COMPLEX SYSTEMS: CONCEPTUAL INTRODUCTION II
Characteristics of simple and complex systems

+ System and its environment

A system is a delineated part of the universe which is distinguished from the rest by an imaginary boundary.
One of the basic concepts in the systems approach is that all systems interact with their environment. How can we then identify what a system is? Aren’t we always making an artificial boundary? In order to perceive or know anything, one must make a distinction. The key idea of "SYSTEM" is that once a system is identified (the boundary described) then one describes:

- the properties of the system, (how to characterize the state of the system);
- the properties of the universe excluding the system which affect the system, and
- the interactions / relationships between them.

Thus, it is not necessary to assume that a system is isolated from or independent of the environment, it is simply a task of the describer to identify the way in which the system is interdependent with the environment.
Simple systems

• single cause $\rightarrow$ single effect

• linear relationship

• predictibility example for simple pattern: 01010101
Complex systems

• circural causality

Circular causality in essence is a sequence of cause and effect whereby the explanation for a pattern leads back to the first cause and either confirms or changes that first cause; Example: A causes B causes C that causes or modifies A.

• logical paradox

A person from the island of Crete asserts, "All Cretans are liars." We can conclude that if he is telling the truth, then he is lying. But if he is lying, then he is telling the truth.
Emergence of complexity

Emergence is:

1. What parts of a system do together that they would not do by themselves: collective behavior.

HOW collective properties arise from the properties of parts.

HOW behavior at a larger scale of the system arises from the detailed structure, behavior and relationships on a finer scale.

In the extreme
HOW MAcroscopic behavior arises from MIcroscopic behavior.

2) What a system does by virtue of its relationship to its Environment that it would not do by itself: e.g. its FUNCTION.

Complex Dynamic Behaviour: CHAOS and related areas
Interaction with the environment

Feedback: is a process whereby some proportion of the output signal of a system is passed (fed back) to the input.

NEGATIVE FEEDBACK

Change in one direction leads to events that reverse the direction of change. Stability is maintained.

Example: thermostat.
positive and negative feedback $\rightarrow$ nontrivial dynamic behavior

physics, chemistry, biology, psychology, economics, behavioral science, political science etc...
Chemical systems: temporal, spatial and spatiotemporal pattern formation

The Belousov-Zhabotinsky (BZ) reaction is named after B. P. Belousov who discovered the reaction and A. M. Zhabotinsky who continued Belousov’s early work. The mechanism of this oscillating reaction was published in 1972 by R. J. Field, Endre Körös, and R. M. Noyes. The work by Field, Körös and Noyes opened an entire new research area:

NONLINEAR CHEMICAL DYNAMICS
Complex chemical patterns

http://online.redwoods.cc.ca.us/instruct/darnold/DEProj/Sp98/Gabe/bzreact.htm
Oscillation is an exotic behavior in chemistry, but the pattern is regular.

From regular to irregular (from predictable to unpredictable):

oscillation to chaos
Chemical Chaos: temporal pattern

Netlogo!

Chemical Wave Propagation: Spatiotemporal pattern

Turing structures: spatial patterns
Biological complexity: from cellular to ecological levels

Levels of organization

- Molecules
- Cells
- Organs
- Organisms
- Population of species
- Ecosystem
- Biosphere
Molecular: Biochemical complexity

Slime mold amoebae of the species Dictyostelium discoideum aggregate as the result of chemotaxis. In these circumstances we observe propagating target and spiral patterns as the amoebae, aggregating into slugs, signal to each other using waves of cyclic AMP that propagate by a diffusion-autocatalysis process analogous to that found in the BZ-waves, and with the same dynamical properties. The slugs are able to exploit the chemical dynamics for aggregation and differentiation, leading to dispersal, and subsequent replication. BZ-type dynamics are an integral part of their survival strategy.
Historically, the first model of MORPHOGENESIS was proposed by Alan Turing in 1952. Mathematically it is a Reaction-diffusion models in 2D. The original intent of the reaction-diffusion model was to explain the “breakdown of symmetry and homogeneity” or the emergence of a pattern in an originally homogenous medium.

A variant of the reaction-diffusion model proposed by Gierer and Meinhardt (1972) was able to capture pigmentation patterns in seashells.
Pigmentation Patterns in Seashells

http://www.cpsc.ucalgary.ca/Research/bmv/vmm/section03.html
BIOLOGICAL NETWORKS

A network can be viewed as a set of largely identical subunits that interact, i.e. communicate, with each other. Once the collection of these sub-units has been identified, three important properties that govern the behaviour of a network can be distinguished:

(a) the connectivity of the network that determines which subunits interact with which other subunits

(b) the strength and nature of these interactions

(c) the total size of the network.

Conceptual basis that enables us to discover and examine common rules governing different biological networks.
Metabolic network

A chemical reaction system that generates essential components such as amino acids, sugars and lipids, and the energy required to synthesize them and to use them in creating proteins and cellular structures is a metabolic network.

Valine, leucine and isoleucine biosynthesis
Neural Networks

cells and synapses

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I\textsubscript{B} \rightarrow \text{IB}

I\textsubscript{O-LM} \rightarrow \text{IO-LM}

I\textsubscript{sept} \rightarrow \text{sept}

EC\textsubscript{p} \rightarrow \text{EC\textsubscript{p}}

CA\textsubscript{1p} \rightarrow \text{CA\textsubscript{1p}}

inhibitory connection
excitatory connection
not explicitly modeled pathway
Ecological networks

foodweb

- simplified food web in a marsh ecosystem:
- direction of energy flow is shown by the red arrows
- food chains rarely follow a precise linear sequence
- food web interconnects several different food chains within the community