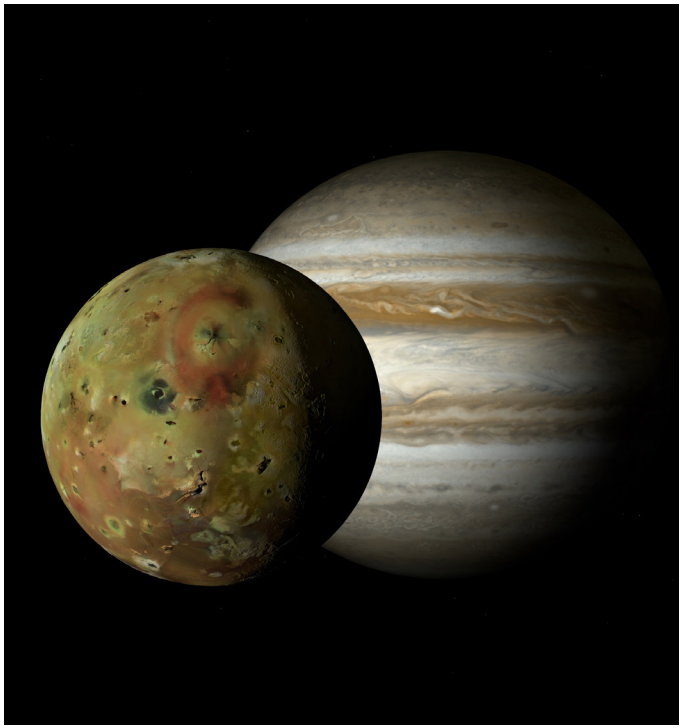
Complex dynamical systems: Ephemeral mechanisms and narrative in science

Dynamical models and the issue of explanation versus prediction

An SIG Mini Conference on Science | Environment | Health
Weggis, Switzerland, August 2016

Hans U. Fuchs
IAMP – Institute of Applied Mathematics and Physics
ZHAW – Zurich University of Applied Sciences at Winterthur
8401 Winterthur, Switzerland

Table of Contents

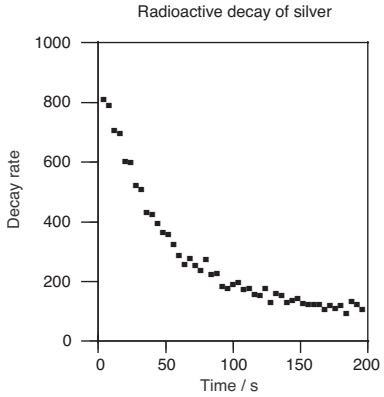


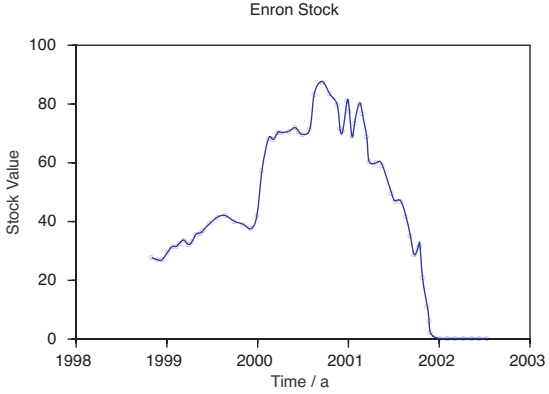
Themes and Arguments

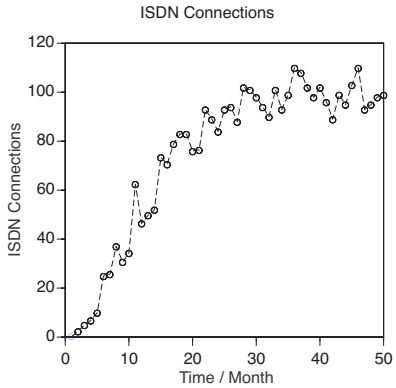
- The notions of ***ephemeral mechanisms*** and ***narrative explanation*** suggest a way for us to ***deal with complex systems***.
- ***Complex systems*** are ***dynamical systems***. Dynamical systems are ***collections of interacting elements***.
- ***Complexity*** can be ***structural*** and ***behavioral***.
- We work with dynamical systems by ***creating models*** and ***simulating*** these models.
- Sometimes, models allow for ***prediction***…but only sometimes—more often than not, ***prediction is impossible*** for chiefly two reasons:
  1. We ***know too little*** about the system, its elements and interactions…
  2. …and even in structurally simple systems, behavior may be ***chaotic***.
- Still, models and their simulations ***explain***, again chiefly for two reasons:
  1. Models are representations of our imagination of (***ephemeral***) ***mechanisms***…
  2. Models are ***story-worlds*** and their simulations are ***stories***. Story-worlds build (ephemeral) mechanisms and stories tell what the mechanisms do. Modeling and simulation are an inherently ***narrative practice***.

