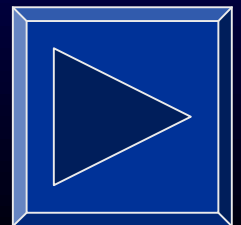


John Holland

- Books
- Enlightenment
- The Great Ideas of the Great Man
- Impact on Economists
- The SFI Economic Program

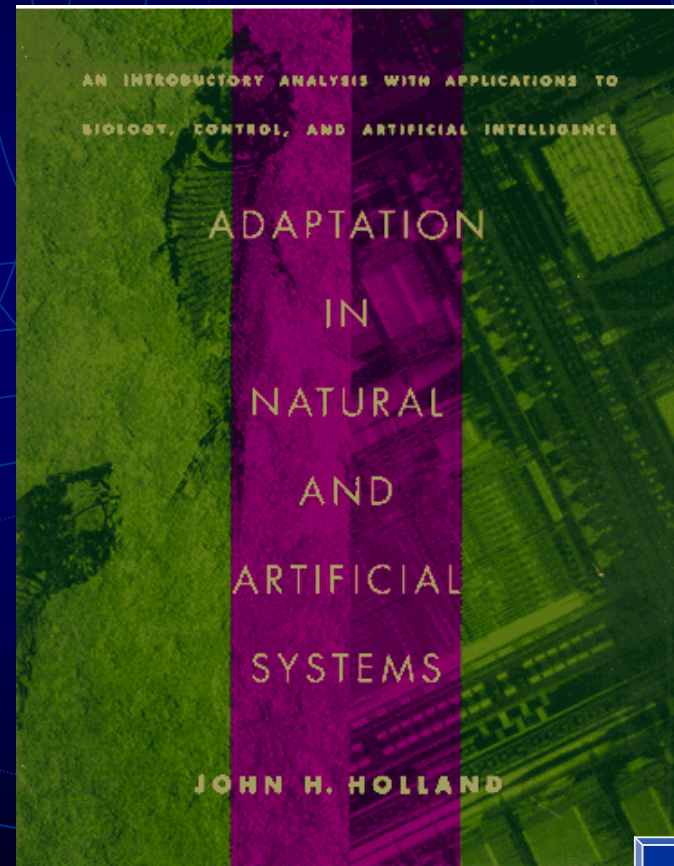
Two Books before the 1990s

- Holland, J. H. (1975), *Adaptation in Natural and Artificial Systems*, Ann Arbor: University of Michigan Press.
- Holland, J. H., K. J. Holyoak, R. E. Nisbett (1987), *Induction : Processes of Inference, Learning and Discovery* (Computational Models of Cognition and Perception), Cambridge: MIT Press.



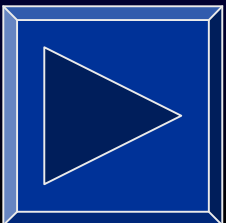
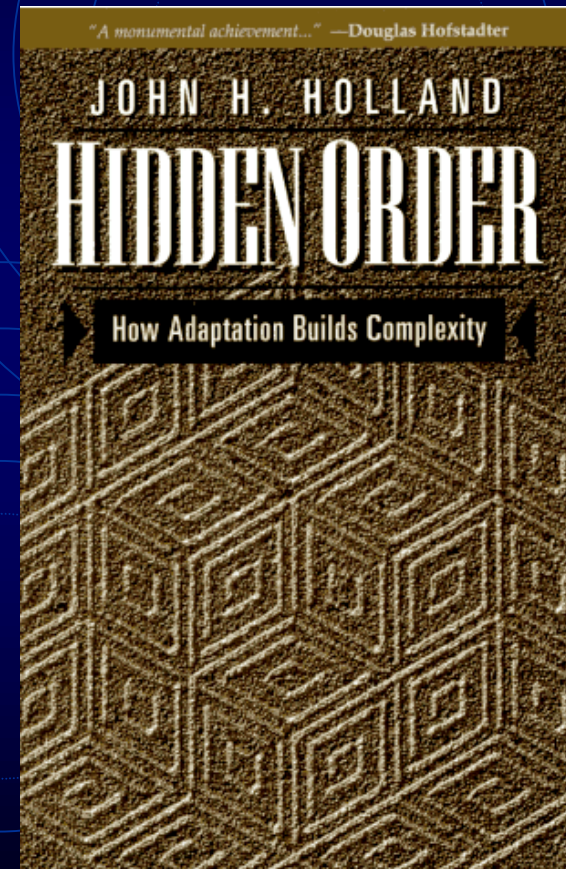
1992

