



Complex system Theory

A Brief Conceptual Introduction

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Outline

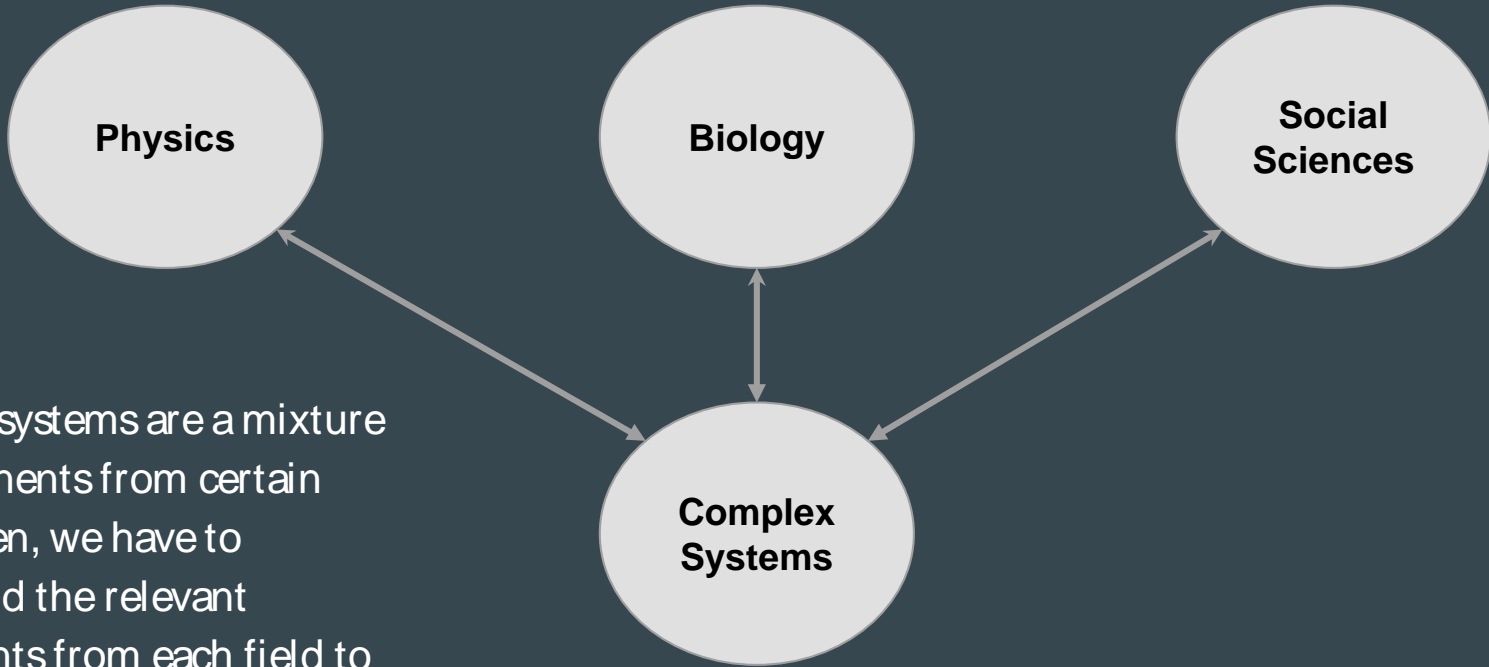
**1.
Components of
Complex System
Theory**

**2.
What are Complex
systems?**

**3.
The Future and
Impact of
Complexity**

What do they have in common?



