

# Complexity

## The Emerging Science at the Edge of Order and Chaos

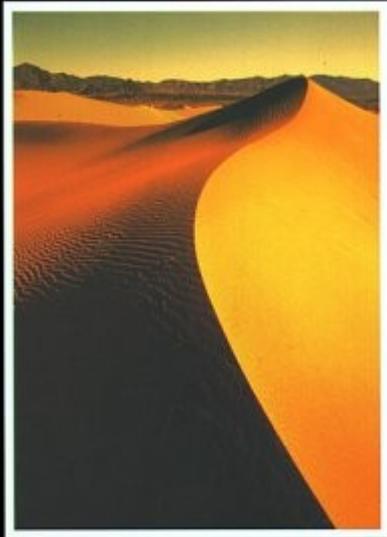
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2005. 05. 10.

# COMPLEXITY



**THE EMERGING  
SCIENCE AT THE EDGE OF  
ORDER AND CHAOS**

**M. MITCHELL WALDROP**

"If you liked *Chaos*, you'll love *Complexity*. Waldrop creates the most exciting intellectual adventure story of the year."  
—*The Washington Post*

- ▶ 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



# Author

## ► 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
- *Man-Made Minds* (1987)
- *Complexity* (1992)
- *Dream Machine* (2002)

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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?



# Question (Cont'd)

- ▶ Why did the stock market crash more than 500 points on a single Monday in October 1987?

**BLACK MONDAY**

**Stock market**

**NIGHTMARE ON WALL ST.**

**CRASH**

There is only one sure investment  
**JESUS CHRIST**  
He will pay you dividends forever!

Investment opportunity below

# 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

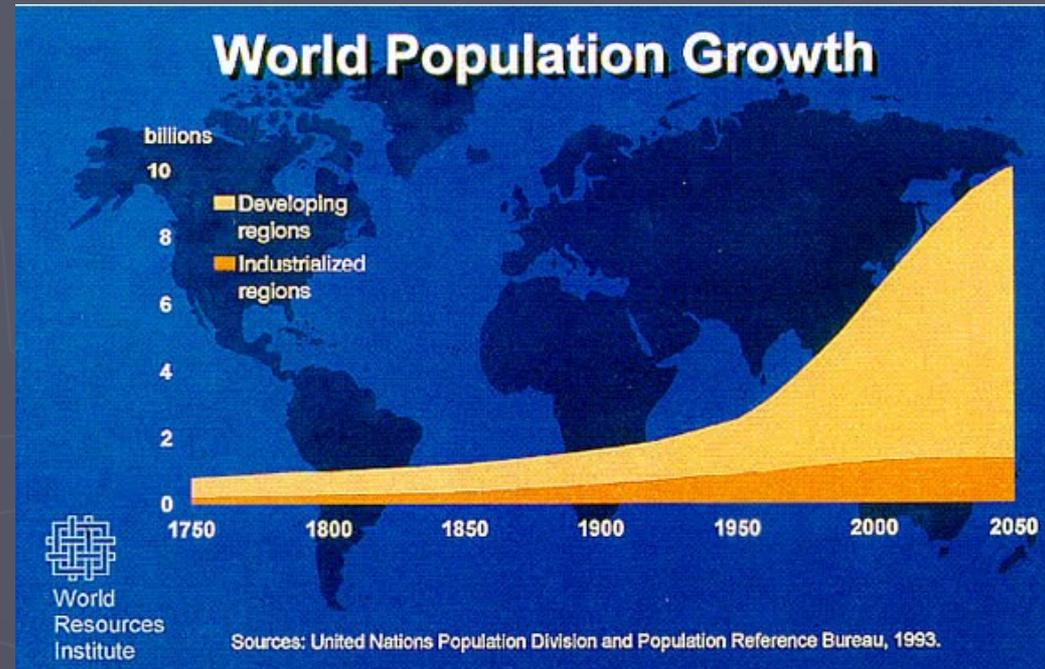
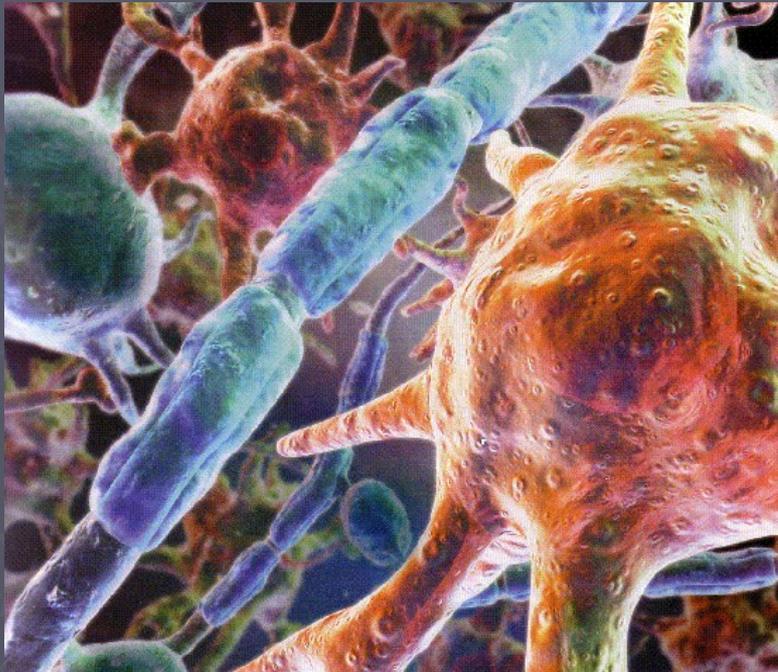
- ▶ “Nobody knows”

