

3rd International Workshop Advances in Cleaner Production

From Modern Thermodynamics to How Nature
Works – a View of Emergent Paradigms Associated
with Sustainability

TOWARDS AN ENGINEERING EDUCATION FOR
SUSTAINABILITY -SELECTED TOPICS

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ESTADUAL DE CAMPINAS

*Those who are inspired by a model other than Nature, a
mistress above all masters, are laboring in vain. -*

Leonardo Da Vinci

“In the last 50 years a fast paced conceptual evolution gained momentum and “...changed our view of Nature” (*Kondepudi and Prigogine, 1998)

“this conceptual evolution reached to nonlinear thermodynamics, introducing the concept of emerging ordered dissipative structures

“most introductory texts in thermodynamics (in engineering , as an example) are limited in scope , restricting the expositions to the study of equilibrium systems- meaning the study of idealized, infinitely slow process

“ Modern Thermodynamics” - From Heat Engines to Dissipative Structures

HOW NATURE WORKS – THE SCIENCE OF SELF ORGANIZED CRITICALITY -PER BAK

"SAND PILE " MODEL -DISTRIBUTION OF AVALANCHES DISPLAYS REGULARITY

The image of the sand pile, retaining its conical shape as more sand is added, became widely known. Although avalanches on the sides of the pile (maintaining its stability) were individual unpredictable in size and timing, the *distribution* of avalanches and their timings displayed an interesting kind of regularity (REVIEW, OSVALDO TERAN ,

AVAILABLE AT

<http://jasss.soc.surrey.ac.uk/4/4/reviews/bak.html>

Some of the characteristics of a self-organised system Bak introduces are:

- The system is *open and dissipative*, and its components are *metastable*.
- The *system organises itself* in a *critical state* with *avalanches* of change at all sizes via which dissipation manifests itself. These avalanches are *regular* but not *periodic*.
- The system is embedded in a single *spatiotemporal fractal structure* (p. 172)..
- A *critically self-organised system might become catastrophically unstable* if it were manipulated and forced into certain optimal states which take it out of its self-organised state.

// It makes me so happy. To be at the beginning again, knowing almost nothing...The ordinary-sized stuff which is our lives, the things people write poetry about-clouds-daffodils-waterfalls ...these things are full of mystery, as mysterious to us as the heavens were to the Greeks...It's the best possible time to be alive, when almost everything you thought you knew is wrong"

Tom Stoppard, cited in "Complexity a Guided Tour" (Mitchell, 2009)

HOLISM REPLACES REDUCITONISM

“I want to know how God created this world. I am not interested in this and that phenomenon, in the spectrum of this or that element. I want to know His thoughts: the rest are details”

Albert Einstein

WICKED PROBLEMS

Some problems are so **complex** that you have to be highly intelligent and well informed **just to be undecided about them**