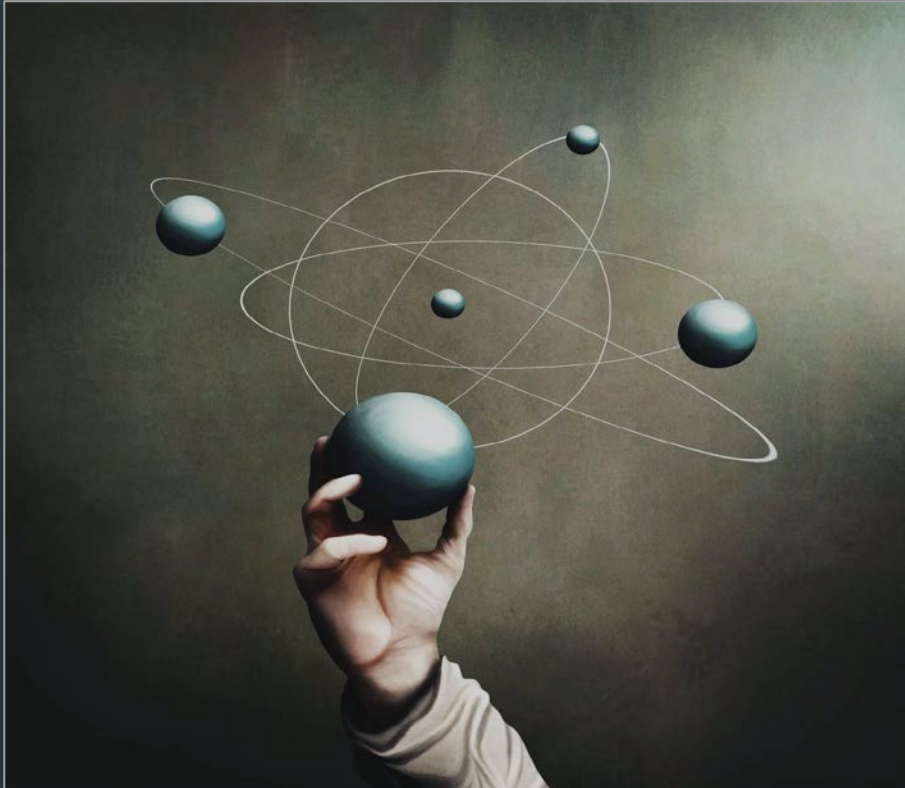


Complex systems are a mixture of components from certain fields. Then, we have to understand the relevant components from each field to understand complex systems.

1.

Components of Complex System theory

What is physics?



- It is an **experimental, predictive, and quantitative** science of matter and its interactions.
- Matter ranging from microscopic to macroscopic
- The field mostly relies on analytical solutions because the four fundamental forces are:
 - Homogeneous (act in the same way everywhere)
 - Isotropic (act in the same in all direction)
 - Forces differ greatly in strength.

Compare and Contrast

- Goals:
 - Experimentally testable, quantitative, and predictive
 - Subject:
 - Physical matter, and their interactions
 - Key Assumptions and fact:
 - Homogeneous,
 - Isotropic,
 - Forces are domain specific
 - Analytical
- Goals:
 - Experimentally testable, quantitative, and predictive
 - Subject:
 - 'Generalized' matter, and their 'generalized' interactions
 - Key Assumptions and fact:
 - Homogeneous (mostly not).
 - Isotropic (mostly not).
 - Interaction can change over time and be **specific** (i.e. Not all elements, only certain pairs or groups of elements, interact with each other.)
 - Algorithmic

Complex System From the physics' perspective

- Composed of many elements describe by state.
- Elements are “*generalized matter*”.
- Interactions may be specific, hence, interaction **networks**.
- Interactions are “*generalized interactions*”
- Interaction can be superposed.
- *Chaotic*, that is depend strongly on the initial conditions and details of the system.
- Complex systems can exhibit a rich structure and have a huge variety of macrostates that often cannot be inferred from the properties of the elements (*Emergence*).

The theory of complex systems is the quantitative, predictive, and experimentally testable science of generalized matter interacting through generalized interactions.

$$M_{ij}^{\alpha}(t)$$

Cell Systems

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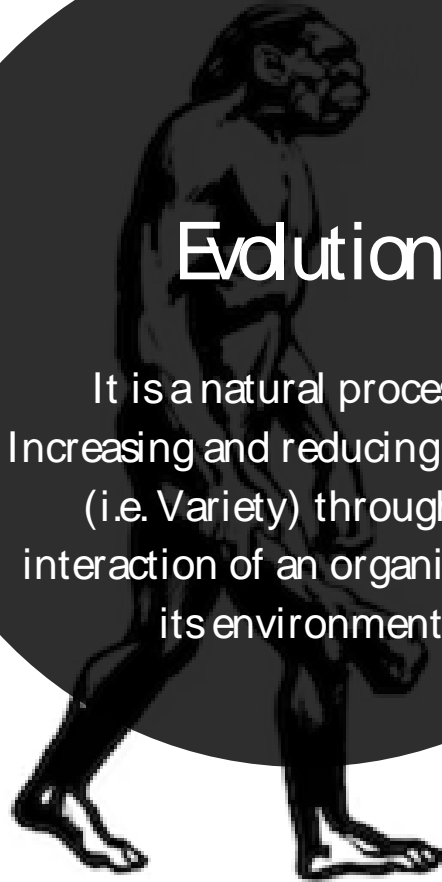
Components of complex systems from Biology