- Holland, J. H. (1992), *Adaptation in Natural and Artificial Systems : An Introductory Analysis With Applications to Biology, Control, and Artificial Intelligence* (Complex A), Bradford Books.



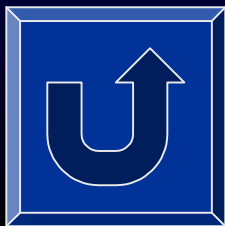
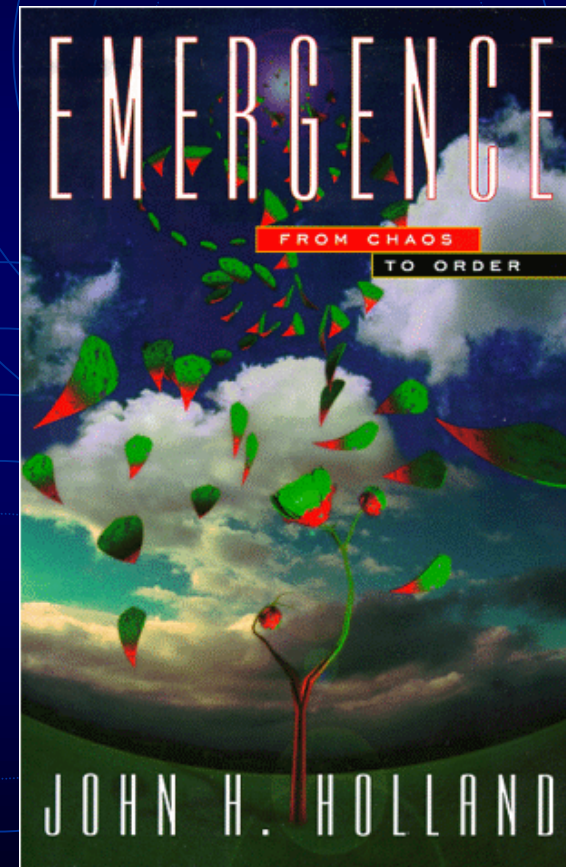
1996

- Holland, J. H. (1996), *Hidden Order : How Adaptation Builds Complexity*, Perseus Press.



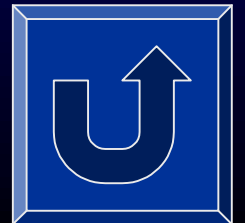
1999

- Holland, J. H. (1999), *Emergence : From Chaos to Order*, Perseus Press.



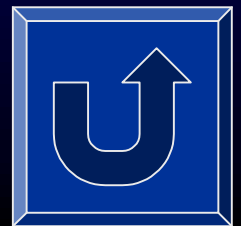
Enlightenment

- Hebb
- Von Neumann
- Fisher



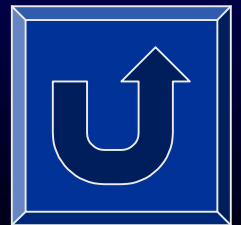
A Window onto the Essence of Thought

- Hebb, D. O. (1949), *The Organization of Behavior*.
 - Connectionism
 - Synapses
 - Cell Assemblies (Subsets of Several Thousand Neurons): Basic Building Block of Information
- pp.158-159



