

Describing, Modeling and Interdisciplinary Analogies of Complexity and Complex Systems

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- Introduction
- What is complexity?
- Historical Development
- Complexity in computer science
- What does complexity not imply?
 - Randomness
 - Complication
- Interdisciplinary approach or what can we learn from other disciplines?
 - Systems biology
- References & Literature

- Master's Thesis in Philosophy for Science and Technology

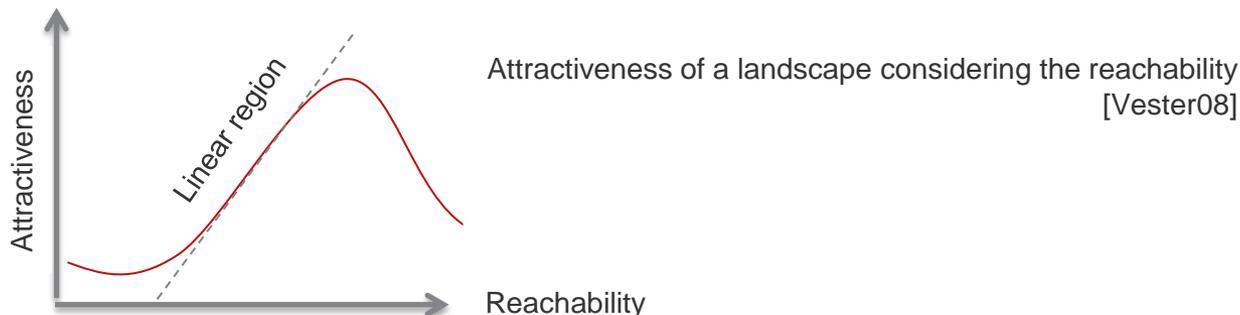
- **MCTS** - Munich Center for Technology in Society



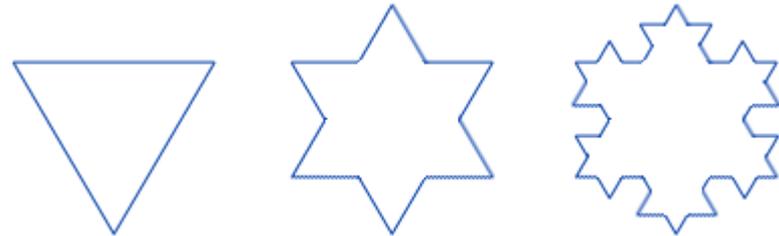
- Supervisor: Prof. Klaus Mainzer
 - Director and Founder of the MCTS
 - Philosopher, Mathematician, Physicist
 - Complex Dynamical Systems and Self-Organization in Nature and Society
 - Artificial Life and Artificial Intelligence
 - Chaos Theory

What is complexity?

- Complexity as a property of a system
 - The system must be an open (dissipative) system
 - Interaction with environment is required
 - Closed systems end up in a steady state (2nd Law of Thermodynamics)
 - Multiple elements are needed
 - Interconnectivity
 - The behavior of a complex system is different to the behavior of its individuals
 - Non-Linearity
 - Interactions within elements are non-linear
 - The common principle of cause and effect is inadequate



- Complexity as a property of a system
 - Dynamic behavior
 - Behavior is changing over time
 - Chaotic behavior
 - Sensitivity to initial conditions (“butterfly-effect”)
 - Self-similarity
 - Scale Invariance
 - Self-organization



- “The whole is more than the sum of its parts” [Aristotle]
 - Life was supposed to be more than a set of organs in a body
 - What is the “more”?

- Scientific progress, especially Newton’s Laws, pushed engineers, scientists and philosophers towards a more reductionist viewpoint
 - Mechanism instead of vitalism
 - “L’Homme Machine” from La Mettrie
 - Human body as a complicated machine, following simple rules
 - Kant later on criticized the idea of reductionism as well as the idea of purpose (teleology) of Aristotle
 - He postulated self-organization in a quite modern sense [Mainzer07]

- What followed was a centuries of controversial discussions between reductionists and vitalists

- From a scientific point of view it is quite reasonable to believe that the laws of nature, underlying all biological processes, are sooner or later going to be found!

- But the awareness of those laws must not necessarily explain emergent properties of complex systems
 - What do the principles of genetic and biology tell us about life?
 - If we understand the operation of neurons can we explain what consciousness really is and means?

- However, different scientific disciplines arisen and they all struggle with the phenomena complexity
 - Systems biology, neuroscience, sociology, ecology,

- Dealing with complexity seems to be one of the big challenges in the 21. century!

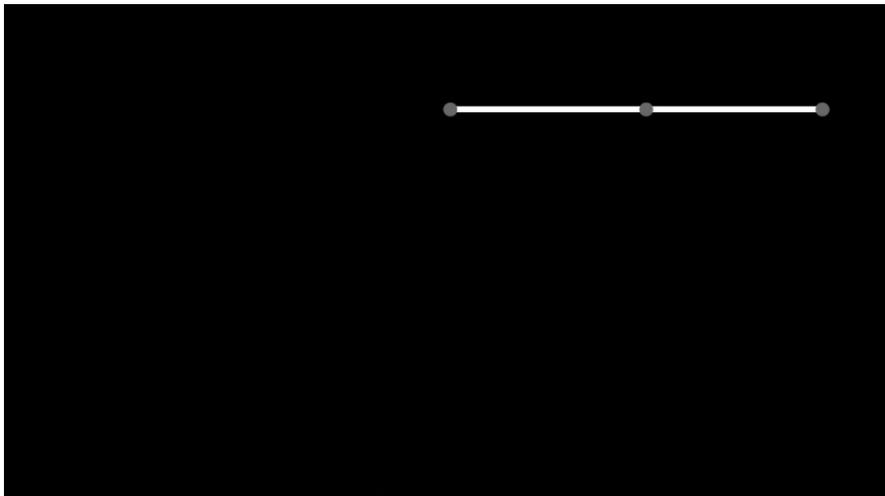
- Computational Complexity Theory
 - Analysis of algorithms
 - What amount of resources (time, space) are required?
 - Computability theory
 - Can a problem in principle be solved or calculated?
- This is **not** what the thesis is going to address!

