Complexity

The Emerging Science at the Edge of Order and Chaos

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This book is ...

- about the science of complexity according to its preface
- Mostly, about the history and the people in Santa Fe institute
- But not all
  - Brian Arthur
  - Stuart Kauffman
  - John Holland
  - Chris Langton
Santa Fe Institute

- A private, non-profit research institute
- Founded in 1984
- Frontiers of complex systems research
M. Mitchell Waldrop

- Ph.D. in elementary particle physics at the University of Wisconsin in 1977
- Senior writer at *Science* magazine from 1980 to 1991
  - *Complexity* (1992)
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► Complex system
► Brian Arthur and “Increasing returns”
► My idea/Conclusion
Question

Why did the Soviet Union’s forty-year hegemony over eastern Europe collapse within a few months in 1989?
Why did the stock market crash more than 500 points on a single Monday in October 1987?
Question (Cont’d)

Why do ancient species and ecosystems often remain stable in the fossil record for millions of years, and then either die out or transform themselves into something new in a geological instant?
Answers

► “Nobody knows”
Complex system

- Common characteristics in questions
  - A system that is complex
  - Spontaneous self-organization
  - Adaptive
  - Chaos
    - Qualitatively different dynamism

- “Complex system”
A system that is complex

A great many independent agents are interacting with each other in a great many ways.
Spontaneous self-organization

Groups of agents seeking mutual accommodation and self-consistency somehow manage to transcend themselves, acquiring collective properties
Adaptive

► Actively try to turn whatever happens to their advantage
Very simple dynamical rules can give rise to extraordinarily intricate behavior.
Characteristics of Complex Systems

A 'complex' system

Emergent behavior that cannot be simply inferred from the behavior of the components

Complex Systems

Involve:

Many Components

Dynamically Interacting

and giving rise to

A Number of Levels or Scales

which exhibit

Common Behaviors

A 'simple' system

Emergence

Hierarchies

Self-Organization

Control Structures

Composites

Substructure

Decomposability

Trandisciplinary Concepts

Across Types of Systems, Across Scales, and thus Across Disciplines
Table of contents

► Complex system
► Brian Arthur’s “Increasing returns”
► Conclusion
Brian Arthur

- External Faculty Member at Santa Fe Institute (was First director of the Economics Program)
- Consultant to Citicorp, Mckinsey and Co., ...
- Dean and Virginia Morrison Professor of Economics and Population Studies at Stanford, 1983-1996
- Ph.D. Operation Research at Berkeley, 1973
Conventional economics

► Stability of the marketplace
► Balance of supply and demand
► Decreasing returns
Decreasing returns

► As more of an input is applied, each additional unit produces less and less additional output.

► Negative feedback
Economic system as complex system

► Arthur affected by ...
  ▪ Molecular biology
  ▪ Prigogine’s Self-organization
    ▶ “The economy is a self-organizing system”

► He believed ...
  ▪ Instability of the marketplace
  ▪ “Increasing returns”: Positive feedback
    ▶ Lock-in, Path-dependence
<table>
<thead>
<tr>
<th>Old Economics</th>
<th>New Economics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreasing returns</td>
<td>Much use of increasing returns</td>
</tr>
<tr>
<td>Based on 19\textsuperscript{th}-century physics (equilibrium, stability, deterministic dynamism)</td>
<td>Based on biology (structure, pattern, self-organization, life cycle)</td>
</tr>
<tr>
<td>If no externalities and equal abilities, we’d reach Nirvana</td>
<td>Externalities and differences become driving force.</td>
</tr>
<tr>
<td>Elements are quantities and prices</td>
<td>Elements are patterns and possibilities</td>
</tr>
</tbody>
</table>
What’s the point?

► What was the point?
  ▪ “The Important thing is to observe the actual living economy out there, It’s path-dependent, it’s complicated, it’s evolving, it’s open, and it’s organic”

► How can you predict anything?
  ▪ Predictions are nice, But essence of science lies in explanation.
Lock-in & Path-dependence

...within a model where agents choose between technologies competing for adoption and where each technology improves as it gains in adoption. ...the economy, over time, can become locked-in by “random” historical events to a technological path that is not necessarily efficient, not possible to predict from usual knowledge of supply and demand functions, and not easy to change by standard tax or subsidy policies. [Arthur89]
Lock-in example

- Clockwise versus Counterclockwise
- QWERTY keyboard layout
- Beta vs. VHS
- Gasoline vs. steam engine
- Light-water nuclear reactor
Increasing returns in High technology

- Marginal cost is next to zero
  - Software, electronics, computers, pharmaceuticals, aerospace
  - Every copy you produce makes the product cheaper and cheaper

- Among high-tech customers, large reward for flocking to a standard
  - A relatively few standard
    - PC (IBM, Macintosh)
    - An airline buying Boeing jet (Boeing, Douglas, Lockheed)
Math model for increasing returns

In 1981, A set of abstract equations based on a sophisticated theory of nonlinear, random processes.

“Economists could not only follow the entire process by which one outcome emerged, they could see mathematically how different sets of historical accidents could cause radically different outcomes to emerge.”
Not the end, but the beginning

► Arthur went to Stanford. But American journals didn’t accept his papers.
  ▪ Reagan administration treated free-market capitalism as a kind of state religion
  ▪ Maximum individual freedom *must* produce the best of all possible worlds in America
► Arthur joined Santa Fe Institute in 1987
Current Research topics in Santa Fe

- Cognitive Neuroscience
- Computation in Physical and Biological Systems
- Economic and Social Interactions
- Evolutionary Dynamics
- Network Dynamics
- Robustness
My Opinion

Almost the problems human can’t solve, is about a complex system, right?
Science itself is a complex system

- Open system that scientists, scientific knowledge, philosophies, technologies, religions, myth interacts.
- Self-organizing, Adaptive, sensitive to initial condition
- Arthur himself was sacrificed by “increasing returns”
My Opinion (Cont’d)

► No silver bullet
  ▪ Software development is essentially difficult

► Software is a complex system in itself
  ▪ Software tends to be the reflection of problem/solution domain: nature and human society.

► Software development is a complex system
  ▪ Software development needs communications of people
Someday, a breakthrough in complex system research – say, prediction of complex system? - and a set of necessary technologies – enough computing power? - might change/destroy your world?

- Need no software developer?
- Need no scientist?
Reference

- "Complexity: The Emerging Science at the Edge of Order and Chaos" by M. Mitchell Waldrop
- http://www.santafe.edu/aboutsfi/faq.php
- http://www.santafe.edu/arthur/
- [Arthur89]