Describing, Modeling and Interdisciplinary Analogies of Complexity and Complex Systems

Master's Thesis initial presentation, Jul. 29 2013

Bernhard Waltl
MCTS – Munich Center for Technology in Society

Software Engineering for Business Information Systems (sebis)
wwwmatthes.in.tum.de

Agenda

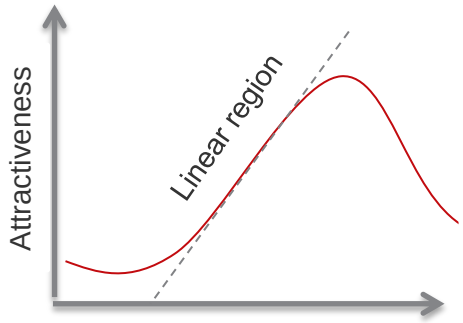
- Introduction
- What is complexity?
- Historical Development
- Complexity in computer science
- What does complexity not imply?
  - Randomness
  - Complication
- Interdisciplinary approach or what can we learn from other disciplines?
  - Systems biology
- References & Literature

Introduction

- 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



Attractiveness of a landscape considering the reachability [Vester08]

What is complexity?

- 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

Historical Development

- “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

Historical Development

- 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!

Complexity in Computer Science

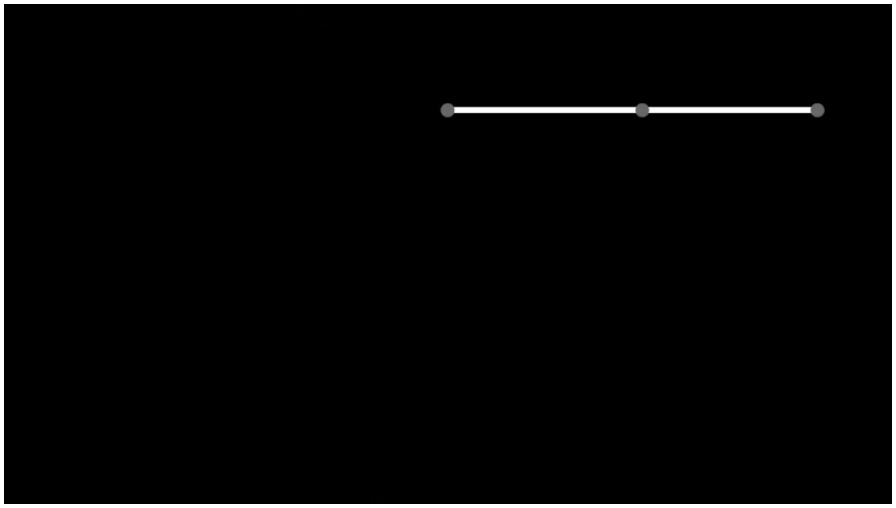
- Computational Complexity Theory
  - Analysis of algorithms
    - What amount of resources (time, space) are required?
  - Computability theory
    - Can a problem in principle be solved or calculated?
- This is **not** what the thesis is going to address!

- 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

What does complexity not imply?

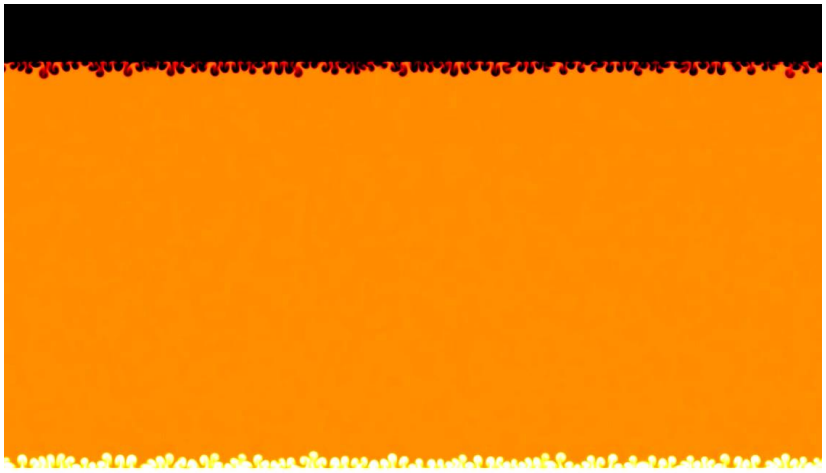
- **Complexity implies randomness?**
  - No, deterministic processes can be highly complex!
  - Forecasting is not possible!
  - E.g. Ideal-Double-Pendulum
  - Two non-linear differential equations that are not analytically solvable!
    - The process itself is high deterministic but small deviation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



Quelle: www.youtube.com/user/khyar

What does complexity not imply?

- **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]



Quelle: www.youtube.com/user/turbulenceteamms

What can we learn from other disciplines?

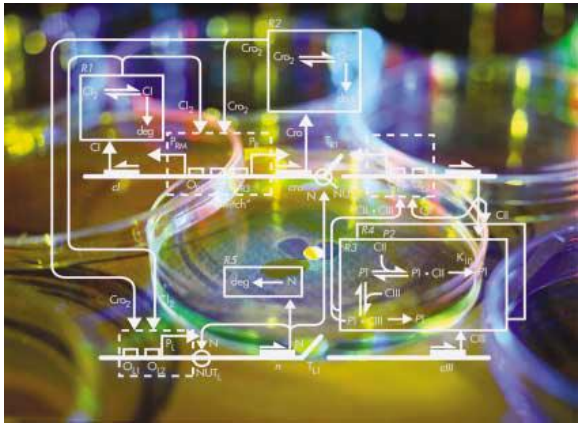
- Thinking in systems is not new in computer science
  - Thinking in non-linear and dynamic interconnections though

- 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]

Example: Systems biology

- Holistic approach instead of the traditional reductionism
  - Discovering emerging properties
  - Organisms functions
  - Properties of cells



- Quantitative modeling of kinetics
  - (chemical reactions with enzyms)
- 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

References

[Aristotle]
Aristotle, Metaphysica

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

[Chakrabarti06]
Bikas Chakrabarti, Anirban Chakraborti, Arnab Chatterjee: Econophysics and Sociophysics – Trends and Perspectives, Wiley, Weinheim 2006

[Mainzer07]
Klaus Mainzer: Thinking in Complexity, Springer, Mainz 2007.

[Weyer08]
Johannes Weyer, Ingo Schulz-Schaeffer: Management komplexer Systeme, München, Oldenbourg 2008.

[Vester08]
Frederic Vester: Die Kunst vernetzt zu denken, dtv, München, 2008

[Helbing10]
Dirk Helbing: Quantitative Sociodynamics, Springer, Berlin Heidelberg 2010