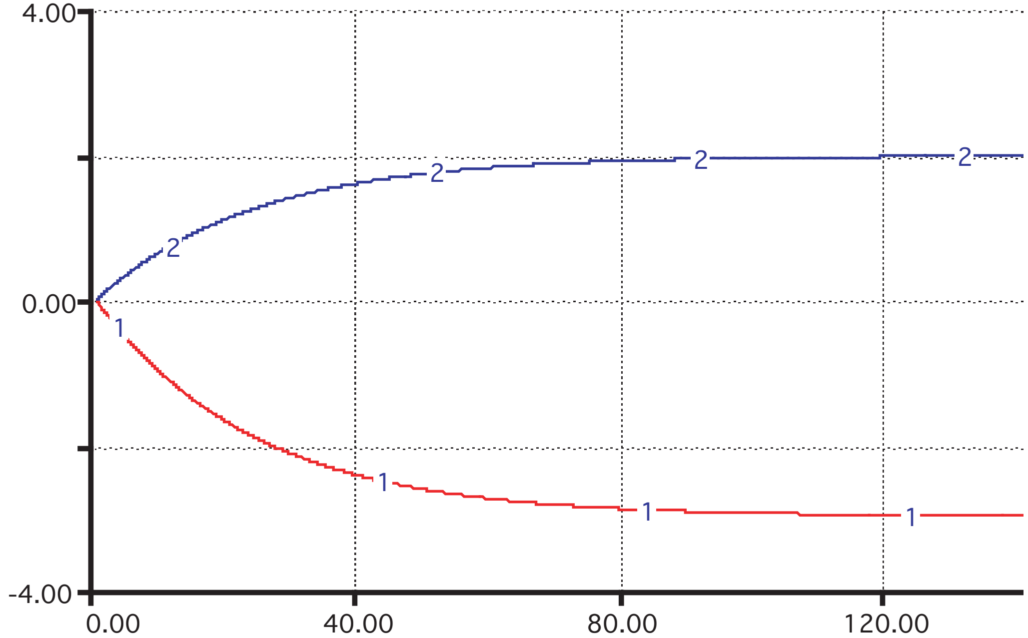
Blod flow versus time

Two capacitors with battery

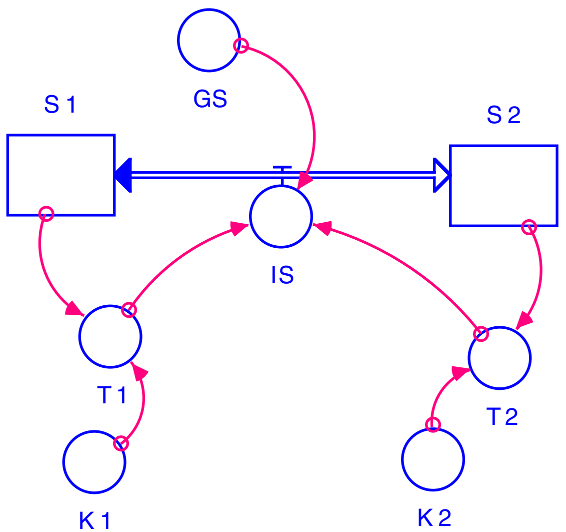


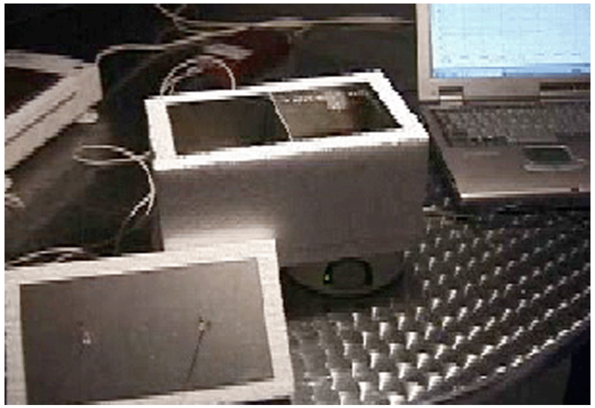
$$I\_Q = G*(U\_S+U\_1-U\_2)$$

Voltage versus time