# Complex system

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

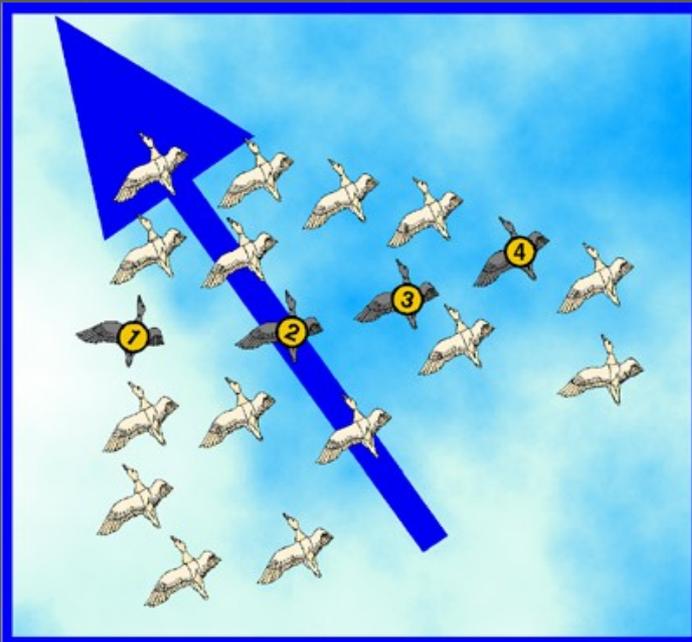
# A system that is complex

- ▶ A great many independent agents are interacting with each other in a great many ways