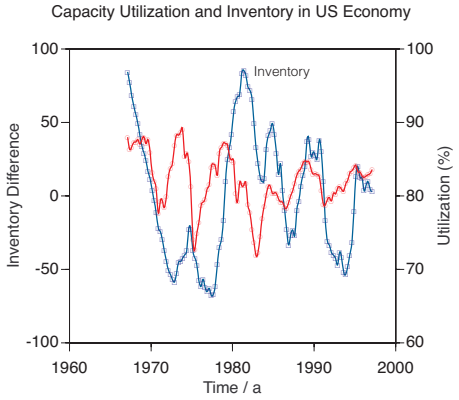
Dynamical Systems and Models

Perception of behavior...





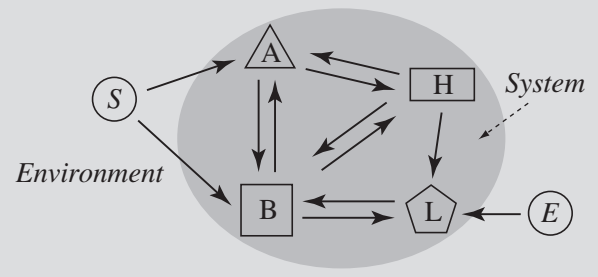




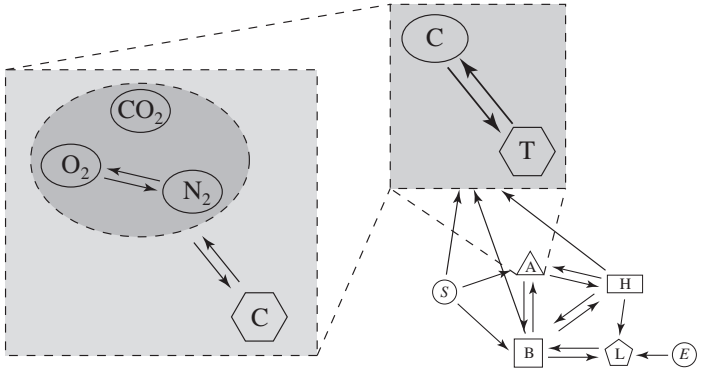
What is behaving like this?

Dynamical Systems and Models

The fashionalble answer is that...
...Systems behave like this



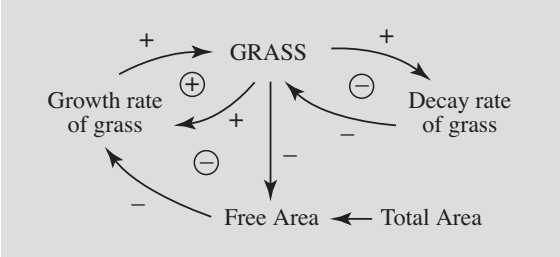
Systems represented as collections of interacting elements

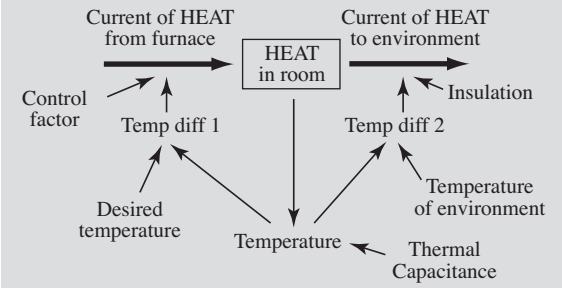


How we carve systems up into elements...
...is completely arbitrary

Dynamical Systems and Models

Feedback and circular logic in models...





In equation form...

Implicit algebraic equations

$$\left.\begin{aligned} G &= a \cdot GRG + b \\ GRG &= c \cdot G \end{aligned}\right\} \Rightarrow G = \frac{b}{1-ac} \qquad \left.\begin{aligned} G &= \frac{a}{DRG} \\ DRG &= c \cdot G \end{aligned}\right\} \Rightarrow G = \sqrt{a/c}$$