Laurence J. Peter, in

Wicked Problems & Social Complexity

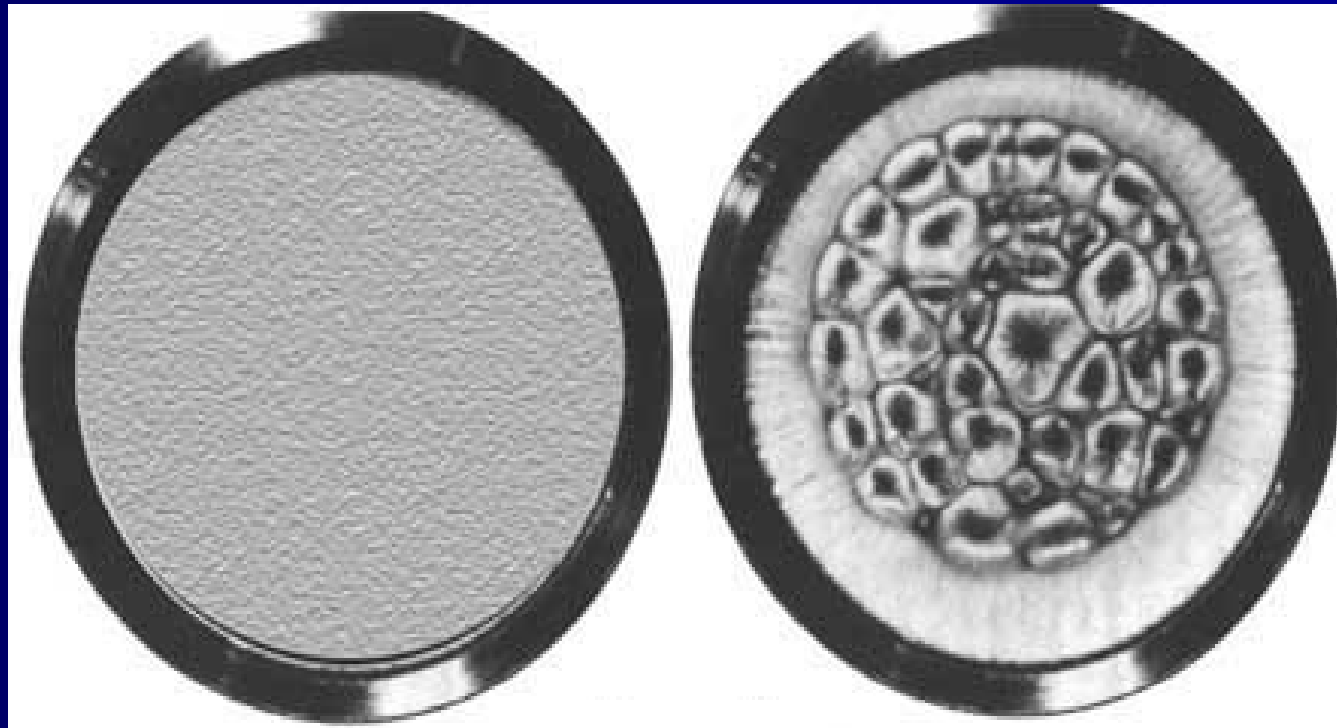
Jeff Conklin, PhD

AN HIERARCHICAL VIEW OF THERMODYNAMICS: TEACHING INTEGRATED VIEW FROM THE BEGINNING

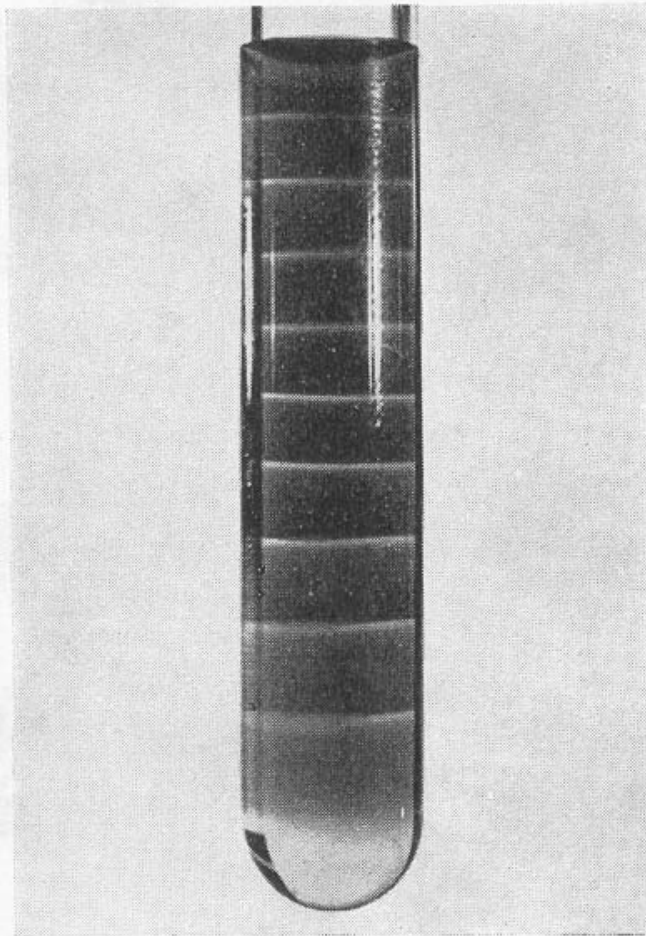
- **CLASSICAL THERMODYNAMICS** -equilibrium, closed, isolated systems
- **LINEAR NON EQUILIBRIUM THERMODYNAMICS**
– flows as linear functions of forces, valid in the neighborhood of equilibrium
- **FAR FROM EQUILIBRIUM** – dissipative structures, nonlinear, bifurcations, multiplicity of solutions, spacial and temporal order

FAR FROM EQUILIBRIUM SYSTEM, NONLINEAR SYSTEMS AS A SOURCE OF ORDER -I

DISSIPATIVE STRUCTURES
THEORY OF CREATION OF STRUCTURES, FAR FROM
EQUILIBRIUM –Bénard cells



FAR FROM EQUILIBRIUM SYSTEM AS A SOURCE OF ORDER-II



Dissipative structure in the Zhabotinski reaction

DISSIPATIVE STRUCTURE TORNADO, INDAIATUBA, SP





ECOLOGY

And God said: " Behold I have given you every herb yielding seed, which is in the surface of all the earth, and every tree, which is the fruit of a tree yielding seed,- to you it shall be for food , and to every beast of the earth, and to every fowl of the air, and to every thing that creepeth upon the earth, wherein there is a living soul, I have given every green herb for food " .

And it was so

Genesis

Cited by Morowitz, in " Energy flow in Biology ", Chapter Ecology. p102

ECOSYSTEMS: Self- Organizing ,Holarchic , Open (SOHO) Systems (Kay,2001). Open, Coherent, Purposive, Irreversible (PICO) Systems (Bittencourt ,2001)

The dynamics of ecosystems and human systems need to be addressed in the context of post-modern science grounded in complex systems thinking. We portray these systems as Self- Organizing Holarchic Open (SOHO) systems and interpret their behaviors and structures with reference to non-equilibrium thermodynamics...