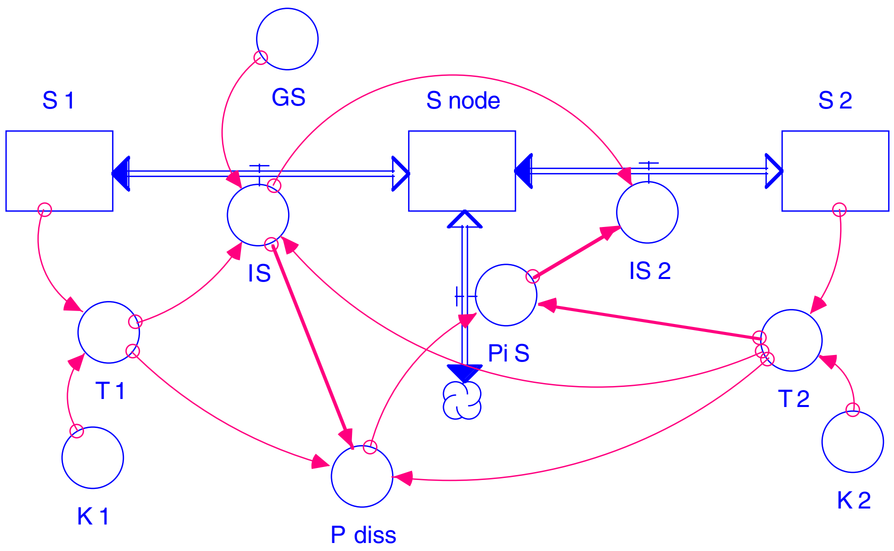


Thermal equilibration

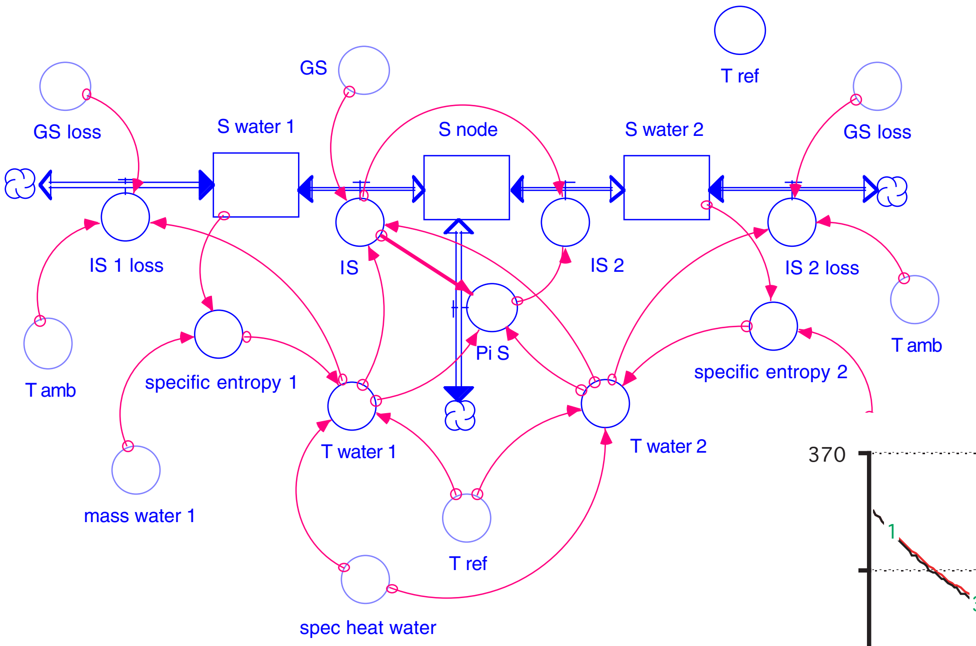


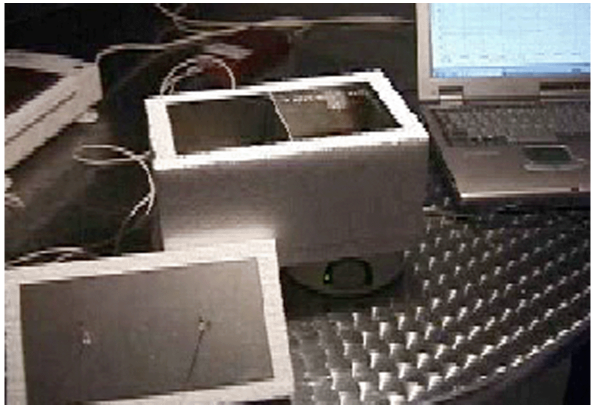


$$IS = GS*(T\_1-T\_2)$$
$$P\_Diss = (T\_1-T\_2)*IS$$
$$Pi\_S = P\_diss/T\_2$$