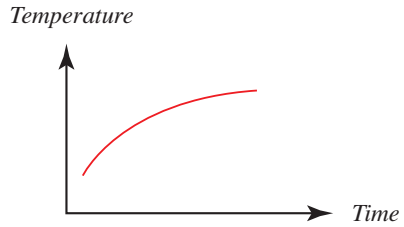
Differential equation (linear)

$$\frac{d}{dt} H = I_{H,in} - I_{H,out}$$

$$I_{H,in} = f\,\Delta T_1 \quad , \quad I_{H,out} = i\,\Delta T_2$$

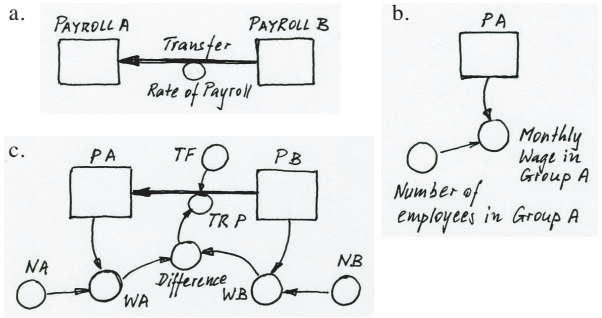
$$T = H/K$$

$$\Delta T_1 = T_D - T \quad , \quad \Delta T_2 = T - T_{amb}$$



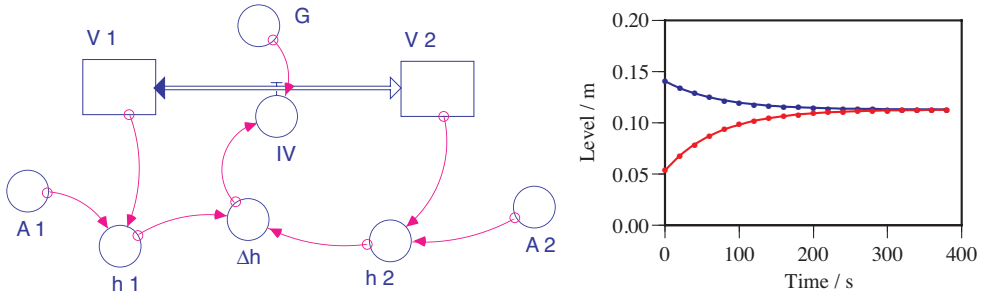
Dynamical Systems and Models

Models, Data, and simulation



P	Payroll
TR	Transfer Rate
W	Wage
N	Number of employees
TF	Transfer Factor

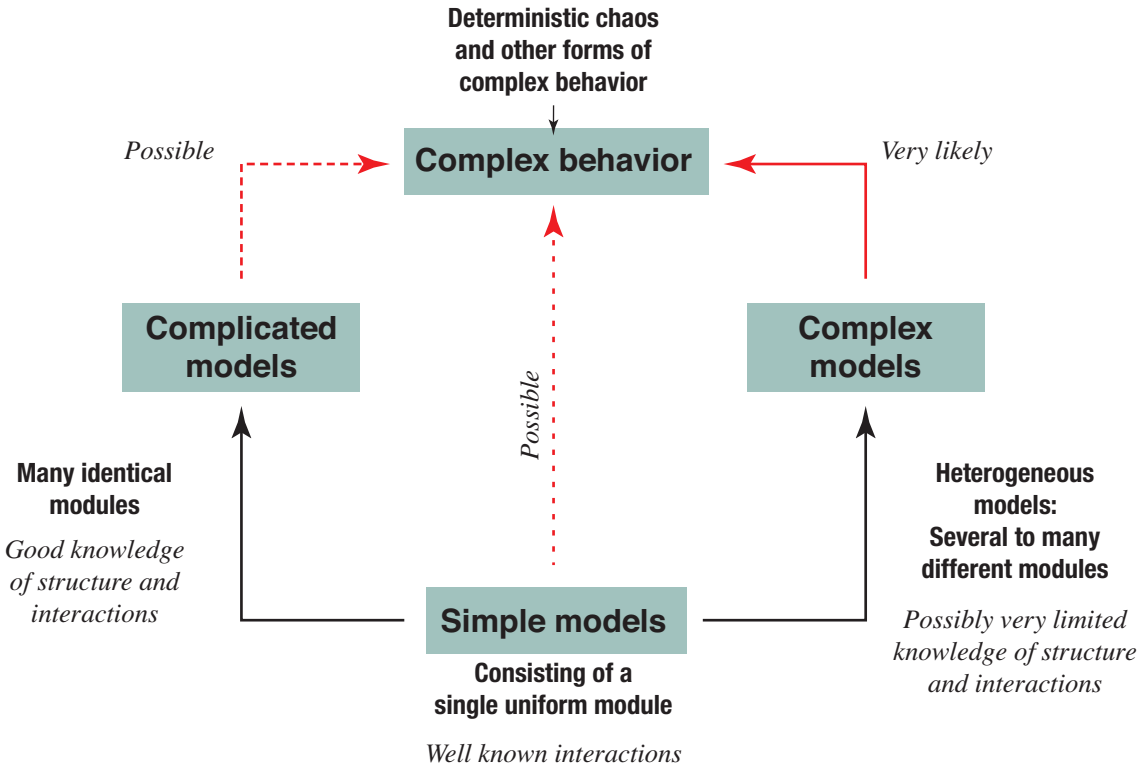
Dynamical models
contain ***storage elements*** *and* ***process quantities…***
and more…



Model diagrams as they appear in system dynamics programs

Complex Systems and Prediction

Models: Simple, comlicated, complex—and complex behavior



Prediction brakes down chiefly for two reasons:

1. We ***know too little*** about the system, its elements and interactions…
2. …and even in structurally simple systems, behavior may be ***chaotic***.

