COMPLEX SYSTEMS: CONCEPTUAL INTRODUCTION III
The architecture of complexity

Herbert Simon (1916-2001)
Nobel prize in Economics 1978
bounded rationality
artificial intelligence: "complex information processing"
Models of My Life [Autobiography]
Decision Making and Problem Solving
Hierarchical Organization

Two watchmakers in Herbert Simon’s classic essay ”The Architecture of Complexity”

"Suppose each watch consists of 1000 pieces. The first watchmaker constructs the watch as one operation assembling a thousand parts in a thousand steps. The second watchmaker builds intermediate parts, first 100 modules of 10 parts each, then 10 subassemblies of 10 modules each, then a finished watch out of the subassemblies, a somewhat longer process, 110 steps longer.

It would seem that constructing a watch in a single sequential process would progress faster and produce more watches. Alas, life being what it is, we can expect some interruptions. Stopping to deal with some environmental disturbance, like a customer, the watchmaker puts down the pieces of an unfinished assembly.

Each time the first watchmaker puts down the single assembly of 1000, it falls apart and must be started anew,
losing up to 999 steps. Interrupting the second watchmaker working on a module of 10 using hierarchical (in the first sense) construction means a loss of at most 9 steps.”

For organizing complexity, the moral is this: taking a few extra steps in the short run, saves many steps in the long run.

In anything less than an environment of no change, the second watchmaker will be much more successful in finishing the complex whole. Using an elegant mathematical demonstration, Simon shows how dramatically more successful the modular-levels principle is in producing stable and flexible complexity. Nature, he says, must use this principle. And, indeed, systems scientists have extensively documented this level pattern of organization, whether physical (such as particle, atom, and molecule), biological (like the example of cell, organ, and body), social (for example, local, regional, and national government), or technological (one example is phones, local exchanges, and long-distance networks”

Complexity takes the form of hierarchy and that hierarchical systems evolve faster than nonhierarchical ones. Very
generally, a hierarchy is a recursive partition of a system into subsystems. Examples of hierarchies are common in social, biological, physical and symbolic (e.g. books) systems. In biological systems, it is argued that hierarchical systems evolve faster because the many subsystems form as many intermediate stable stages in the process. Similarly in the problem solving activity, mainly a selective trial-and-error process, intermediate results constitute stable subassemblies that indicate progress.
Economics and Complexity

Why a New Approach is Needed?

● **Neoclassical economics**
  * Behavioral model for people:
    : Fully-informed
    : Rational
  * People interact only indirectly with one another (through markets)
  * Focus on equilibrium outcomes

● **Complexity approach**
  * People are adaptive
  * They interact directly with one another
  * Focus on dynamics
  * Methodology: equation vs. agent-based modeling?

W. Brian Arthur
http://www.santafe.edu/wba/Papers/Papers.html
GAME THEORY

• There are 2 or more players

• There is some choice of action where strategy matters

• The game has one or more outcomes, e.g. someone wins, someone loses

• The outcome depends on the strategies chosen by all players; there is strategic interaction

http://www.gametheory.net/

John von Neumann - Oscar Morgenstern

John Nash
APPLICATION of GAME THEORY

• Economics

• Political Science

• Social Psychology

• Biology
MINORITY GAME

A minority game (MG) is a repeated game where $N$ (odd) players have to choose one out of two alternatives (say A and B) at each time step. Those who happen to be in the minority win. Although being rather simple at first glance this game is subtle in the sense that if all players analyze the situation in the same way, they all will choose the same alternative and will lose. Therefore, players have to be HETEROGENOUS. Moreover, there is a frustration since not all the players can win at the same time: this is an essential mechanism for modelling competition.

MG is an abstraction of the famous El-Farol’s bar problem (Brian W. Arthur, Am. Econ. Assoc. Papers and Proc 84, 406, (1994)): 100 people would like to go to a bar (El Farol) which is too crowded if there are more than 60 people.
Econophysics

Econophysics tries to apply physics methods to theoretical economics

http://www.unifr.ch/econophysics/

Minority game
A minority game (MG) is a repeated game where N (odd) players have to choose one out of two alternatives (say A and B) at each time step. Those who happen to be in the minority win. Although being rather simple at first glance this game is subtle in the sense that if all players analyze the situation in the same way, they all will choose the same alternative and will lose. Therefore, players have to be heterogeneous. Moreover, there is a frustration since not all the players can win at the same time: this is an essential mechanism for modelling competition.

MG is an abstraction of the famous El-Farol’s bar problem (Brian W. Arthur, Am. Econ. Assoc. Papers and Proc 84, 406, (1994)): 100 people would like to go to a bar (El Farol) which is too crowded if there are more than 60 people.