- What computer science has in common to many other scientific disciplines is the system approach
 - Dealing with complex systems in reductionist way can be dangerous
 - Holistic approach can explain and forecast behavior where other approaches fail

- Holistic approach in Software Engineering and Enterprise Architectures

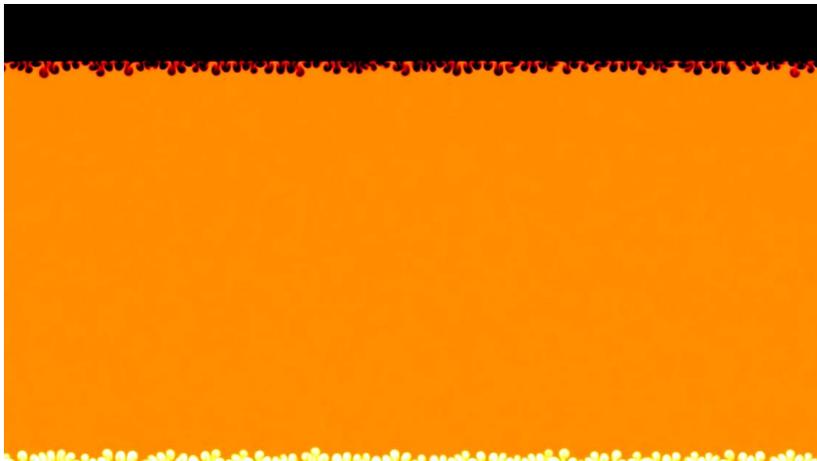
▪ Complexity implies randomness?

- No, deterministic processes can be highly complex!
- Forecasting is not possible!
- E.g. Ideal-Double-Pendulum
- Two non-linear differential equations that are not analytically solvable!
 - The process itself is high deterministic but small deviation yield large deviations
 - *“When the present determines the future, but the approximate present does not approximately determine the future” – Edward Lorenz, Meteorologist*



▪ Complexity implies complication?

- In general not, but the question itself is not that clear!
- Complexity and complication describe different aspects of a system
- Complexity is an emerging system property
- A complex system is not necessarily complicated but needs different approaches and methods to be described properly
 - E.g. Phase transitions, Bifurcations, Non-deterministic Processes,...
- E.g: Rayleigh–Bénard convection [Nicolis87]



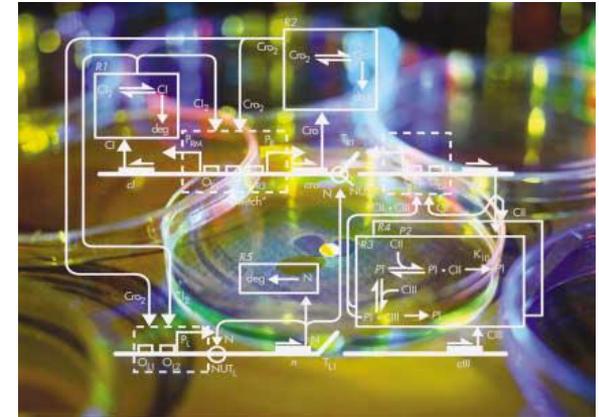
What can we learn from other disciplines?

- Thinking in systems is not new in computer science
 - Thinking in non-linear and dynamic interconnections though

- Other disciplines have studied their objectives and research objects and developed new approaches to deal with complexity:
 - Sociology
 - Sociodynamics (qualitative & quantitative) [Helbing10]
 - Biology
 - Systems biology
 - Neurology
 - Human Brain Project, Brain Activity Map
 - Economy
 - Econophysics [Chakrabarti06]



- Holistic approach instead of the traditional reductionism
 - Discovering emerging properties
 - Organisms functions
 - Properties of cells
- Quantitative modeling of kinetics
 - (chemical reactions with enzymes)
- Mathematical modeling and simulations (Various tools and new technologies)
- Control theory and cybernetics
- Genome Projects
 - Determining the complete genome sequences of an organism (animal, plant, bacterium,.....)



What can we learn from other disciplines?

- Focusing on method transfer rather than model transfer
 - Stochastic principles
 - Non-linear dynamics
 - Multi-Layer modeling (micro & macro levels)
 - Progress and Success of modeling approaches
 - In-Silico-Experiments (Simulations)
 - Identifying order parameters that indicate phase transitions

SUGGESTIONS, QUESTIONS, REMARKS?

I think the next century will be the century of complexity.
- Stephen Hawking, 2000

[Aristotle]
Aristotle, *Metaphysica*

[Nicolis87]
Gregoire Nicolis, Ilya Prigogine: *Die Erforschung des Komplexen – Auf dem Weg zu einem neuen Verständnis der Naturwissenschaften*, Piper, München 1987

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