Complex Systems and Prediction

Complex heterogeneous systems and models	Types of modules pN – physical & chemical nature, bN – biological nature, M – machines and buildings, H – human, HH – groups of humans
┐ Origin and evolution of solar system	pN – pN – pN – …
┐ Evolution of life on Earth	bN – bN – bN – pN – …
┐ Tacoma Narrows bridge	pN – B
┐ Operating nuclear power plant	pN – M – H – HH
┐ Economic system	HH – pN – bN
┐ Piloting an airplane	pN – M – H
┐ Snow flakes forming	pN
┐ Blood circulatory system	bN – (pN) – (H)
┐ Epidemic	bN – HH
┐ Evolution of language	H – HH
┐ Ecological system	bN – pN – HH

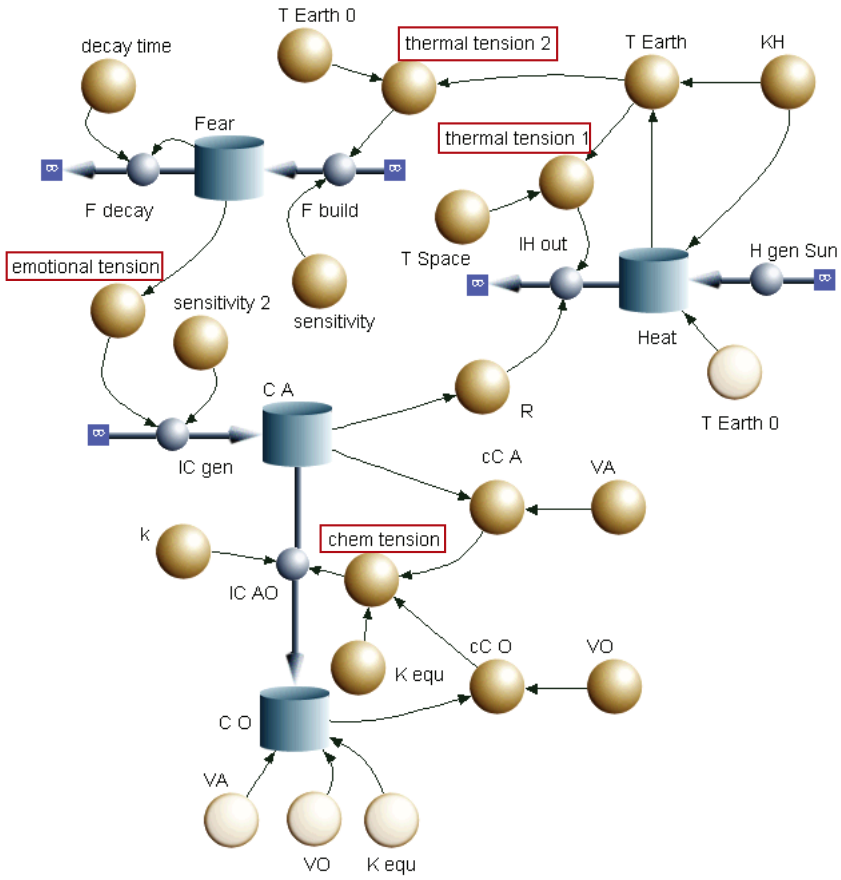
How could we ever achieve* complete *knowledge of such systems?