Given the phenomena exhibited by SOHO systems, conventional science approaches to modelling and forecasting are inappropriate...

- We also link SOHO system descriptions to issues of human preferences and choices , and to the implications for achieving them through adaptive management ... and appropriate structures for governance (KAY)

PROPERTIES OF COMPLEX SYSTEMS WHEN THINKING ABOUT ECOSYSTEMS (BASED ON MAY,2000)

- **NON-LINEAR** - BEHAVE AS A WHOLE, IT IS A *SYSTEM* -NOT UNDERSTOOD BY DECOMPOSABLE INTO PIECES
- **HIERARCHICAL – HOLARCHICALLY NESTED** -SYSTEMS WITHIN A SYSTEM –RECIPROCATING CONTROLS
- **INTERNAL CAUSALITY** – NON-NEWTONIAN, NOT A MECHANISM , CHARACTERIZED BY GOALS (PURPOSIVE?) AUTOCATALYSIS, , SELF ORGANIZING, SURPRISES
- **WINDOW OF VITALITY** - A RANGE WITHIN WHICH SELF-ORGANIZATION CAN OCCUR. SYSTEM STRIVES FOR OPTIMUM, NOT MINIMUM OR MAXIMUM
- **MULTIPLE STEADY STATES** – MULTIPLE ATTRACTORS POSSIBLE, SYSTEM STATE A FUNCTION (ALSO) OF HISTORICAL EVENTS
- **CATASTROPHIC BEHAVIOR** – BIFURCATIONS (MOMENTS OF UNPREDICTABLE BEHAVIOR);FLIPS (SUDDEN DISCONTINUITIES , RAPID CHANGE) , SHIFTING STEADY STATES MOSAIC
- **CHAOTIC BEHAVIOR** - WE HAVE LIMITED ABILITY FOR PREDICTION (I. E., WEATHER FORECASTS) REGARDLESS OF HOW MUCH INFORMATION WE HAVE AND HOW SOPHISTICATED ARE OUR COMPUTERS

**ATTRIBUTES OF LIVING SYSTEMS THAT NEED
TO BE INTRODUCED TO STUDENTS
INVOLVING THERMODYNAMICS, MATH,
SYSTEMS**

**OPEN
IRREVERSIBLE
DYNAMIC
NON-LINEAR
COMPLEX
COHERENT
PURPOSIVE
ENDOWED WITH REPRODUCTION WITH
INVARIANCE
ADAPTATIVE**



ABOUT THERMODYNAMICS

FROM CLASSICAL TO IRREVERSIBLE

- Curricula traditionally emphasizes reversible processes in thermodynamics, linearity and continuity in mathematics, and economy is dominated by mechanistic models. Reductionism prevails
- " The majority of the phenomena studied in biology, meteorology, astrophysics, and other subjects are irreversible processes which take place outside the equilibrium state" , Prigogine
- Classical thermodynamics : "... once the second law is formulated, concentrates on the properties of system which have reached thermodynamic equilibrium ", Glansdorf and Prigogine , " "Particularly applicable to closed systems " Katchalsky

LIVING SYSTEMS



THE STRANGE OBJECTS OF JACQUES MONOD

JACQUES MONOD

"CHANCE AND NECESSITY"

STRANGE OBJECTS

- OBJECTS ENDOWED WITH A PURPOSE OR PROJECT
 - OBJECTIVITY LEADING TO SUBJECTIVITY

HIERARCHY OF SYSTEMS (BOULDING) GENERAL SYSTEMS THEORY (BERTALANFY)

- **Frameworks:** systems comprising static structures: atoms in a crystal
- **Clockworks:** simple dynamic systems with predetermined motions, such as the clock and the solar system.
- **Cybernetic systems:** systems capable of self-regulation in terms of some externally prescribed target or criterion: thermostat.
- **Open purposive systems:** capable of self-maintenance based on a throughput of resources from its environment, such as a living cell.
- **Blueprinted-growth systems:** containing preprogrammed instructions for development, the egg-chicken system.
- **Internal-image systems:** systems capable of a detailed awareness of the environment, image or knowledge as a whole: animals
- **Symbol-processing systems:** self-conscious, use language: humans

JACQUES MONOD

CHANCE AND NECESSITY - ON THE
NATURAL PHILOSOPHY OF MODERN BIOLOGY

THE NATURAL AND THE ARTIFICIAL

MARS – (NASA)



NATURAL IN MARS

MARS (NASA)