- For complex systems, the framework of physics is incomplete.
- several key features of complex systems that have been adopted from biology. In particular, we discuss the concepts of **evolution**, **adaptation**, **robustness**, **self-organization**, and, again, **networks**



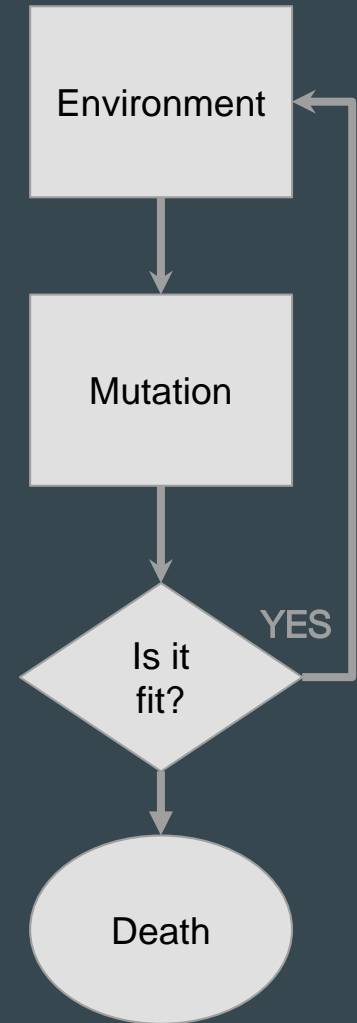
Evolution

It is a natural process of
Increasing and reducing diversity
(i.e. Variety) through the
interaction of an organism with
its environment.



The Evolutionary Process

- Three critical components:
 - Replication
 - Stochastic
 - Variation (i.e. Mutation)
 - Environment
 - Not fixed, always changing
- Existence of “Booms” and “Crashes”.



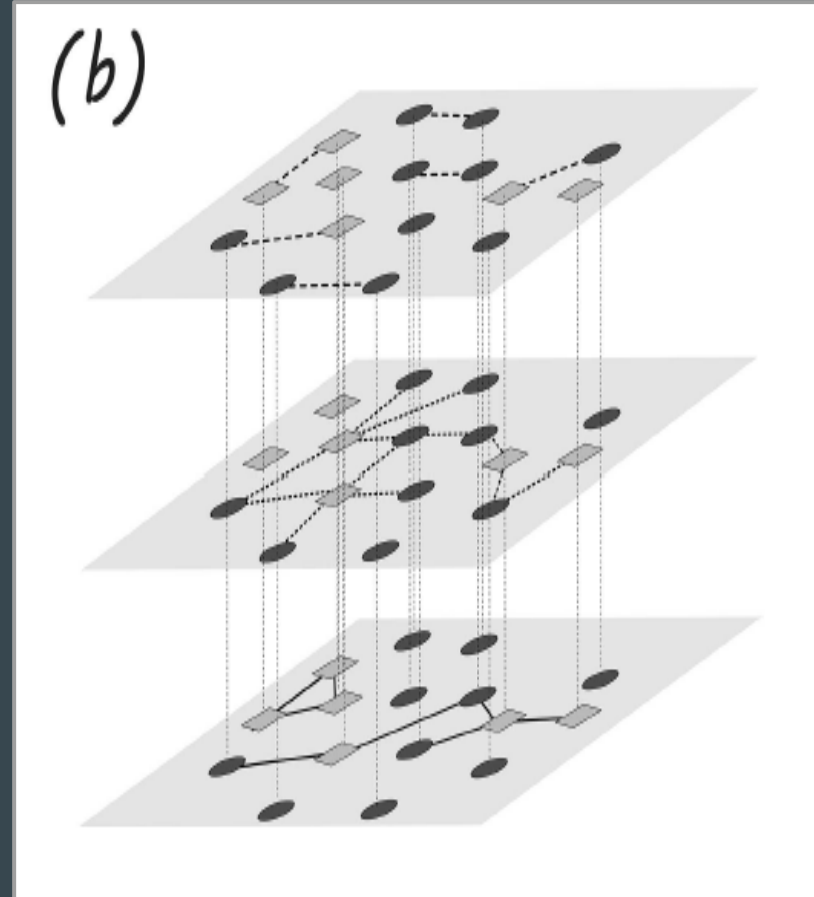


Components of complex systems from the social sciences

- Key features of complex systems that have been adopted from social science: co-evolution, multilayered interactions, and game theory.