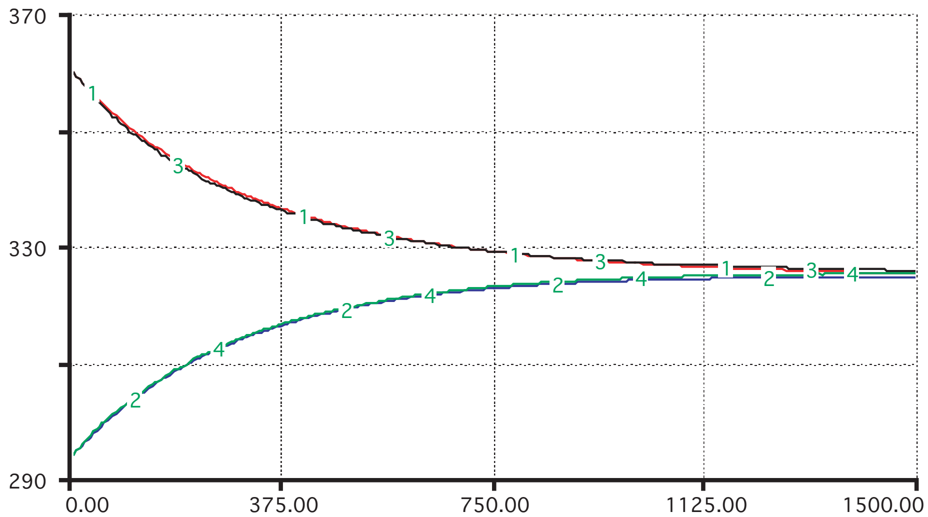


Thermal equilibration: Experiment

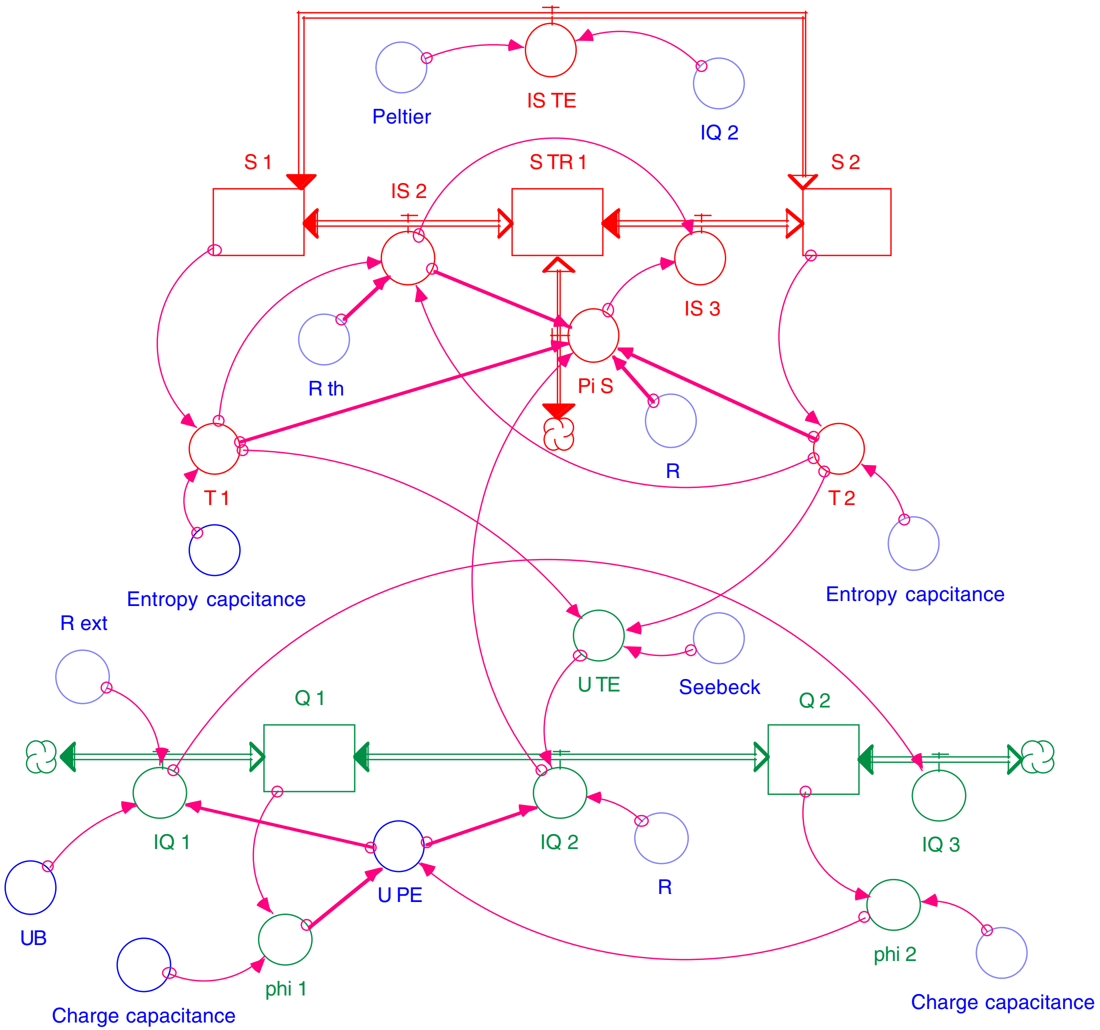


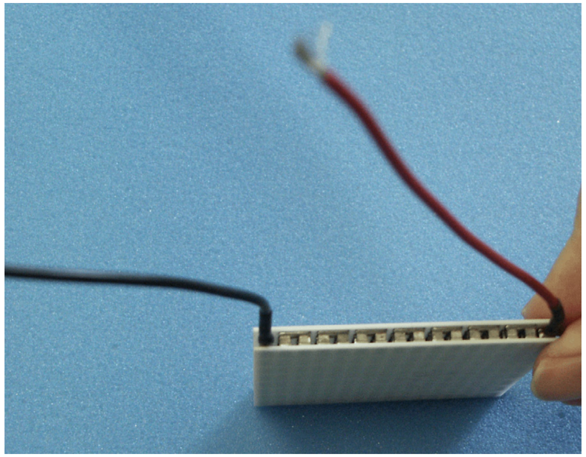


Temperature versus time



Peltier device: Principle





U_TE = Seebeck*(T_2-T_1)