BEEHIVE -OBJECT ENDOWED WITH A PURPOSE OR PROJECT

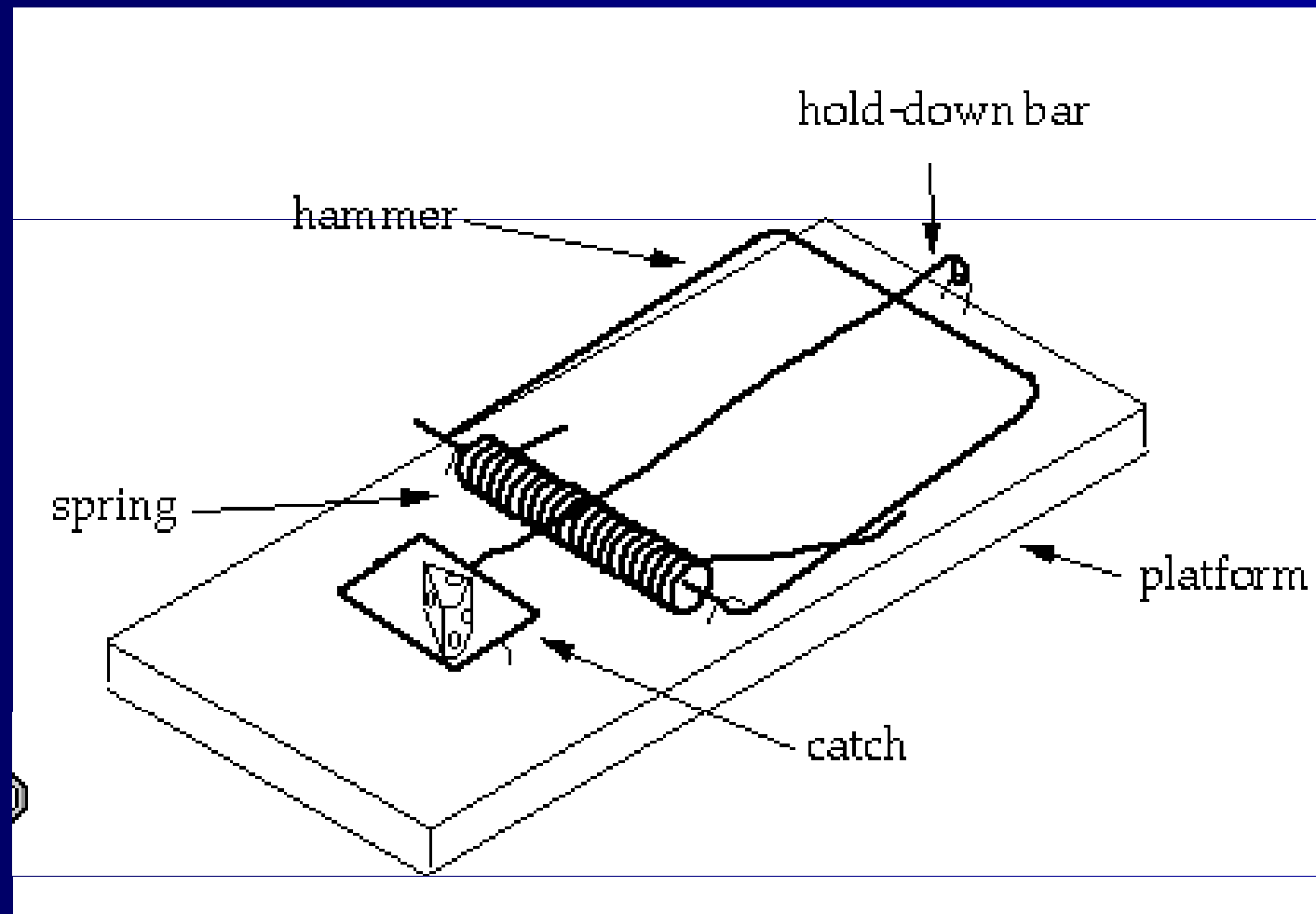


THE NATURAL OBJECT CLOUDS



MOUSETRAP: STRANGE OBJECT

RESULTS FROM ARTIFACT PRODUCING ACTIVITY ON EARTH



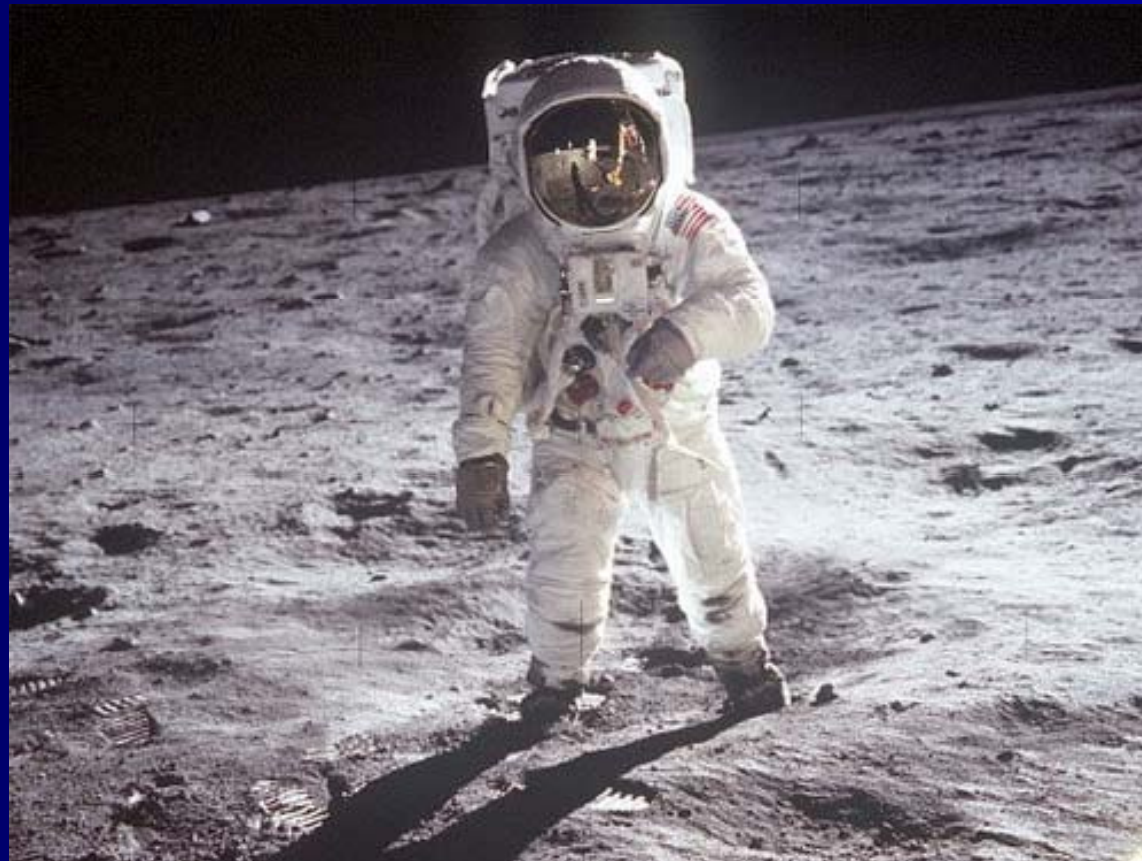
THE PURPOSIVE STRANGE OBJECT LEAF



© Stuart McKim

A PURPOSEFUL, STRANGE OBJECT IN THE MOON

SURROUNDED BY NATURAL OBJECTS-NASA



BIOLOGICAL SYSTEMS –JACQUES. MONOD*

ATTRIBUTES OF LIVING SYSTEMS

- REPRODUCTIVE INVARIANCE
- TELEONOMY
- AUTONOMOUS MORPHOGENESIS

*Chance and Necessity –On the natural philosophy of modern biology. Penguin Books, 1971