Complex Systems and Prediction

Heterogeneous Models

A model of human driven ***Carbon Cycle***

Tensions *drive the dynamics*

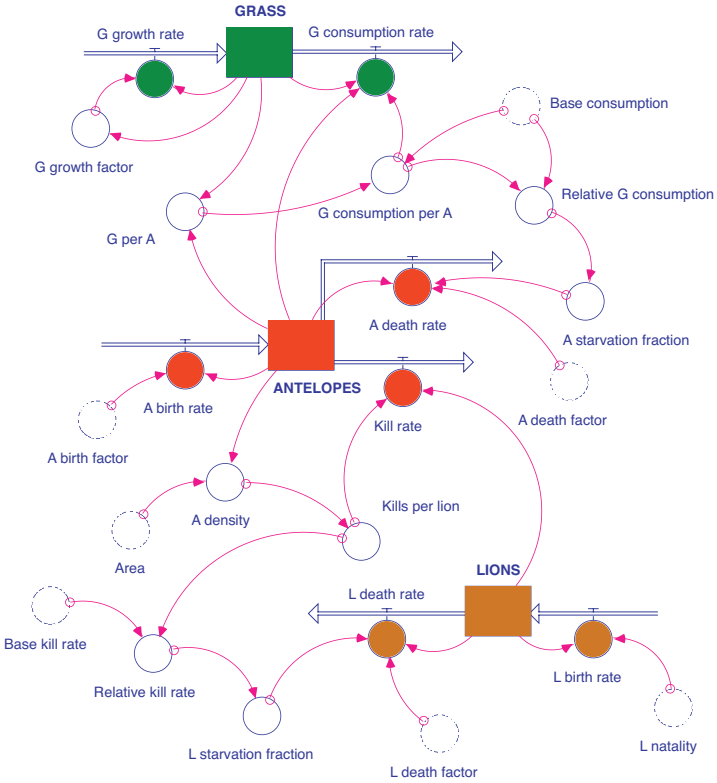


Modules

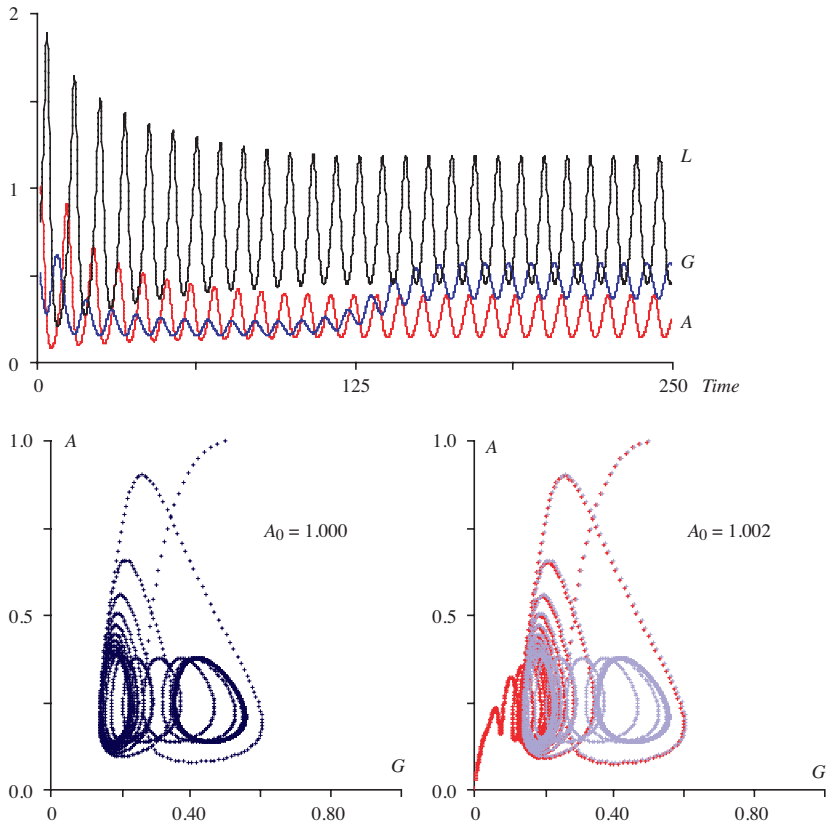
CO2 input – HH
Atmosphere C – pN
Ocean C – pN
Atmosphere Heat – pN
Human Hear – H

Complex Systems and Prediction

Complex behavior

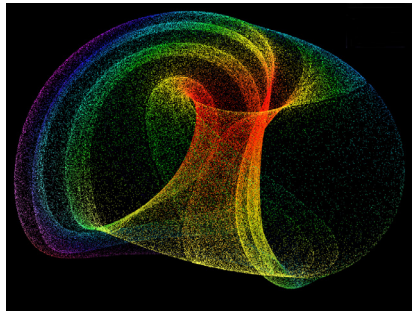


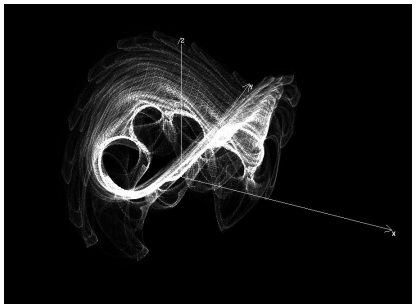
A model of Lions, Antelopes, and Grass



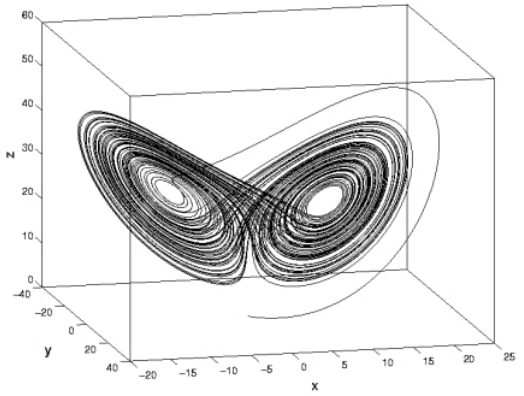
Complex Systems and Prediction

Minimal conditions for complex behavior (Deterministic Chaos)





$$\frac{dx}{dt} = \sigma(y - x)$$
$$\frac{dy}{dt} = x(\rho - z) - y$$
$$\frac{dz}{dt} = xy - \beta z$$