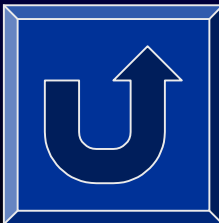
Legacy of Von Neumann

- Using computers in two ways:
 - A general-purpose computational device
 - The basis for a general theory of automata, natural and artificial
- pp.161-162



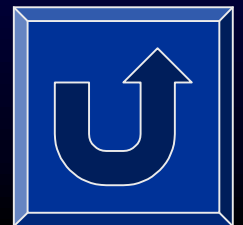
Fruitful Source of Ideas

- Fisher, R. A. (1929), *The Genetical Theory of Natural Selection*.
 - Foundation of ``Neo-Darwinian'' Theory of Evolutionary Change
- pp. 163-165



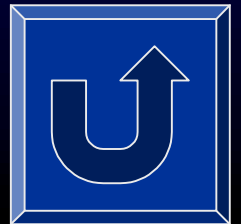
The Great Ideas

- Genetic Algorithms
- Classifier Systems
- Adaptive Agents



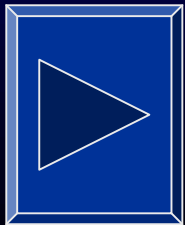
Ideas of Genetic Algorithm

- In a Nutshell
- Key Words
- From the late 1950s to the early 1970s



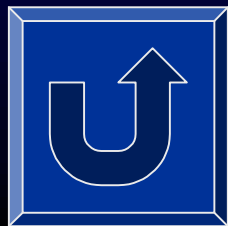
In a Nutshell

- The genetic algorithm is, from an immense space of **building blocks** which are basic units of learning and information, to construct a **evolving hierarchy of building blocks**.
- This construction process is **self-organizing**.
- It functions like the real economy: behaves like the emergence of firms, ways of production, specialization and division, while the idea is motivated by **Hebb**.



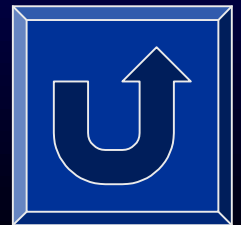
In a Nutshell

- One can use computer to simulate a process of the evolving hierarchy.
- Specifically, Holland chose binary strings as the generic representation of a building block.



Key Words

- Building Blocks
- Evolving Hierarchy
- Self-Organization



pp.166-170

Burks

Holland



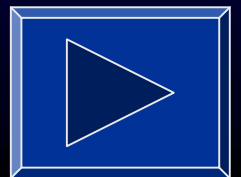
The Logic of Computers Group

1961

A Logical Theory of Adaptive Systems
Informally Described

1964

Tenure



Fisher's Independent-Gene Assumption



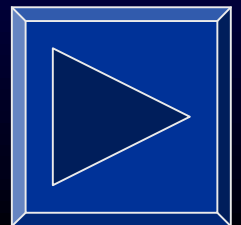
Equilibrium



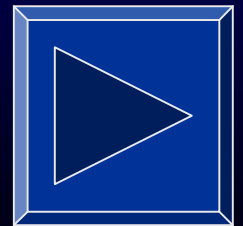
Immense Space of Possibilities



Evolution



- You have a system exploring its way into an immense space of possibilities, with no realistic hop of ever finding the single ``best'' place to be.
- **All evolution can do is look for improvements, not perfection.**



How evolution could explore this immense space of possibilities and find the useful combinations of genes-- without having to search over every square of territory?