GEORGESCU ROEGEN

THE ENTROPY LAW AND THE ECONOMIC
PROCESS

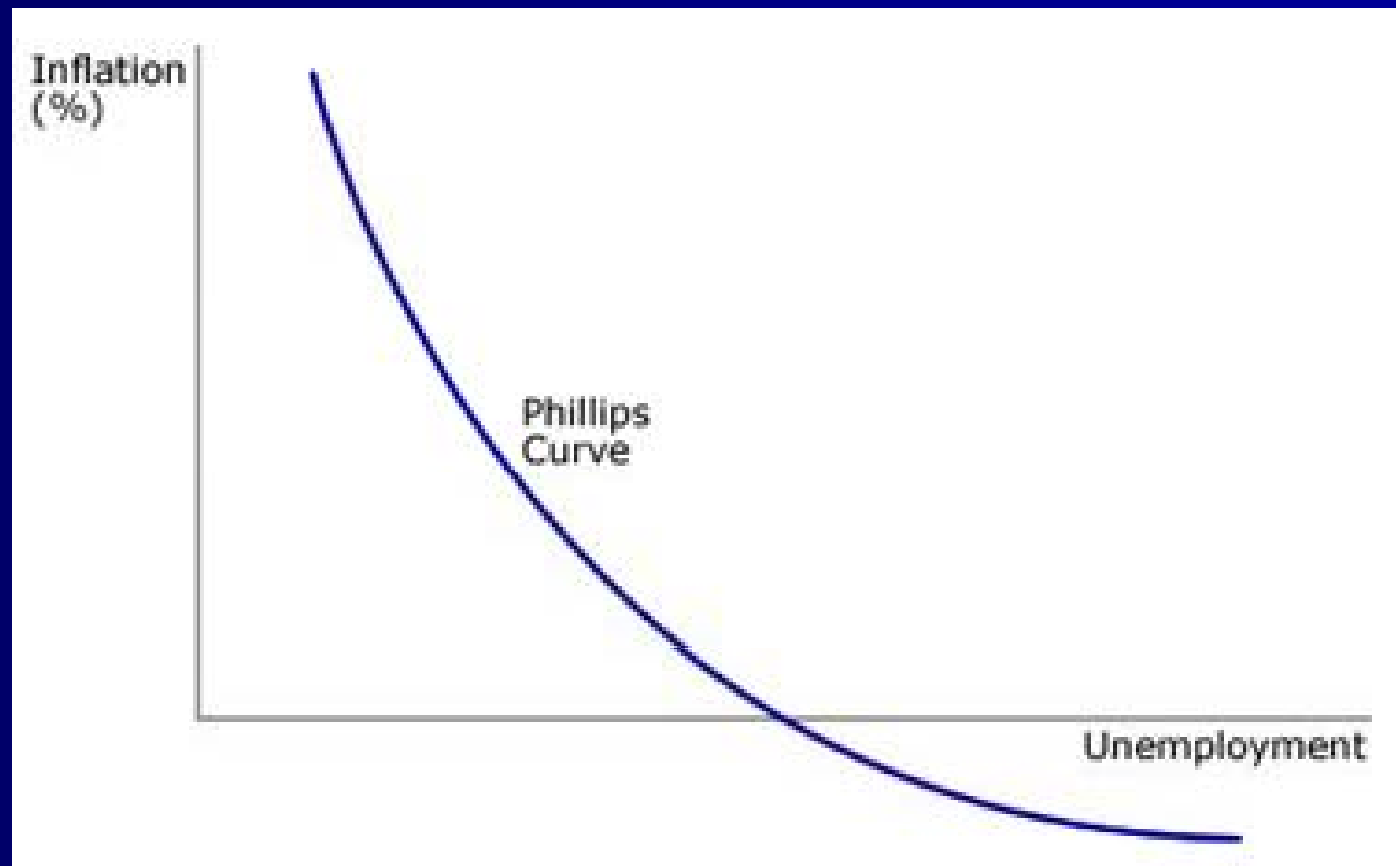
THERMODYNAMICS IN ECONOMICS, LIFE, ECOLOGY -"BIOLOGY AS THE MECCA FOR ECONOMICS"

- ECONOMISTS IGNORED THE ENTROPIC NATURE OF THE ECONOMIC PROCESS
- NOT EVEN WARS... FOUGHT THE CONTROL OF THE WORLD NATURAL RESOURCES AWOKED ECONOMISTS FROM THEIR SLUMBER (Georgescu-Roegen)
- ECONOMY SEEN AS A CIRCULAR FLOW BETWEEN PRODUCTION AND CONSUMPTION WITHOUT INLETS AND OUTLETS
- ENTROPY LAW REGARDED AS THE GREATEST TRANSFORMATION SUFFERED BY PHYSICS
- LIFE BEARING STRUCTURES MAINTAINED BY SUCKING LOW ENTROPY AND DISCHARGING AS HIGH ENTROPY
- PURPOSE, *CAUSA FINALIS*, PURPOSIVE ACTIVITY (Monod)
- BIOLOGY AS THE MECCA FOR ECONOMY
- IGNORING THE REAL NATURE OF ECONOMICS: RESULTS IN ENERGY CRISIS, POLLUTION
- * "The Entropy Law and the Economic Process ", Georgescu-Roegen, 1971