Multilayered time varying networks

- Social systems can be thought of as time-varying multilayered networks.
- Interactions happen simultaneously at more or less the same strength scale on a multitude of superimposed interaction networks.
- Interactions change over time



Co-evolution

- the derivatives mean ‘*change within the next time step*’ and should not be confused with real derivatives.
- The first equation means that the states of element i change as a ‘function’, F , that depends on the present states of j .
- The second equation specifies how the interactions evolve over time as a function G that depends on the same inputs, states of elements and interaction networks.



$$\frac{d}{dt}\sigma_i(t) \sim F\left(M_{ij}^{\alpha}(t), \sigma_j(t)\right)$$
$$\frac{d}{dt}M_{ij}^{\alpha}(t) \sim G\left(M_{ij}^{\beta}(t), \sigma_j(t)\right).$$

2.

What are complex systems?

Co-evolving Multilayered networks.

Facts summary about complex systems

- Complex systems are composed of many elements. (nodes)
- These elements interact with each other through one or more interaction types. (links)
- Networks = nodes and links.
- Multilayer network can evolve independently or co-evolve.
- Interactions are not static but change over time.
- Elements are characterized by states that can evolve with time.
- The dynamics of co-evolving multilayer networks is usually highly non-linear (i.e **Chaotic**).
- Complex systems are context-dependent.
- Complex systems are algorithmic.
- **Emergent Properties.**

“More is different.” -Philip W. Anderson

What do they have in common?



3.

The Future and Impact of Complexity

Consistent Mathematical Framework

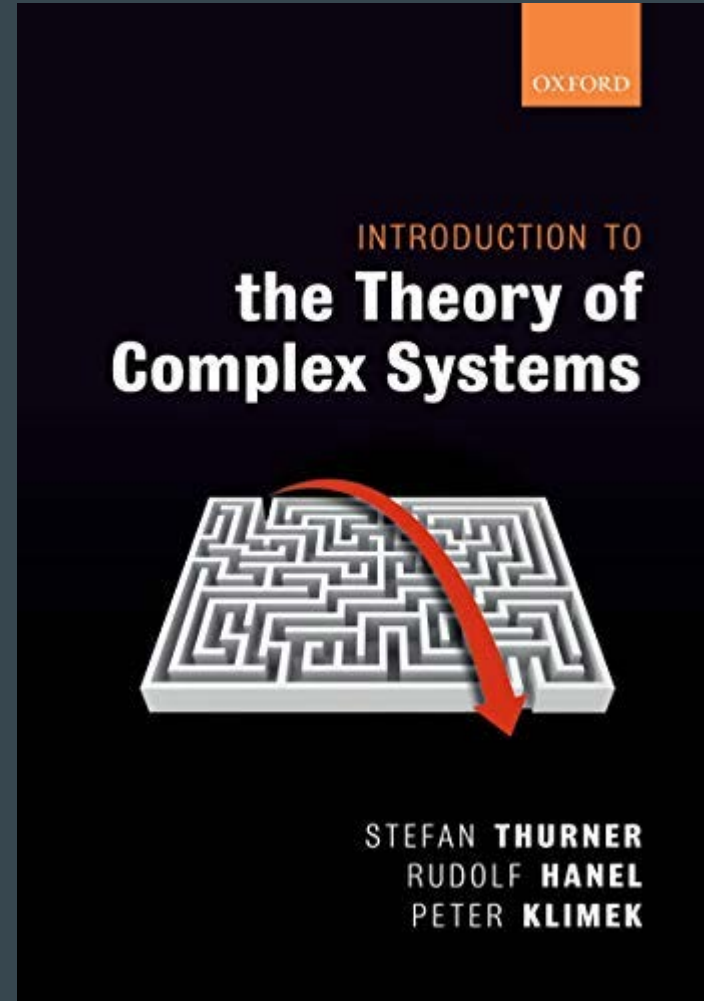
- Meaningful generalization of statistical mechanics, and information theory so that
- they finally become useful for complex systems.
- Categorizing probabilistic complex systems. Once we know which universality class a particular system belongs to, we know how it behaves statistically, how to identify its relevant parameters, and where its transition and breaking points might be.
- Unifying the many different approaches to evolution and co-evolution into a single mathematical framework.
- Developing mathematical formalisms for co-evolutionary dynamics of states and
- interactions.
- Lack of appropriate algorithm

Possible Impact of Complex System Theory

- Governmental Policies
 - Predict Possible consequences of Socio-Political and economic policies
- Finance
 - More efficient financial markets.
 - Predict Booms and crashes
- Neuroscience
 - Brain mapping project
- Condensed Matter Physics
- And More.

Reference

All information presented came from the textbook:
Introduction to the Theory of Complex System, published in 2018.



Thank you for your time!