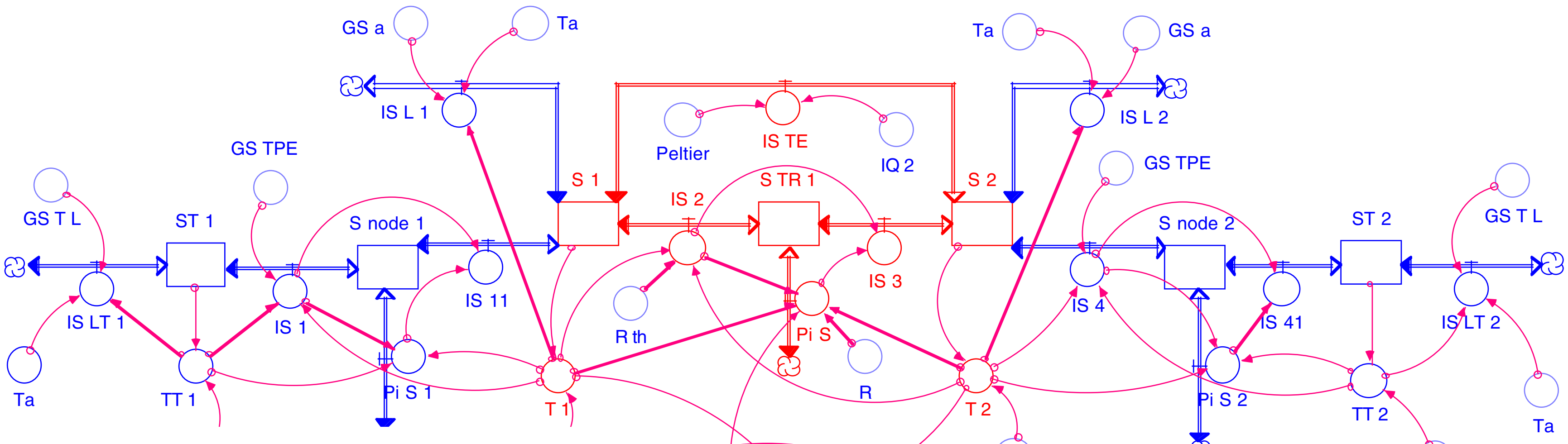
IS_TE = Peltier*IQ_2

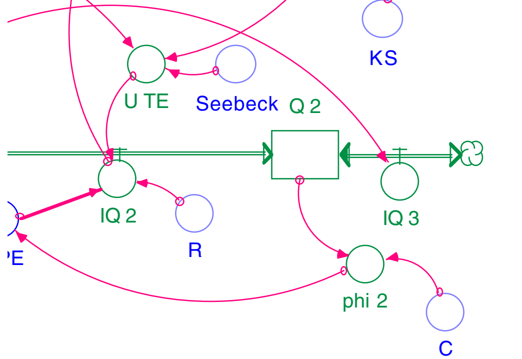
Pi_S = P_diss/T_2

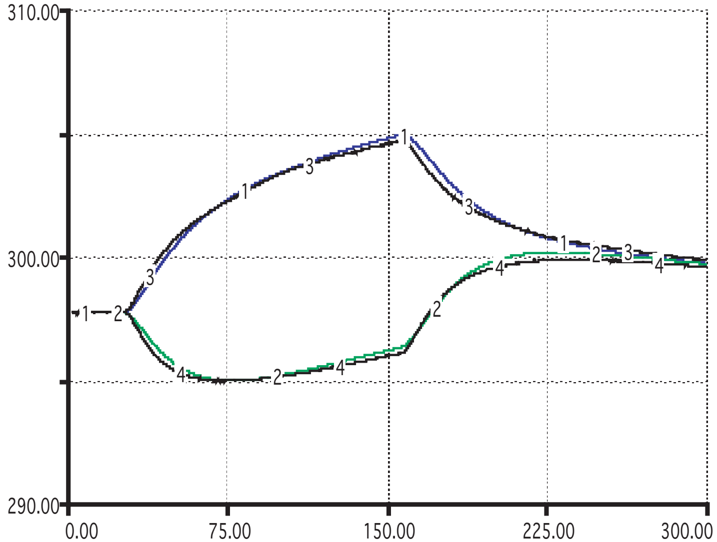
P_diss =

-IS_2*(T_2-T_1) + R*IQ_2^2

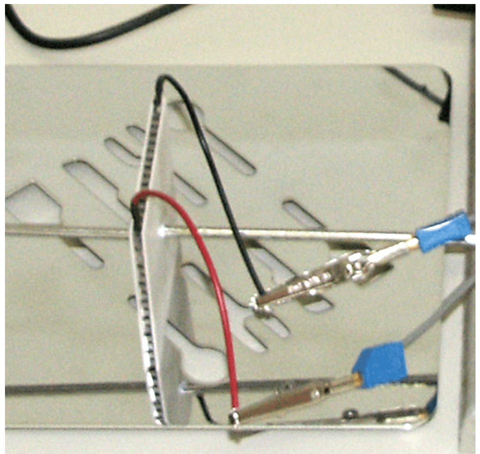
Thermal equilibration: Experiment





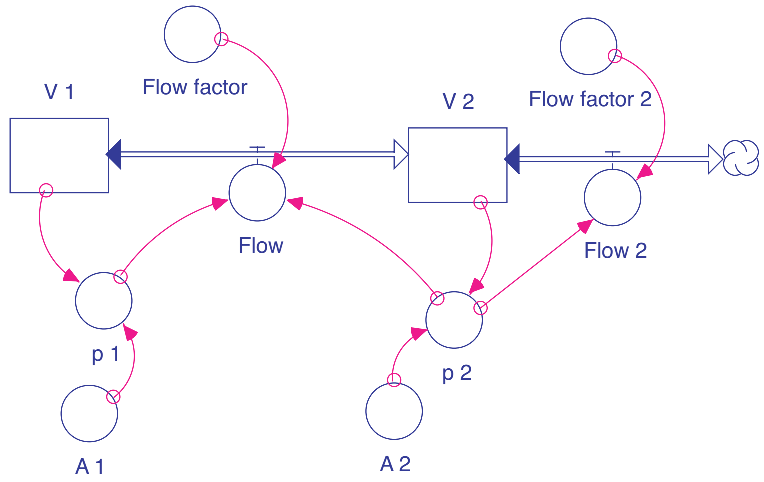


Temperature versus time



Summary 1: Creating and using SD models

- We can construct models step by step by assembling a system made up of a few graphical symbols.
- The symbols represent basic elements of human reasoning (see Part 2).
- Complete models can be simulated.
- Simulation results can be compared to data take in the lab.
- Models can be extended, single relations can be changed, parameters can be adjusted… We move back and forth between modeling and experiment.
- SD modeling allows us to work on some fairly complex real life applications.



Summary 2: Structure of SD models in physics

Some quantities are stored, they can flow (and sometimes, they are produced). There are differences (of potentials) which lead to

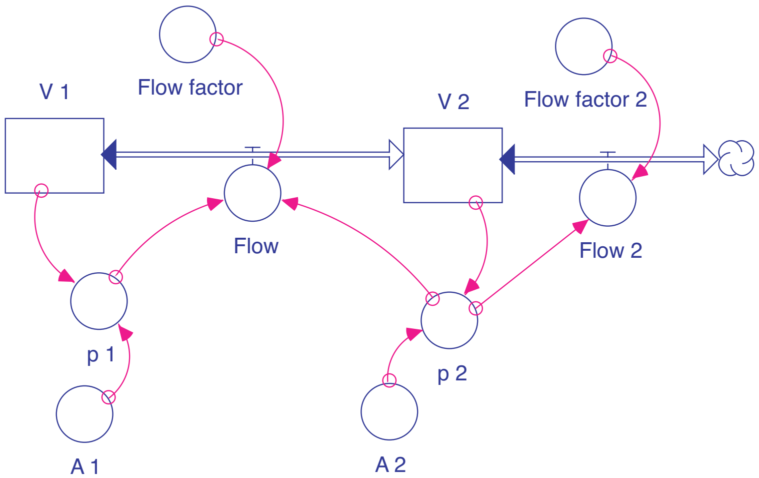
- flows
- changes of flows
- production rates