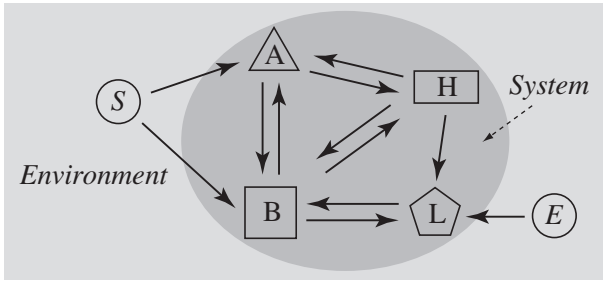


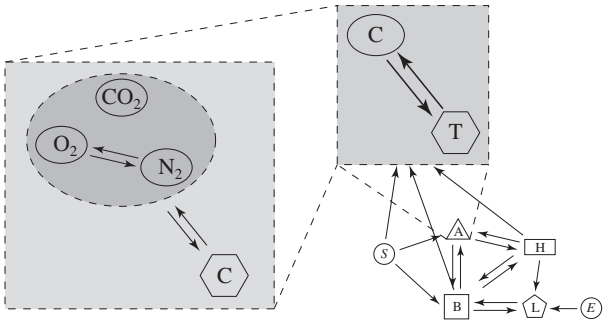
- *Autonomous*
- *Three dimensional*
- *Non-linear*

Ephemeral mechanisms

Thinking in terms of mechanisms (mechanistic systems)…

Glennan S. (2010): Ephemeral Mechanisms and Historical Explanation. *Erkenntnis* **72**, 251–266.





The grain at which the mechanism is viewed is central to the form explanation takes…

Stable mechanisms…

…are (dynamical) systems having parts that interact according to "generalizations describing about how changes in properties of one part bring about changes in properties of another part."

Generalizations of this type are ***not "laws."*** This distinction is important for including sciences such as biology…

Ephemeral mechanisms…

"I take an ephemeral mechanism to be a collection of interacting parts where:

1. the interactions between parts can be characterized by direct, invariant, change-relating generalizations
2. the configuration of parts may be the product of chance or exogenous factors
3. the configuration of parts is short-lived and non-stable, and is not an instance of a multiply-realized type."

Ephemeral mechanisms

Historical explanation, narrative, and (ephemeral) mechanisms… (1)

"I will take it to be the defining characteristic of an historical explanation that it explains the occurrence of some particular event or state of affairs by describing how it came to be.

"Ephemeral mechanisms share important characteristics with their more stable cousins, and these shared characteristics will help us to understand connections between scientific and historical explanation.

The ***historical explanations*** I have been considering are ***singular causal explanations of particular events***. I have argued that these explanations ***are narrative explanations***, and that narratives should be construed as ***descriptions of ephemeral mechanisms***."

(Glennan (2014): Aspects of Human Historiographic Explanation…)

Ephemeral mechanisms

Historical explanation, narrative, and (ephemeral) mechanisms… (2)