PAUL ORMEROD - A MORTE DA ECONOMIA

PHILLIPS CURVE

- INFLATION VERSUS UNEMPLOYEMENT



INFLATION AND UNEMPLOYMENT UNITED STATES DIFFERENT YEARS

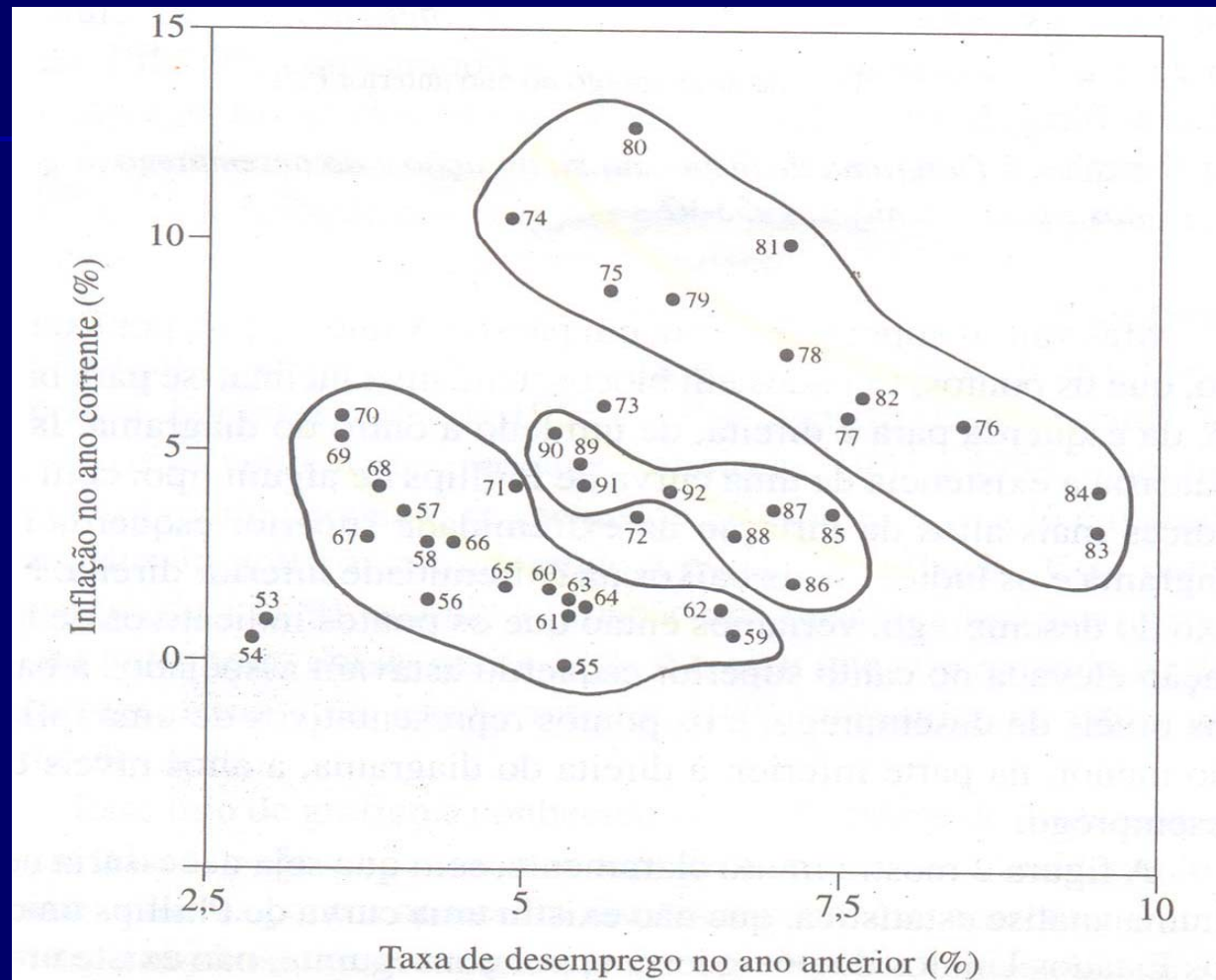
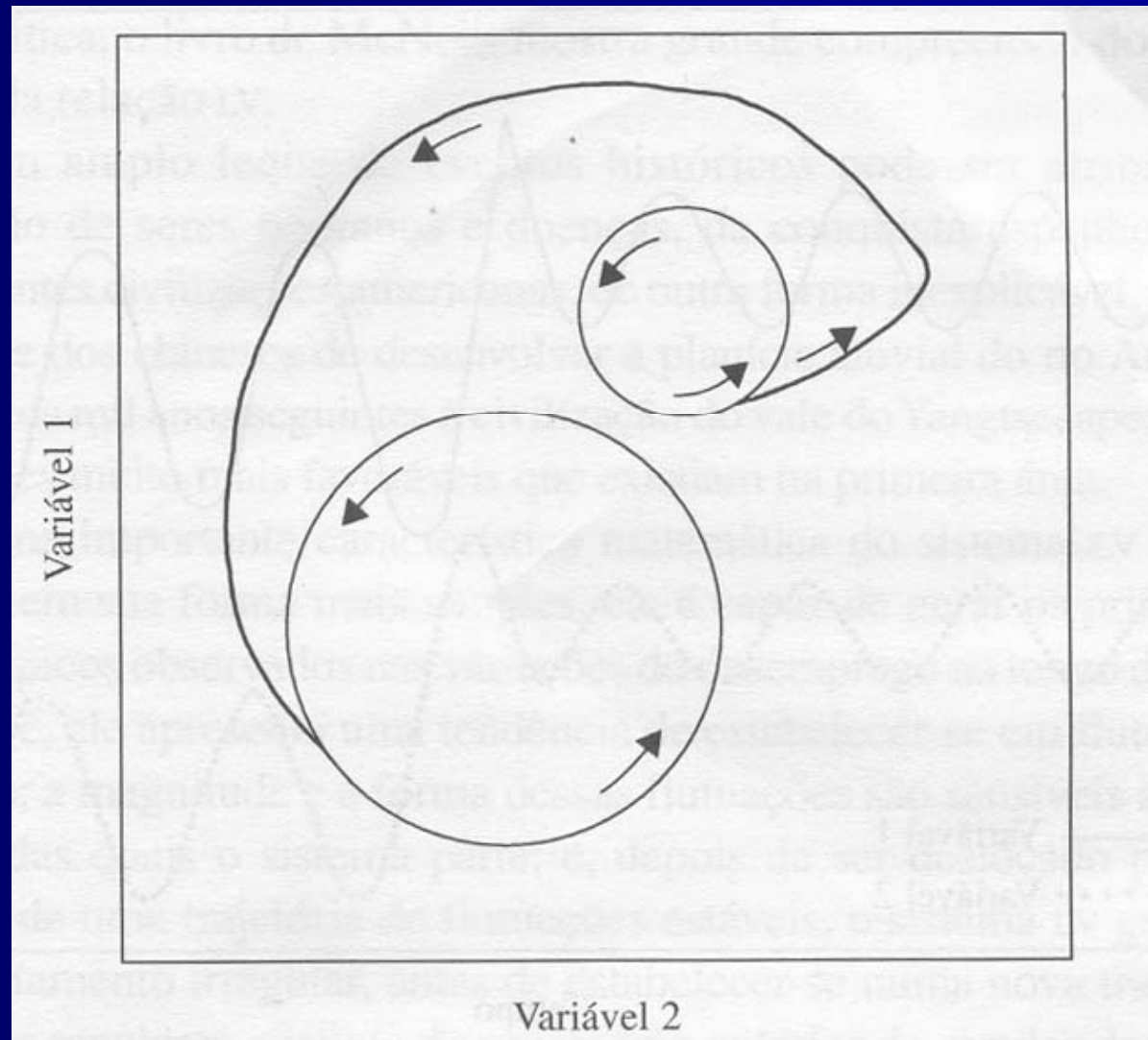