Differences are produced by

- storage
- pumps (in a generalized sense)

When quantities flow through a difference, energy is released. The energy released is

- used to drive other processes (set up other differences)
- dissipated
- stored or transferred

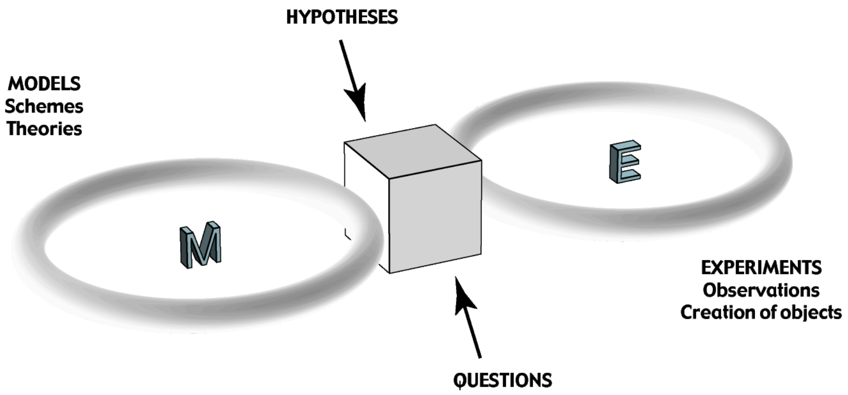


Part 2

Creativity and basic forms of thought

A theory of creativity in science, the gestalt of physical processes, imaginative structures and figurative thought, and analogical reasoning

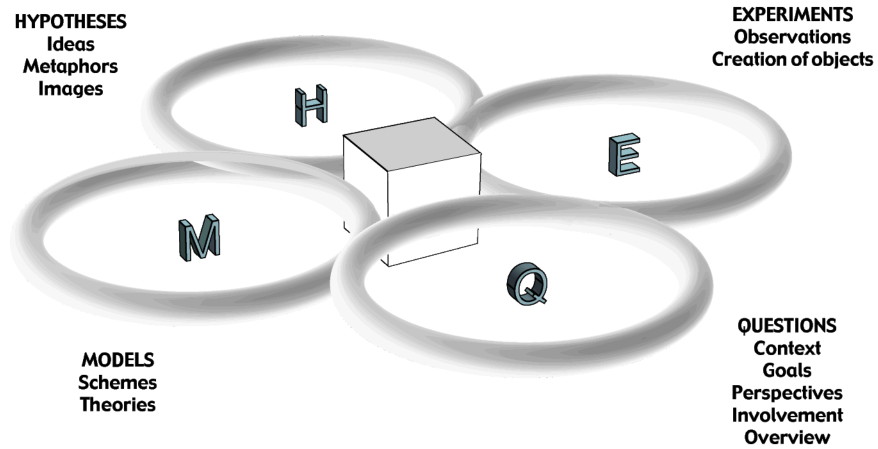
A model of creativity in the sciences



A bi-cycle represents the interaction between modeling and experiment. A cycle is a model for a type of cognitive tool.

Steps leading to the creation of hypotheses and the generation of good questions, can be represented as two additional cycles.

See Kieran Egan on cognitive tools.



The roots of creativity in the sciences

Creativity, in the sense of the generation of ideas and hypotheses, is rooted in **imaginative structures** of human thought.

Imagination (Vorstellungskraft: I. Kant), grows from the human capacity to *re-present* situations with the help of representational tools (mimesis, language, writing, drawing…).

Metaphor is an example of this type of representation: One thing is represented in terms of another.

> *Metaphor is the capacity, or cognitive tool, that enables people to see one thing in terms of another* (Kieran Egan, 2005).

From metaphor grows the perception of (structural) similarity which is used in **analogical reasoning**.

Let us see how humans conceptualize large classes of physical processes…

The gestalt of physical processes

Human perception of phenomena such as fluids, electricity, heat, motion

The concept of “heat,” for example, is abstracted by perception from the sum total of thermal experiences in the form of a **gestalt**: An entity that encompasses more than the sum of its parts. While we do not differentiate a gestalt of a collective of phenomena (such as electricity or heat) consciously, we do notice aspects. The most fundamental **aspects** humans use to talk about such a **gestalt** are

Table 1: The gestalt of collectives of physical phenomena

ASPECT OF GESTALT	METAPHORIC STRUCTURE
Intensity (quality)	Polarity such as light-dark, warm-cold, high-low, fast-slow, strong-weak. The concepts are structured metaphorically by the image schema of verticality (intensity as a level).
Quantity (substance)	Substance-like concepts are metaphorically structured in terms of fluid substances.
Force or power	Prototypical causation as the **gestalt** of direct manipulation.

Prototypical causation: The gestalt of direct manipulation

The **gestalt of direct manipulation**

Lakoff (1987, p. 54), Lakoff and Johnson (1980, p. 70)

Aspects of the gestalt

1. There is an **agent** that does something.
2. There is a **patient** that undergoes a change to a new state.
3. Properties 1 and 2 constitute a single event; they overlap in time and space; the agent comes in contact with the patient.
4. Part of what the agent does (either the motion or the exercise of will) precedes the change in the patient.
5. The agent is the **energy source**; the patient is the **energy goal**; there is a **transfer of energy from the agent to patient**.
6. …

Evidence for the gestalt of physical processes 1

Journalism students judging the validity of linguistic expressions using heat and temperature

Persons are asked if they agree or disagree with certain expressions

- The temperature is high
- Today, the heat is high
- There is lots of heat in this room
- There is lots of temperature in this room
- Heat drives the engine
- Temperature drives the engine

Tabelle 2: Agreement with classes of expressions[a]

	as substance	as cause	as level
Heat	**0.67 (1)**	**0.77 (1)**	**0.14 (0)**
Temperature	**0.09 (0)**	**0.09 (0)**	**0.83 (1)**

a. Agreement (1) or disagreement (0) with expressions using heat and temperature. Expected results in parentheses. Results of a questionnaire given to journalism students in Summer of 2004.