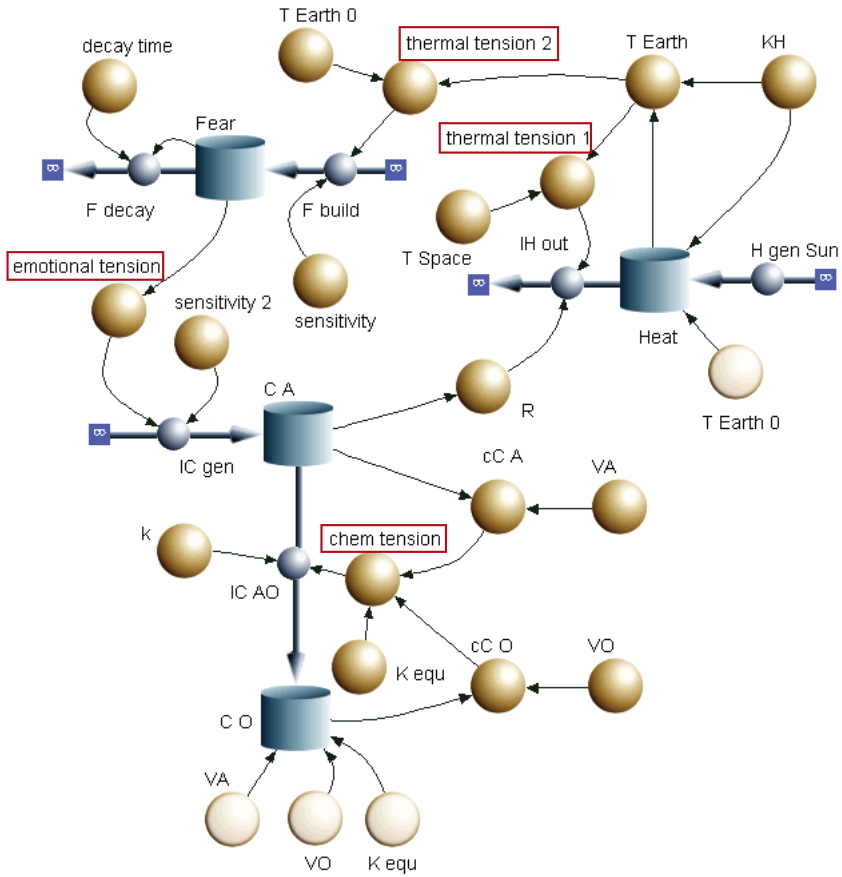
"A market is a mechanism consisting of a number of parts—buyers, sellers, products, money, etc. The actions of and interactions between these parts can be described by change-relating generalizations—for instance, generalizations describing changes in buying behavior in response to changes in price of products. Collectively, the structure of and interactions between these parts entail that the mechanism will behave in regular and predictable ways.

"Explanations of this sort are analogous to mechanistic explanations in science where a scientist seeks to explain a repeatable phenomena by showing it to be the product of a certain sort of mechanism of which there are many instances that operate on many occasions.

"While such explanations are general and ***not historical*** […], they ***still*** have a ***narrative*** structure."

(Glennan (2014) on a stable mechanisms form of explanation of the market crash of 2008…)

NARRATIVE EXPLANATION IN PHYSICAL SCIENCE



Once upon a time there were four characters—carbon, heat, comfort, and fear living on the same planet…

They could get bigger or smaller, they could move around and stay put in places they liked.

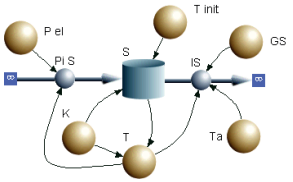
Above all, they could be intense or relaxed, gentle or harsh. How they were, and how big they were, determined their power. All of them were powerful and they wanted to have their share of the world they lived in…

They followed simple instincts. Tensions that would arise from differences in their intensities drove their behavior and would influence the other characters who, in turn, changed their tensions, and so on…

NARRATIVE EXPLANATION IN PHYSICAL SCIENCE

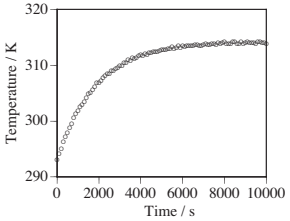
- Our mind perceives/creates a perceptual unit/gestalt that might be called the ***Gestalt of Force*** (Fuchs, 2006, 2011).
- ***Perception of forces starts with differences or tensions.*** We also perceive that a phenomenon can cause another – ***perception of causality***. Our mind goes on to create the notion of ***powerful agents.***
- Science and many other human fields of inquiry can be ***put in the form of narratives*** (stories, that is) because of the centrality of the ***perception of forces*** (Fuchs, 2015).
- In a formal science, ***story-worlds*** and ***stories*** can be associated with ***models*** and ***simulations***, respectively. Being aware of this helps us design science learning starting at young age (Fuchs, 2013a,b).
- In the sense presented here, models and simulations are explanatory since story-worlds and stories are satisfying questions about ***what, who, why***?

Story-World & Dynamical Model



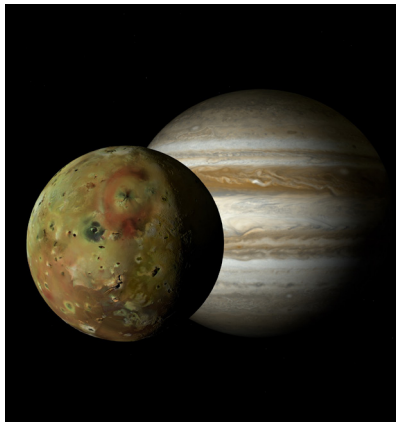
Story & Simulation

Once upon a time there was a small town called Little Hollow. Children and grown ups in Little Hollow were waiting for winter…



Summary (and suggestions?)