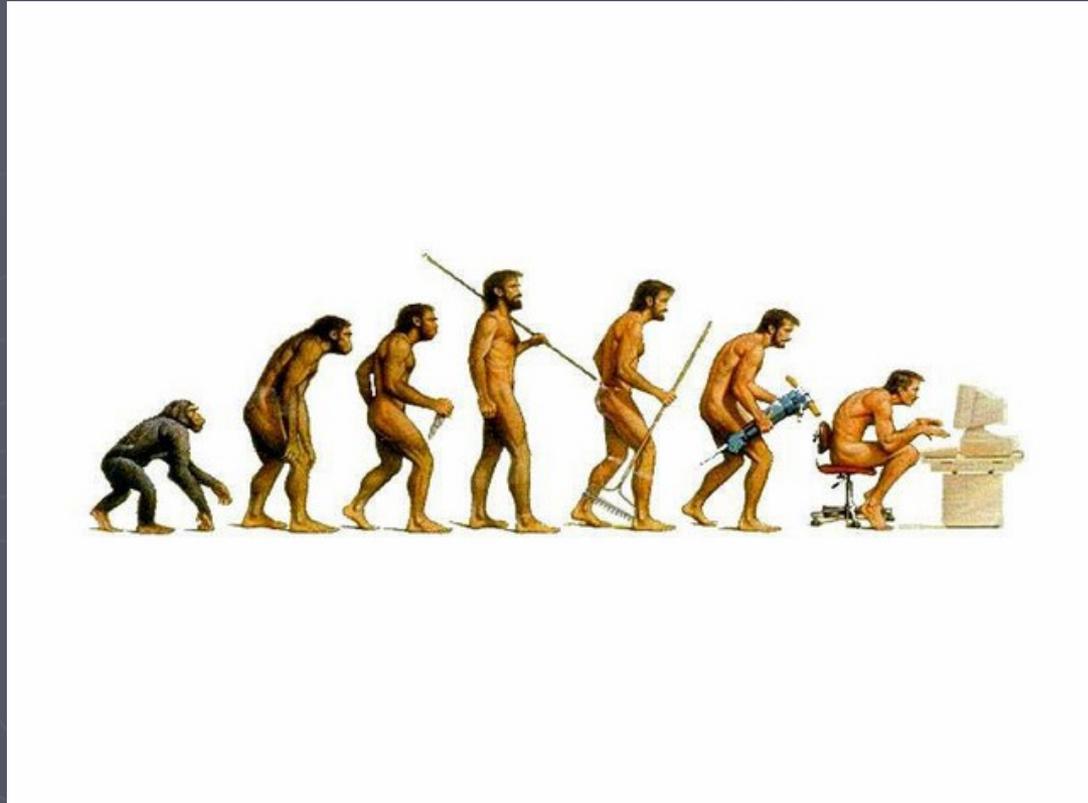
# Spontaneous self-organization

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



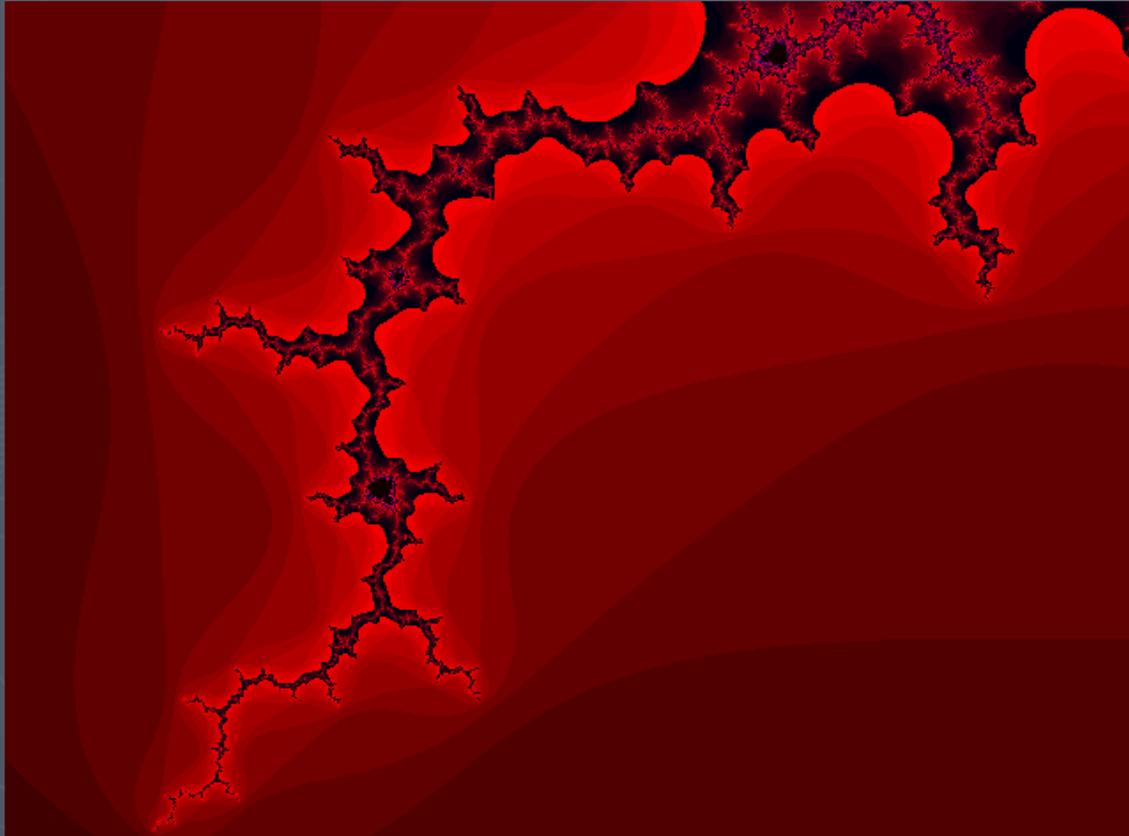