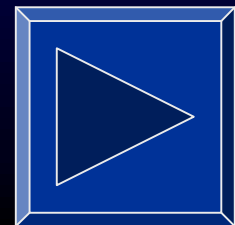
Carnegie Tech

Newell and Simon

General Problem Solver

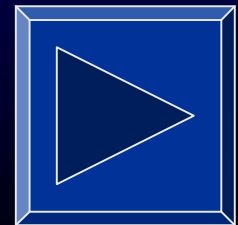
Step-by-Step If-Then Rules

Heuristic Search



A Unifying Principle in Adaptation

Biological Foundation of the Theory of Adaptation



Building Block

Cluster

Cells

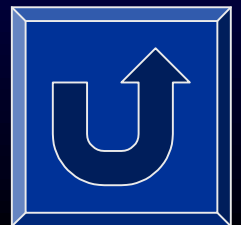
Subroutines

Tissues

Organs

Organisms

Ecosystems



pp. 181-182

Rule-Based Systems

Allen Newell and Herbert Simon
at Carnegie-Mellon

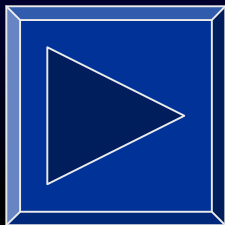


Does it make sense?

Hebb's Reasoning Cell

Bulletin Board Metaphor

Adaptive Agent



p.183

What is wrong with the Rule-Based system?



Symbols: Bird

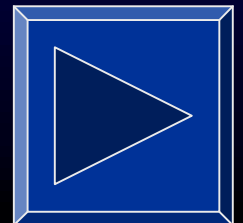


Holland's Puzzle



**Where do such symbolic concepts
come from in the first place?**

How do they evolve and grow?



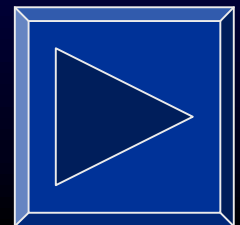
pp. 183-184

Concepts has to be understood in Hebbian terms, as emergent structures growing from some deeper neural substrate that is constantly being adjusted and readjusted by input from the environment.



Classifiers

What is the difference between classifiers and the above-mentioned 'rules'?



Classifier Systems



Conflict Resolution



Top-Down Resolutions

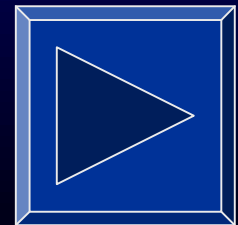
Bottom-Up Resolutions



Competition and Cooperation



Auction



Auction



Hebbian Reinforcement



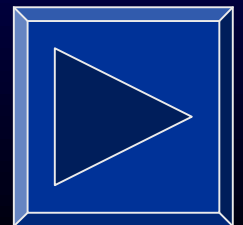
Free-Market Economy



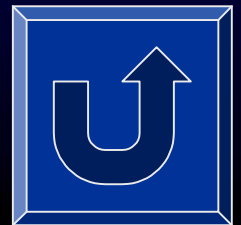
Bucket-Brigade Algorithm



Classifier System



- Holland's classifier system is a cognitive architecture into which the genetic algorithm is embedded so as to allow **adaptive modification** of a population of **string-based if-then rules** (whose condition and action parts are fixed length binary).



Classifier System



What is the problem?



It could not create anything new.

Solution



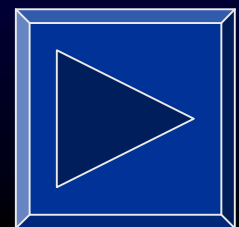
Genetic Algorithms

+

Classifier System

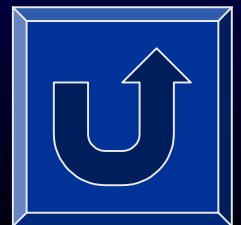


Adaptive Agent



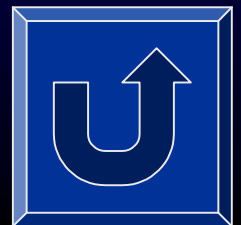
Adaptive Agents

- By adding the genetic algorithm as a third layer on top of **the bucket brigade** and the **rule-based system**, Holland could make an adaptive agent that not learned from experience but could be *spontaneous* and *creative*.