MG is simply a game with artificial agents with partial information and bounded rationality. (Herbert Simon is cited very rarely in the econophysics literature.)
Minority game

Inductive strategis; mental schemes, hypotheses or behavioral rules

Bar Attendance in the first 100 Weeks

MG: very crude model of financial markets: minority mechanism is found in markets.
Stock market as a complex adaptive system
ECONOPHYSICS

Econophysics tries to apply physics methods to theoretical economics with the optimism of the physicists
http://www.unifr.ch/econophysics/

- deals with real market data

- derive empirical laws

- construct phenomenological theories

obvious drawback: interacting units in economics are 'thinking agents' with adaptive strategies; and not 'mindless' particles obeying simple microscopic laws
Social Networks and Complexity

- Acquaintanceship Networks


The experiment was designed to see if randomly selected starter-people from all walks of life would be able to find a target-person using only a network of friends. Two separate studies were done, in both cases the target-people were in Cambridge, MA. The starting cities were Omaha, NB. and Wichita, KA.

About 150 people were selected from each of the cities and given a document folder that contained the following:

1. The name and address and some personal data on the target-person.
2. A set of rules. The most important of which was: "if you do not know the target-person on a firstname basis, then pass the document folder on to one friend that you feel is most likely to know the target. That friend must be someone you know on a first-basis."

3. A roster. Each person who got the folder had to put their name on the list. This served to show who it came from and also kept the folder from making any loops.

4. Tracer cards. Each person who transmitted the folder had to fill out and mail the tracer card.

The results: It took a median of 5 intermediate friends to go from the starter to the target person. The range was from 2 to 10.

What is the probability that any two people, selected arbitrarily from a large population, will know each other?
What is the length of the shortest chain of acquaintances between two people chosen at random?

- *Hollywood Universe*

  Find the shortest path from any actor to Kevin Bacon, using the association rule

  Unlike society in general, film actor associations are well documented

- *Collaborative graphs*

  ![Paul Erdős](image)

  **Paul Erdős**

  (1913-1996)
### The Erdős Number Project

http://www.oakland.edu/ grossman/erdoshp.html

<table>
<thead>
<tr>
<th>Erdős Number (E. n)</th>
<th>Total People</th>
</tr>
</thead>
<tbody>
<tr>
<td>E. n 0</td>
<td>1 person</td>
</tr>
<tr>
<td>E. n 1</td>
<td>502 people</td>
</tr>
<tr>
<td>E. n 2</td>
<td>5713 people</td>
</tr>
<tr>
<td>E. n 3</td>
<td>26422 people</td>
</tr>
<tr>
<td>E. n 4</td>
<td>62136 people</td>
</tr>
<tr>
<td>E. n 5</td>
<td>66158 people</td>
</tr>
<tr>
<td>E. n 6</td>
<td>32280 people</td>
</tr>
<tr>
<td>E. n 7</td>
<td>10431 people</td>
</tr>
<tr>
<td>E. n 8</td>
<td>3214 people</td>
</tr>
<tr>
<td>E. n 9</td>
<td>953 people</td>
</tr>
<tr>
<td>E. n 10</td>
<td>262 people</td>
</tr>
<tr>
<td>E. n 11</td>
<td>94 people</td>
</tr>
<tr>
<td>E. n 12</td>
<td>23 people</td>
</tr>
<tr>
<td>E. n 13</td>
<td>42 people</td>
</tr>
<tr>
<td>E. n 14</td>
<td>7 people</td>
</tr>
<tr>
<td>E. n 15</td>
<td>1 person</td>
</tr>
<tr>
<td>E. n 16</td>
<td>0 people</td>
</tr>
</tbody>
</table>

**Average Erdős number:** 4.69
Graphs

<nodes or vertices, edges>
Euler and the bridges
Königsberg (Kaliningrad)

STATISTICAL analysis of large graphs
Brian HAYES: Graph Theory in Practice I,II
American Scientist 88(1), 88(2), 2000
REGULAR, RANDOM and REAL WORLD GRAPHS

lattice-like (several neighbors)
regular + random effects
random
COGNITIVE COMPLEXITY

in a narrow sense related to personality theory:


It has been used as a basis for discussion on the complexity of personal constructions of the real world (and particularly of other people) in psychology.

It asks the subjects to rate a number of people known to them on a number of attributes. The dimension of the inferred mental model of these people is then estimated as their cognitive complexity. So, for example, people who assign to all their friends positive attributes and to their enemies negative attributes would have a one-dimensional mental model of their acquaintances, as everybody is aligned along this good/friend - bad/enemy scale. Such people are said to be cognitively simple. A person who indicated that some of both their friends and enemies were good and bad would have at least a two-dimensional model with people placed across a good-bad, friend-enemy pair of axes. This person would have a higher score and would be called more cognitively complex.