# Adaptive

- ▶ Actively try to turn whatever happens to their advantage

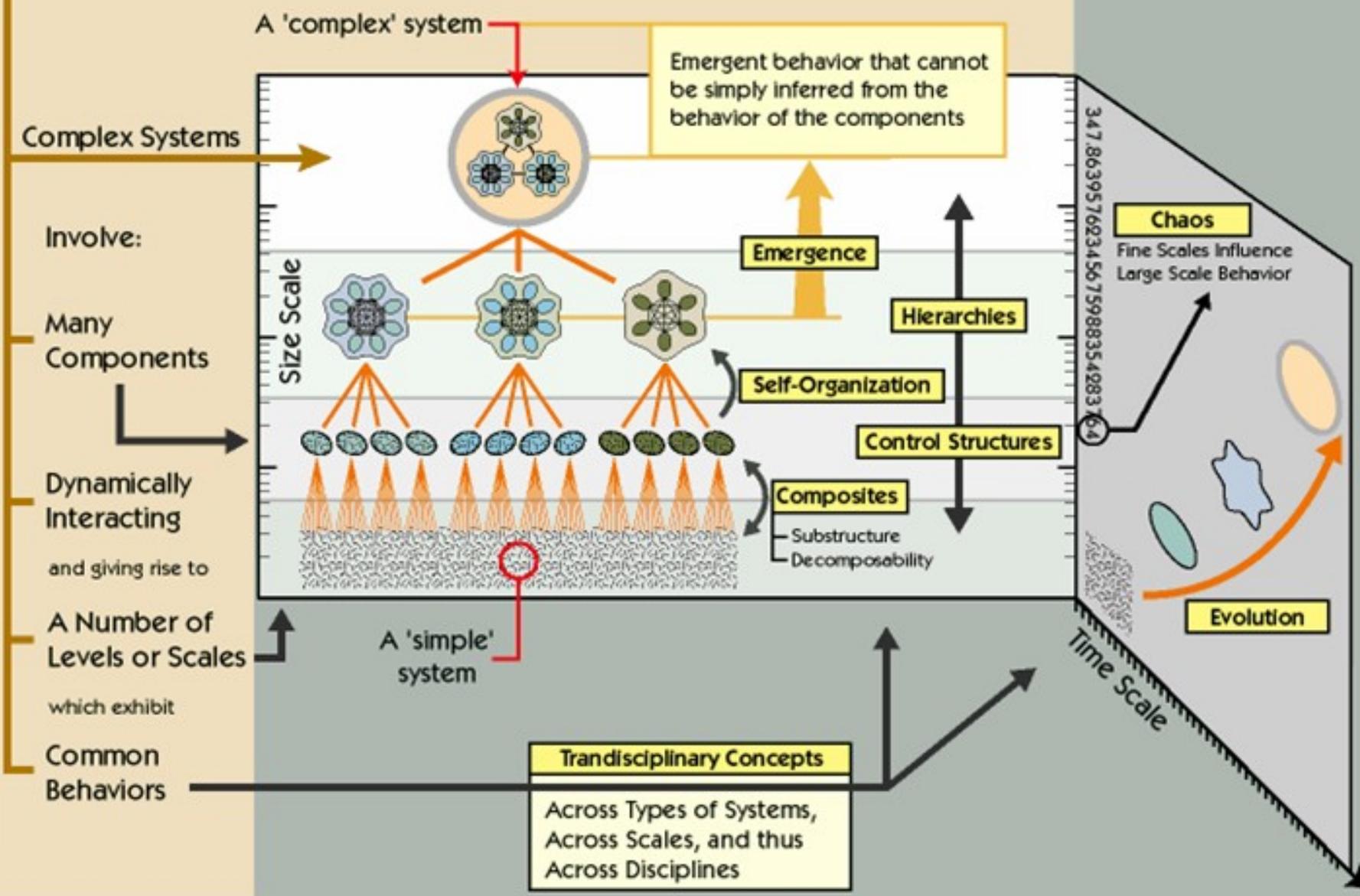


# Chaos

- ▶ Very simple dynamical rules can give rise to extraordinarily intricate behavior