Holland and Economists

- The SFI Physics and Economics Workshop
- Holland's Lecture on the Workshop
- When Arthur Meets Holland

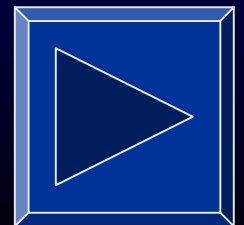


March 9, 1986 (p.90)

Bob Adams

John Reed (Citicorp)

What can the institute help him understand the world economy?

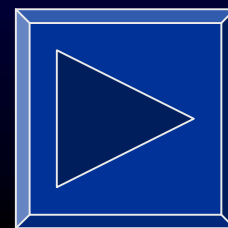


Aug. 6, 1986 (p.92)

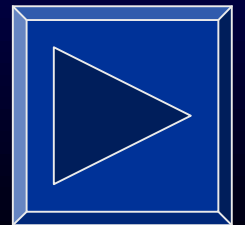
Phil Anderson



John Reed (Citicorp)

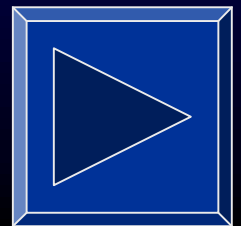


- The Idea of An Economy Program (p.95)
- Organize a Physics and Economics Workshop (p.96-97)
 - Tobin
 - Arrow
- Arrow and Anderson's list (p.97)
 - Arthur (p.98),



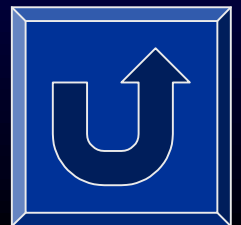
Arrow's List of Economists

- Kenneth Arrow,
- Thomas Sargent,
- Hollis Chenery,
- Jose Scheinkman, and
- Brian Arthur



Sante Fe Institute's Economic Conference (p.136--)

- Ten Full Days
- Sep. 8, 1987



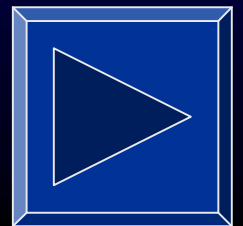
Lecture Title

- The Global Economy as an Adaptive Process by John Holland (University of Michigan)
- Holland, J. (1990), ``**The Global Economy as an Adaptive System,**'' in P. Anderson, K. Arrow, and D. Pines (eds.), *Santa Fe Institute Studies in Science of Complexity: The Economy as an Evolving Complex System,* Addison-Wesley, Redwood City.



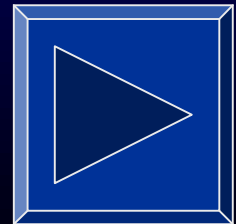
Three Characteristics

- Each of these systems is a network of many `agents` acting in parallel.
- Complex adaptive system has many levels of organization, with agents at any one level serving as the building blocks for agents at a higher level.



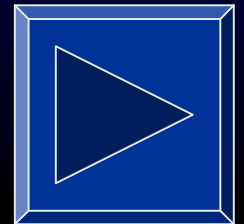
Three Characteristics

- Complex adaptive systems are constantly revising and rearranging their building blocks as they gain experience.

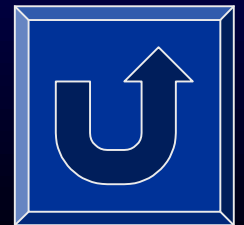


Building Blocks

- At some deep, fundamental level, said Holland, all these processes of learning, evolution, and adaptation are the same.
- And one of the fundamental mechanisms of adaptation in any given system is this revision and recombination of the building blocks.

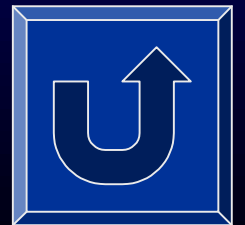


- It is essentially meaningless to talk about a complex adaptive system being in equilibrium: the system can never get there.
- It is always unfolding, always in transition.