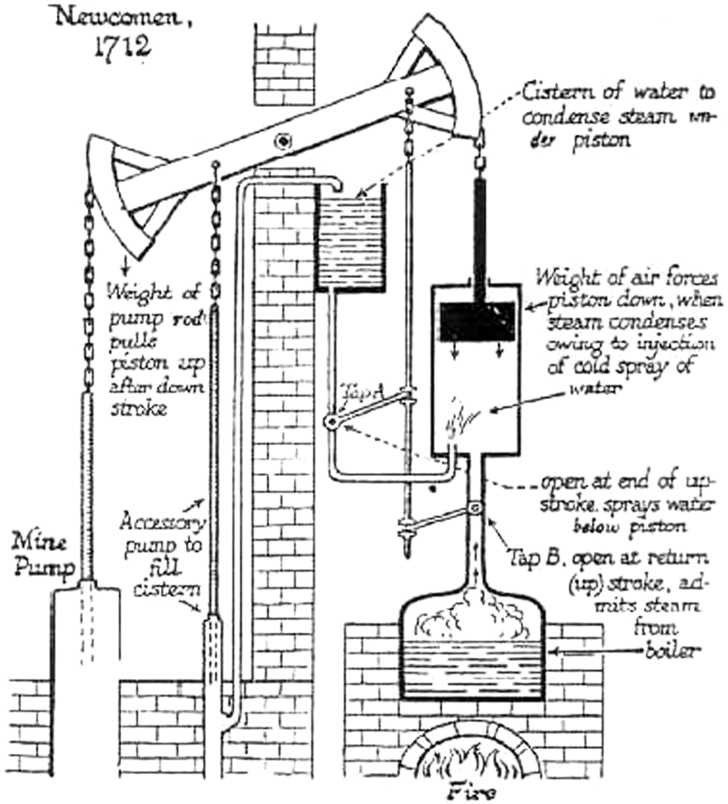
Evidence for the gestalt of physical processes 2

Sadi Carnot’s image of the waterfall and its comparison to the power of heat

Sadi Carnot (1796-1832)

Réflexions sur la puissance motrice du feu

D'après les notions établies jusqu'à présent, on peut comparer avec assez de justesse la *puissance motrice de la chaleur* à celle d'une *chute d'eau* […]. La puissance motrice d'une chute d'eau dépend de sa hauteur et de la quantité du liquide; la puissance motrice de la chaleur dépend aussi de *la quantité de calorique* employé, et de ce qu'on pourrait nommer, de ce que nous appellerons en effet *la hauteur de sa chute*, c'est-à-dire de *la différence de température* des corps entre lesquels se fait l'échange du calorique.



Diagrammatic View of Newcomen's Atmospheric or Fire Engine (1712)

Evidence for the gestalt of physical processes 3

The concept of heat in the Accademia del Cimento

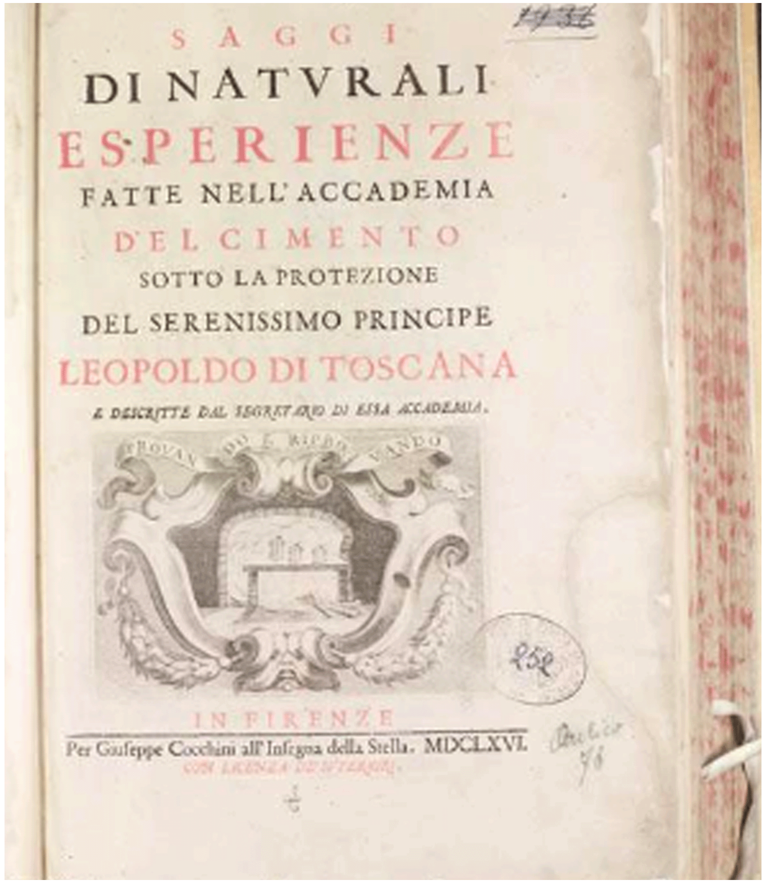
The concept of heat of the members of the Accademia del Cimento: Saggi di naturali esperienze… (1667)

M. Wiser and S. Carey (1983): When Heat and Temperature were one.

“The Experimenters’ concept of heat had three aspects: **substance** (particles), **quality** (hotness), and **force**.”