- The notions of ***ephemeral mechanisms*** and ***narrative explanation*** suggest a way for us to ***deal with complex systems***.
- ***Complex systems*** are ***dynamical systems***. Dynamical systems are ***collections of interacting elements***.
- ***Complexity*** can be ***structural*** and ***behavioral***.
- We work with dynamical systems by ***creating models*** and ***simulating*** these models.
- Sometimes, models allow for ***prediction***…but only sometimes—more often than not, ***prediction is impossible*** for chiefly two reasons:
  1. We ***know too little*** about the system, its elements and interactions…
  2. …and even in structurally simple systems, behavior may be ***chaotic***.
- Still, models and their simulations ***explain***, again chiefly for two reasons:
  1. Models are representations of our imagination of (***ephemeral***) ***mechanisms***…
  2. Models are ***story-worlds*** and their simulations are ***stories***. Story-worlds build (ephemeral) mechanisms and stories tell what the mechanisms do. Modeling and simulation are an inherently ***narrative practice***.



References

Ephemeral mechanisms

Glennan S. (1996): Mechanisms and the Nature of Causation. *Erkenntnis* **44**, 49-71.

Glennan S. (2010): Ephemeral Mechanisms and Historical Explanation. *Erkenntnis* **72**, 251–266. DOI 10.1007/s10670-009-9203-9

Glennan S. (2010): Mechanisms. *The Oxford Handbook of Causation*, edited by Helen Beebee, Christopher Hitchcock and Peter Menzies. Oxford: Oxford University Press.

Narrative in science

Fuchs, H. U. (2006). From image schemas to dynamical models in fluids, electricity, heat, and-motion. Examples, practical experience, and philosophy. *Proceedings of the 2006 GIREP conference*. University of Amsterdam.

Fuchs, H. U. (2011). Force Dynamic Gestalt, metafora e pensiero scientifico. Atti del Convegno *'Innovazione nella didattica delle scienze nella scuola primaria: al crocevia fra discipline scientifiche e umanistiche'*, Modena, Italy: Artestampa. English version: Force Dynamic Gestalt, Metaphor, and Scientific Thought. ZHAW, Institute of Applied Mathematics and Physics www.zhaw.ch/~fusa/LITERATURE/Literature.html

Fuchs, H. U. (2013a). Il significato in natura. In F. Corni (Ed.), *Le scienze nella prima educazione. Un approccio narrativo a un curricolo interdisciplinare* [Meaning in nature—From schematic to narrative structures of science], Erickson, Trento, Italy. ZHAW, Institute of Applied Mathematics and Physics. www.zhaw.ch/~fusa/LITERATURE/Literature.html

Fuchs, H. U. (2013b). Costruire e utilizzare storie sulle forze della natura per la comprensione primaria della scienza. In F. Corni (Ed.), *Le scienze nella prima educazione. Un approccio narrativo a un curricolo interdisciplinare* [Designing and using stories of forces of nature for primary understanding in science] Trento, Italy: Erickson. ZHAW, Institute of Applied Mathematics and Physics. www.zhaw.ch/~fusa/LITERATURE/Literature.html

Fuchs H. U. (2015): From Stories to Scientific Models and Back: Narrative framing in modern macroscopic physics. *International Journal of Science Education* **37** (5-6), 934-957.

Morgan M. S. (2001): Models, stories, and the economic world. *Journal of Economic Methodology*, **8**(3), 361-384.

Morgan M. S. (2012): *The World in the Model. How Economists Work and Think*. Cambridge University Press, Cambridge, UK.

Wise M. N. (2011): Science as (Historical) Narrative. *Erkenntnis* **75**(3), 349-376.

Dynamical models

Fuchs H. U. (2002): *Modeling of Uniform Dynamical Systems*. Orell Füssli, Zurich. Electronic version online: https://home.zhaw.ch/%7efusa/MUDS/MUDS_TOP.html

Fuchs H. U. (2010): *The Dynamics of Heat. A Unified Approach to Thermodynamics and Heat Transfer*. Springer, New York.

Explanation versus prediction

Stuart Glennan (2014): Aspects of Human Historiographic Explanation: A View from the Philosophy of Science. In *Explanation in the Special Sciences - The Case of Biology and History*, edited by Andreas Hüttemann, Marie I. Kaiser, and Oliver Scholz. New York: Springer.

Norris S. P., Guilbert S. M., Smith M. L., Hakimelahi S., Phillips L. M. (2005): A Theoretical Framework for Narrative Explanation in Science. *Science Education* **89**, 535-563.

Daniel Hutto (2008): *Folk Psychological Narratives. The Sociocultural Basis of Understanding Reasons*. MIT Press, Cambridge, MA.

Kennedy A. G. (2012): A non representationalist view of model explanation. *Studies in History and Philosophy of Science*, Part A **43**(2):326-332.