Complex Systems: Concepts, Literature, Possibilities and Limitations

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Public Policy as a Complex System

• The goal of Public Policy is often to alter or maintain the behavior of a large group of individuals and organizations to achieve some societally desirable outcome.

• But individuals are heterogeneous and the react to each other’s actions, which can create a feedback between individuals and government.

• The outcome of public policy is the product of these emergent properties and feedbacks.
What is Complex Systems?

- A system composed of many interacting parts in which the emergent outcome of the system is a product of the interactions and the feedbacks between that emergent outcome and individual decisions.

- A natural lens for public policy analysis.

http://ccl.northwestern.edu/netlogo/models/TrafficBasic
Emergence

- Emergence = ‘the action of the whole is more than the sum of the parts’ (Holland, 2014)
• The effect of the emergent result on the decisions of the individuals
How do you understand Complex Systems?

• Complex Systems can be difficult to predict, control and manage, which in many ways is the goal of public policy

• Complex Systems analysis, often carried out through modeling and simulation, can serve as a flight simulator (Holland, 1996; Sterman, 2000)
Zozobra (Redfish)
Leverage Points

• Leverage points are places where the complex system can potentially be shifted from one regime to another with the least effort (Bankes, 1993)

• Related to:
  
  • Tipping Points: places where a small change in an input can dramatically affect the outcome (Scheffer, 2010)

• Complex Systems analysis often gives you the most when it tells you the least

http://ccl.northwestern.edu/netlogo/models/Fire
Path Dependence is when the current possibilities are limited by past choices.

Brown et al., 2005, IJGIS
Sensitivity to Initial Conditions

- Sensitivity to Initial Conditions (The Butterfly Effect): in its strong form a condition of chaos which says that every starting point is arbitrarily close to another starting point with a significantly different future (Lorenz, 1972)

- Chaos: when the present determines the future, but the approximate present does not approximately determine the future. — Lorenz

- Weak Version - Where you start matters significantly
Non-Linearity and Dynamics

• Inputs do not necessarily affect outputs in a linear manner

• Interactions between various inputs mean that you can not just solve problems by breaking them down one-by-one

http://ccl.northwestern.edu/netlogo/models/GiantComponent
Robustness

- Robustness is when a system maintains its characteristic behavior even after perturbation (Bankes, 2002)

http://ccl.northwestern.edu/netlogo/models/Ethnocentrism
Diversity and Heterogeneity

- Individuals in Complex Systems are often significantly diverse and heterogeneous (Page, 2010)

- Most traditional modeling approaches fail to accurately capture the heterogeneity of individuals
Interconnectedness and Interactions

- Individuals are connected and affect each other’s decision

Bin Laden Retweet Network

Hurricane Sandy Retweet Network

US 2012 Election Retweet Network
Tools of Complex Systems

- The Tools of Complex Systems give researchers the ability to model the properties described above
  - Agent-Based Modeling
  - Social Network Analysis / Network Science
  - System Dynamics Modeling
  - Geographic Information Systems
  - Machine Learning
  - Dynamical Systems
- Often complemented by more traditional methods, such as statistical analysis, psychological experiments, surveys, and game theory
One of the goals of complex systems is to use concepts such as these to build a language of modeling that are generalize able.

A language that can be used to described many different types of systems.

Sometimes called universality.
Applications

- Finance and the Economy
- Cities
- Ecology
- Transportation Systems
- Education
- Legislative Analysis
- Business
- Land-use and Land-change
- Anthropology
- History
- Biology
- Medicine
- Sociology
- Tourism
- Disaster Management
- Engineering
When is Complex Systems Useful?

- Medium Numbers
- Complex but Local Interactions
- Heterogeneity
- Rich Environments
- Temporal Aspects
- Adaptation
Advantages of Complex Systems Analysis

- Multiple scales of interactions
- Heterogeneity of individuals
- Adaptive and Evolutionary behavior
- Potential to overcome the Lucas critique
- Integration of Complex Environments
Complex Environments

• Social Networks, GIS, 3D Environments, Different Topological Configurations

Stonedahl, Rand and Wilensky, 2010

Lechner et al., 2006
Communication of Results

• Create powerful visualizations

• Have an ontology closer to the real world

• Explore the robustness of results

Axtell et al., 2002

Maroulis et al., 2014

Maroulis et al., 2014
Limitations

- High Computational Cost
- Benefit of more insight and data to intermediate stages
- Many Free Parameters
  - Simply exposing parameters that other models assume
- May Require Individual-Level Behavioral Knowledge
  - Provides better insight
Why the Resistance?

- Lack of Education about Complex Systems
- The Drunk, The Keys and The Streetlight
  - People want to search for solutions where it is easy
- Centralized and Deterministic Mindset (Resnick and Wilensky, 1993)
  - People expect their to be a central leader
  - People expect that everything happens for a “cause” and negate the possibility of chance
Complex Systems and Psychohistory

• Psychohistory is a fictional science used by Isaac Asimov’s character, Hari Seldon, in the Foundation series.

• Psychohistory combines history, sociology, and mathematics to make approximate predictions about the future behavior of large groups of people.

• Complex Systems has the potential to help us understand how large groups of individuals and organizations will react to new public policy potentially paving the way for a real psychohistory.

• However, the goal is not to make specific predictions, but can help us to embrace uncertainty.
Any Questions?

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Upcoming Complexity in Business Conference in Washington, DC (10/30-31)