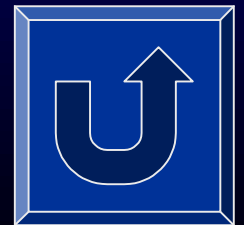
SFI Economic Program

- Motivation
- Artificial Stock Markets



Motivation

- Echo
- Evolving An Artificial Economy
- Bounded Rationality
- Equilibrium



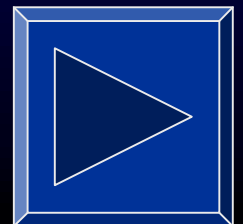
Echo

- What is Adaptation?
- What is Emergence?
- And many more questions that economists may never realized they had been asking.



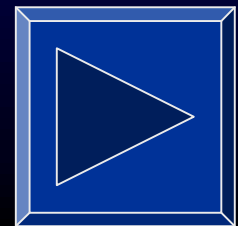
Evolving an Artificial Economy

- But it would have to be all these little agents, programmed to get smart and interact with each other.
- Then in this dreamlike idea, you'd go in one morning and say, 'Hey, look at these guys! Two or three weeks ago all they were doing was bartering, and now they've got joint stock companies.'



Evolving an Artificial Economy

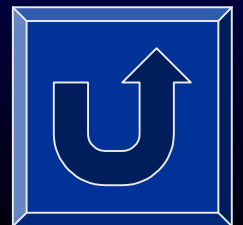
- Then the next day you'd come in and say, 'Oh--they've discovered central banking.'
- Then a few days later you'd have all your colleagues clustered around and you're peering in: 'Wow! They've got labor unions!'
- What'll they think of next?' Or half of them have gone Communist.



Artificial Stock Market

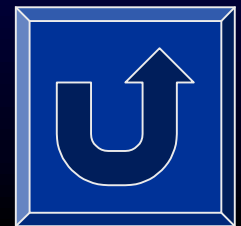
- ``By the time I got to Santa Fe in June 1988,’’ he says, ``I’d realized that we need to start with a more modest problem than building a whole artificial economy’’ And that led to the artificial stock market.’’

(p.269)



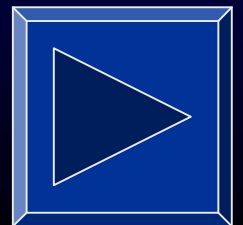
Set the Dial of Rationality

- There is only one way to be perfectly rational, while there are an infinite of ways to be partially rational.
- So, which way is correct for human beings?
- ``Where do you set the dial of rationality?'' (p.250-251)



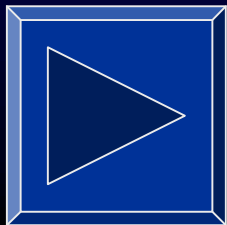
Equilibrium

- The question was does realistic adaptive behavior lead you to the rational expectation outcome? (p.271)
- The answer was yes--but only if the problem is simple enough, or if the conditions are repeated again and again.



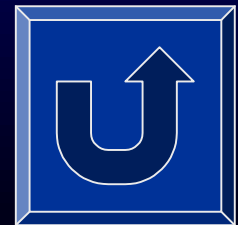
Equilibrium

- But if it's an on-off situation that's never going to happen again, or if the situation is very complicated, so that your agents have to do an awful lot of computing, then you're asking for a hell of a lot.



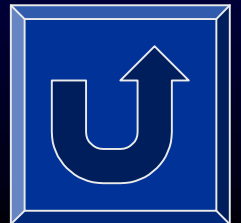
Equilibrium

- Because you're asking them to have knowledge of their own expectations, of the dynamics of the market, of other people's expectations, of other people's expectations about other people's expectations, et cetera.



Artificial Stock Market

- P. 269
- Fall, 1988
- GA and Classifier Systems
- Palmer, 1989



The SFI Economic Program

- P. 243