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
Complex Dynamical Systems

TABLE OF CONTENTS

1. THEMES AND ARGUMENTS

2. DYNAMICAL SYSTEMS AND MODELS

3. COMPLEX SYSTEMS AND PREDICTION

4. EPHEMERAL MECHANISMS

5. NARRATIVE EXPLANATION

6. SUMMARY AND SUGGESTIONS

REFERENCES
Complex Dynamical Systems

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*. 
Complex Dynamical Systems

**DYNAMICAL SYSTEMS AND MODELS**

**PERCEPTION OF BEHAVIOR...**

- Radioactive decay of silver
- Enron Stock
- ISDN Connections
- Capacity Utilization and Inventory in US Economy

**WHAT IS BEHAVING LIKE THIS?**
Complex Dynamical Systems

**Dynamical Systems and Models**

*THE FASHIONABLE ANSWER IS THAT…*

*…SYSTEMS BEHAVE LIKE THIS*

**Systems represented as collections of interacting elements**

**How we carve systems up into elements…**

*…IS COMPLETELY ARBITRARY*
Complex Dynamical Systems

**DYNAMICAL SYSTEMS AND MODELS**

**FEEDBACK**

AND CIRCULAR LOGIC IN MODELS...

**IN EQUATION FORM...**

**IMPLICIT ALGEBRAIC EQUATIONS**

\[
\begin{align*}
G & = a \cdot GRG + b \\
GRG & = c \cdot G \\
\end{align*}
\]

\[
G = \frac{b}{1-ac}
\]

\[
G = \frac{a}{DRG}
\]

\[
DRG = c \cdot G
\]

**DIFFERENTIAL EQUATION (LINEAR)**

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

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

\[
T = H/K
\]

\[
\Delta T_1 = T_D - T , \quad \Delta T_2 = T - T_{amb}
\]
Complex Dynamical Systems

**DYNAMICAL SYSTEMS AND MODELS**

**MODELS, DATA, AND SIMULATION**

Model diagrams as they appear in system dynamics programs

Dynamical models contain storage elements and process quantities... and more...

<table>
<thead>
<tr>
<th>P</th>
<th>Payroll</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR</td>
<td>Transfer Rate</td>
</tr>
<tr>
<td>W</td>
<td>Wage</td>
</tr>
<tr>
<td>N</td>
<td>Number of employees</td>
</tr>
<tr>
<td>TF</td>
<td>Transfer Factor</td>
</tr>
</tbody>
</table>
Complex Dynamical Systems

**COMPLEX SYSTEMS AND PREDICTION**

**MODELS: SIMPLE, COMPLICATED, 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 Dynamical Systems

### Complex Systems and Prediction

### Complex Heterogeneous Systems and Models

<table>
<thead>
<tr>
<th>Complex Systems</th>
<th>Types of Modules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tacoma Narrows bridge</td>
<td>pN – B</td>
</tr>
<tr>
<td>Operating nuclear power plant</td>
<td>pN – M – H – HH</td>
</tr>
<tr>
<td>Economic system</td>
<td>HH – pN – bN</td>
</tr>
<tr>
<td>Piloting an airplane</td>
<td>pN – M – H</td>
</tr>
<tr>
<td>Snow flakes forming</td>
<td>pN</td>
</tr>
<tr>
<td>Blood circulatory system</td>
<td>bN – (pN) – (H)</td>
</tr>
<tr>
<td>Epidemic</td>
<td>bN – HH</td>
</tr>
<tr>
<td>Evolution of language</td>
<td>H – HH</td>
</tr>
<tr>
<td>Ecological system</td>
<td>bN – pN – HH</td>
</tr>
</tbody>
</table>

_How could we ever achieve complete knowledge of such systems?_
**Complex Dynamical 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 Dynamical Systems

**COMPLEX SYSTEMS AND PREDICTION**

**COMPLEX BEHAVIOR**

A model of lions, antelopes, and grass.
Complex Dynamical Systems

**COMPLEX SYSTEMS AND PREDICTION**

**MINIMAL CONDITIONS FOR COMPLEX BEHAVIOR**
**(DETERMINISTIC CHAOS)**

\[
\begin{align*}
\frac{dx}{dt} &= \sigma(y - x) \\
\frac{dy}{dt} &= x(\rho - z) - y \\
\frac{dz}{dt} &= xy - \beta z
\end{align*}
\]

- Autonomous
- Three dimensional
- Non-linear
**Complex Dynamical Systems**

**EPHEMERAL MECHANISMS**

**THINKING IN TERMS OF MECHANISMS (MECHANISTIC SYSTEMS)…**


---

**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.”
Complex Dynamical Systems

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…)}
“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…)
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...
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?*
Complex Dynamical Systems

**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*. 
Complex Dynamical Systems

REFERENCES

**Ephemeral mechanisms**


**Narrative in science**


**Dynamical models**


**Explanation versus prediction**