A weakly differentiated gestalt

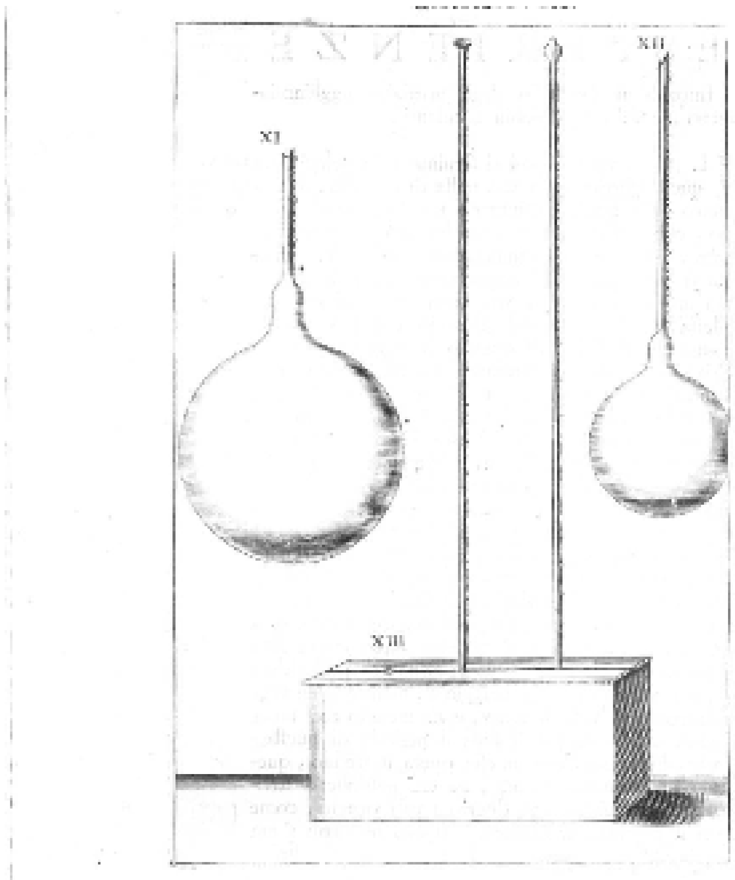
It seems that the Experimenters did not really distinguish between these aspects of the gestalt of heat.


SAGGI
DI NATVRALI
ESPERIENZE
FATTE NELL' ACCADEMIA
DEL CIMENTO
SOTTO LA PROTEZIONE
DEL SERENISSIMO PRINCIPE
LEOPOLDO DI TOSCANA
E DESCRITTE DAL SEGRETARIO DI ESSA ACCADEMIA.
IN FIRENZE
Per Giuseppe Cocchini all'Insegna della Stella. MDCLXVII.

The concept of heat of the members of the Accademia del Cimento: Saggi di naturali esperienze… (1667)

The description of thermal phenomena by the Experimenters demonstrates clearly the image corresponding to direct causation: Hot or cold bodies are the sources of heat or cold. Heat or cold are emitted by the sources, and they influence other bodies. The Experimenters were interested in the "force" or "power" of heat (or of cold).

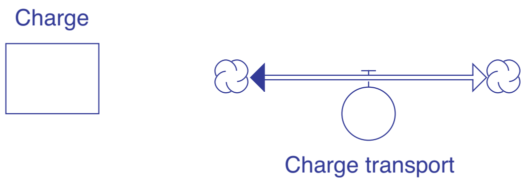
See M. Wiser and S. Carey (1983)



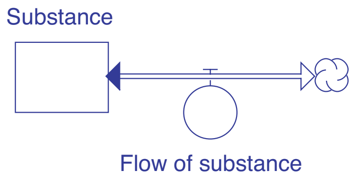
Evidence for the gestalt of physical processes 4

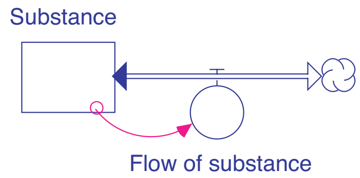
Visual expressions of the metaphors used to structure the aspects of the gestalt

Substance-based thinking (storage and flow/production)

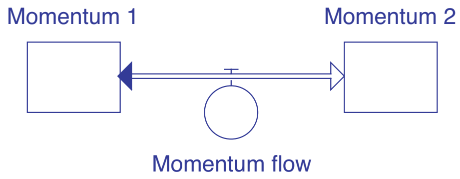


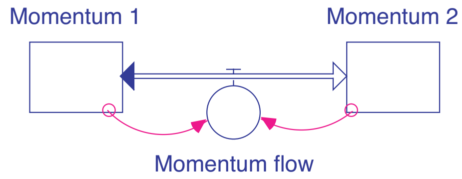
Causative thinking / With feedback-thought



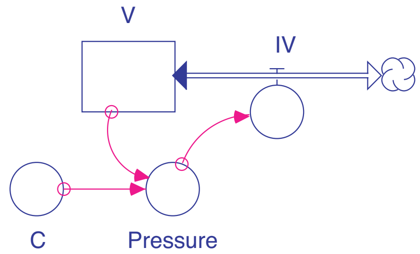


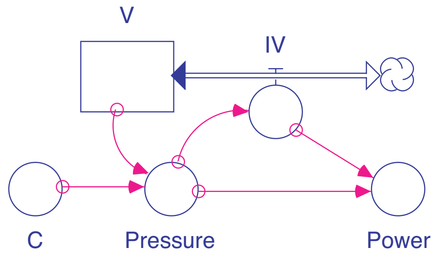
Causative thinking (interaction) / With feedback-thought





(Level differences)
(Releasing energy)