# Characteristics of Complex Systems

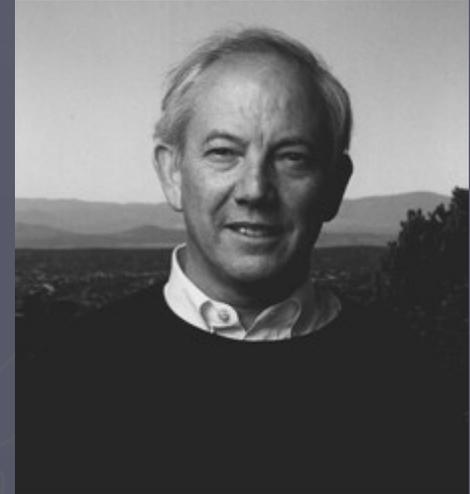


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- ▶ Complex system
- ▶ **Brian Arthur's "Increasing returns"**
- ▶ Conclusion

# 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

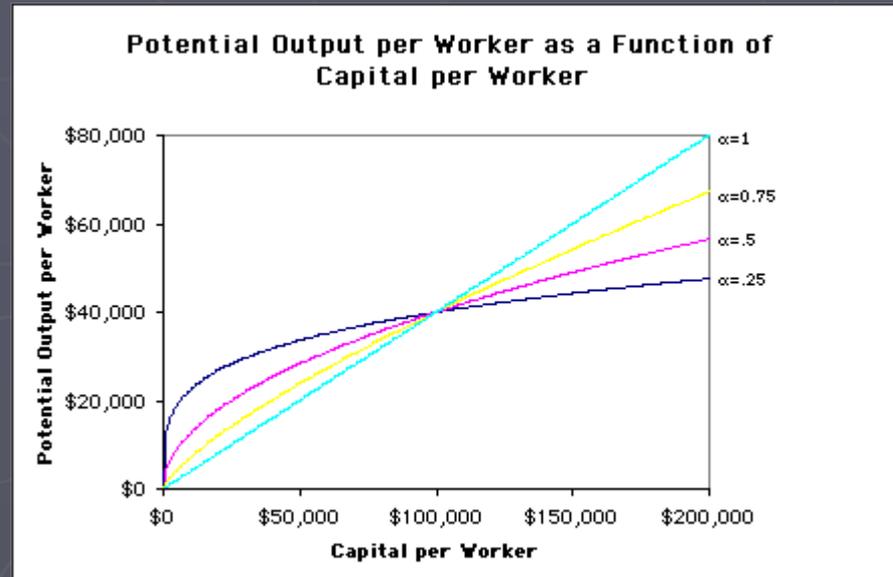


# Conventional economics

- ▶ 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

# Economics Old and New

Old Economics	New Economics
Decreasing returns	Much use of increasing returns
Based on 19 <sup>th</sup> -century physics (equilibrium, stability, deterministic dynamism)	Based on biology (structure, pattern, self-organization, life cycle)
If no externalities and equal abilities, we'd reach Nirvana	Externalities and differences become driving force.
Elements are quantities and prices	Elements are patterns and possibilities

# 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?

# My Opinion (Cont'd)

- ▶ 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

# My Opinion (Cont'd)

- ▶ 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
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- ▶ [http://en.wikipedia.org/wiki/Complex\\_system](http://en.wikipedia.org/wiki/Complex_system)
- ▶ <http://www.santafe.edu/arthur/>
- ▶ [Arthur89]  
*"Competing Technologies, Increasing Returns and I  
Economic Journal, 99, 106-131, 1989"*
- ▶ [http://en.wikipedia.org/wiki/Ilya\\_Prigogine](http://en.wikipedia.org/wiki/Ilya_Prigogine)