Evidence 5: The gestalt of abstract concepts

Concepts such as **pain** or **love** are conceptualized in the same manner as physical concepts such as heat or electricity. The have a similar gestalt with the same aspects of

quantity (substance) / intensity (quality) / force or power

Linguistic expressions

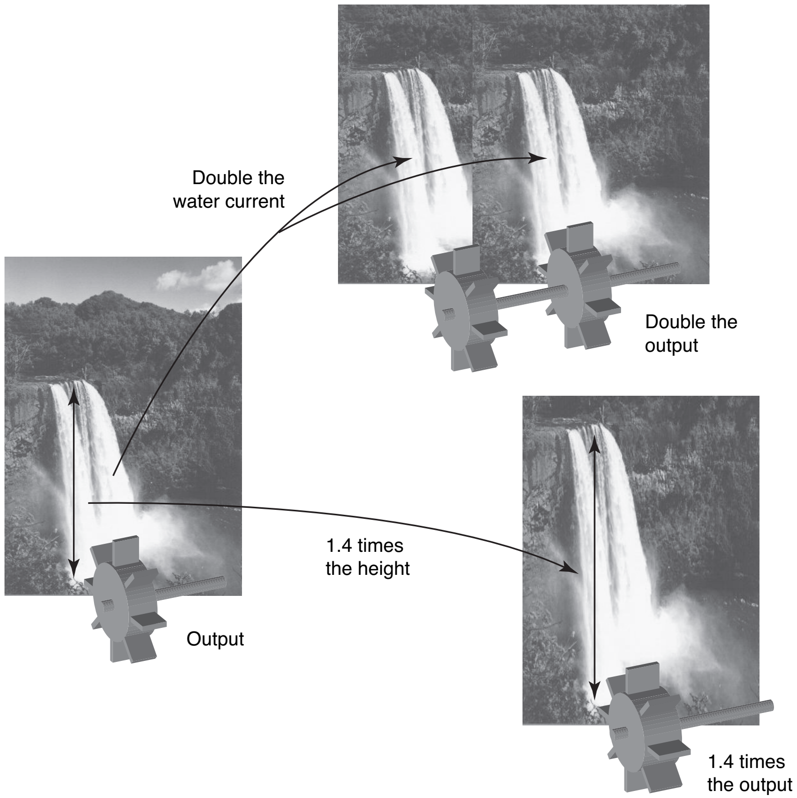
- The pain was to strong
- The level of pain went down
- More and more pain…
- The pain gained control of me
- The aspirin took away my headache
- The headache soured my mood

Entailments of the conceptualization

Two broken teeth means double the pain. More pain means higher intensity. More pain means the pain is more powerful. Higher intensity leads to more power.

Entailments of the metaphoric structure of physical concepts

An example of entailments that can be brought into quantitative form



$$Power =$$

$$Level\ difference \cdot Current\ of\ substance$$

Carnot and analogies…

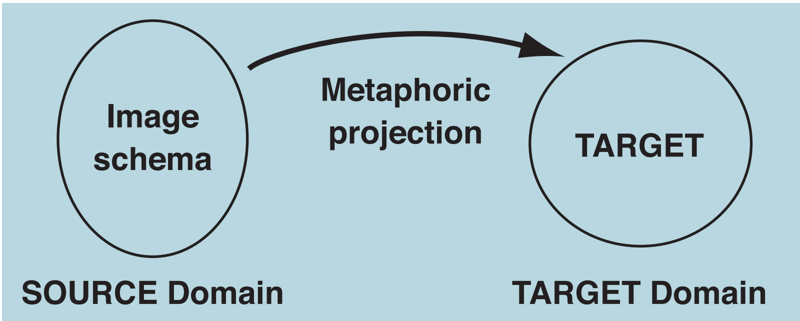
The structure of basic metaphors

Image schemata as primal source domain

Image schema is a recurring structure of, or within our cognitive processes, which establishes patterns of understanding and reasoning. It emerges from our bodily interactions, linguistic experience and historical context. [**Image schemata are gestalts** (M. Johnson, 1987, Chapter 5): *The Body in the Mind*).]

Examples: up/down, inside/outside, near/far, balance, object, process, path

Image schemata are projected metaphorically onto more abstract domains. (Metaphors are one-sided projections.)

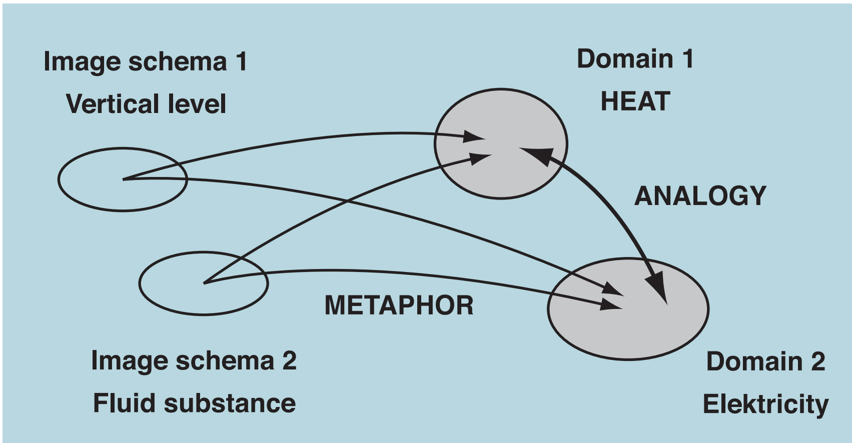


Metaphors and analogical reasoning

Origin and meaning of analogies

When different domains of experience are structured metaphorically by the same source domains (such as by the same image schemata), these domains become comparable (they start to look similar).

This comparison can be applied in the construction of analogies. An analogy is a double-sided mapping (more or less symmetrical).



Three consequences…

…among many others…

1. **Take seriously the metaphorical nature of graphical interfaces for human thought processes.**

   The soul never thinks without an image. Aristotle, *De Anima*, Book III, Part 7

   The Greeks […] never forgot that direct vision is the first and final source of wisdom. Rudolf Arnheim, *Visual Thinking*, p. 12.

2. **Make use of concepts that are "built into" humans…**

   … and you won't have to worry so much "conceptual change."

3. **Make explicit use of analogies offered by the metaphoric nature of the human mind.**

   And I cherish more than anything else the Analogies, my most trustworthy masters. Johannes Kepler (Optics, Quoted in Polya, 1973.)

LITERATURE

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