FIGURA 3 *Diagrama de dispersão da inflação e do desemprego nos Estados Unidos, 1953-92*

MODELO LOTKA-VOLTERRA MULTIPLE SOLUTIONS –MULTIPLE ATTRACTORS



ATTRACTORS

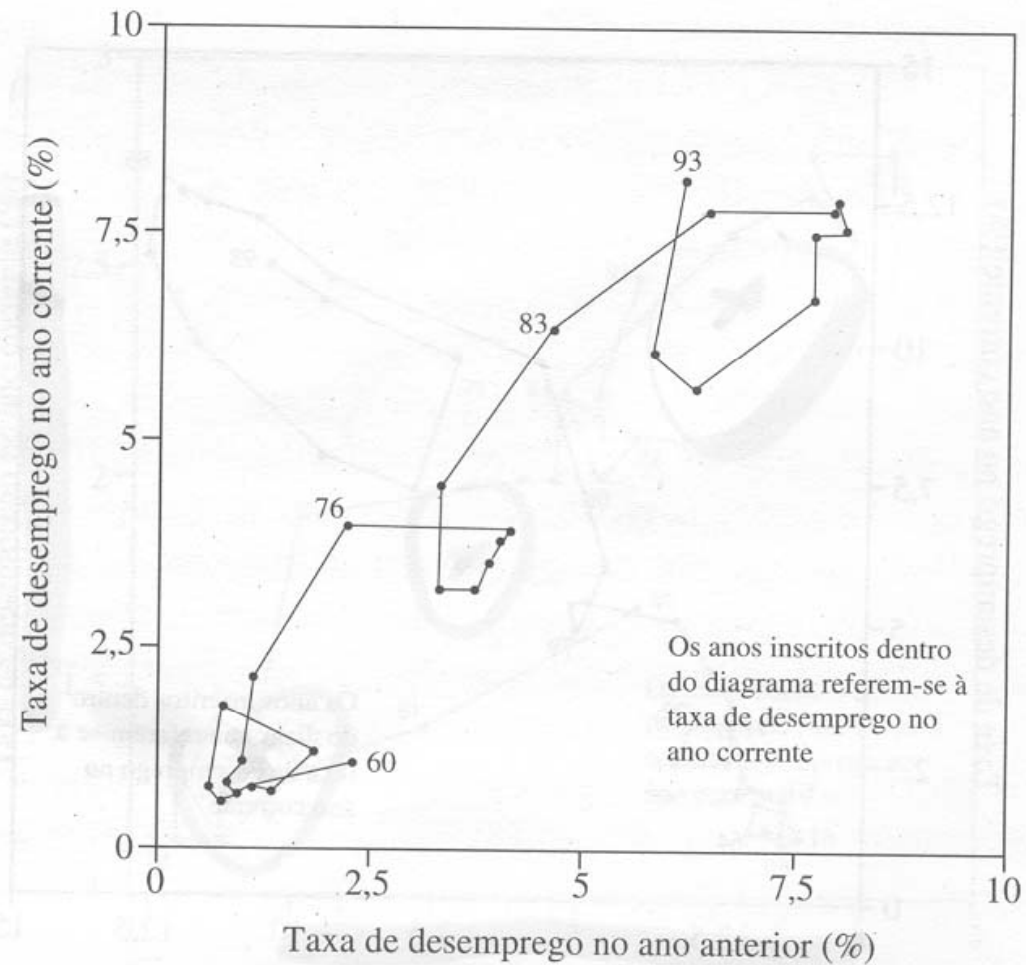
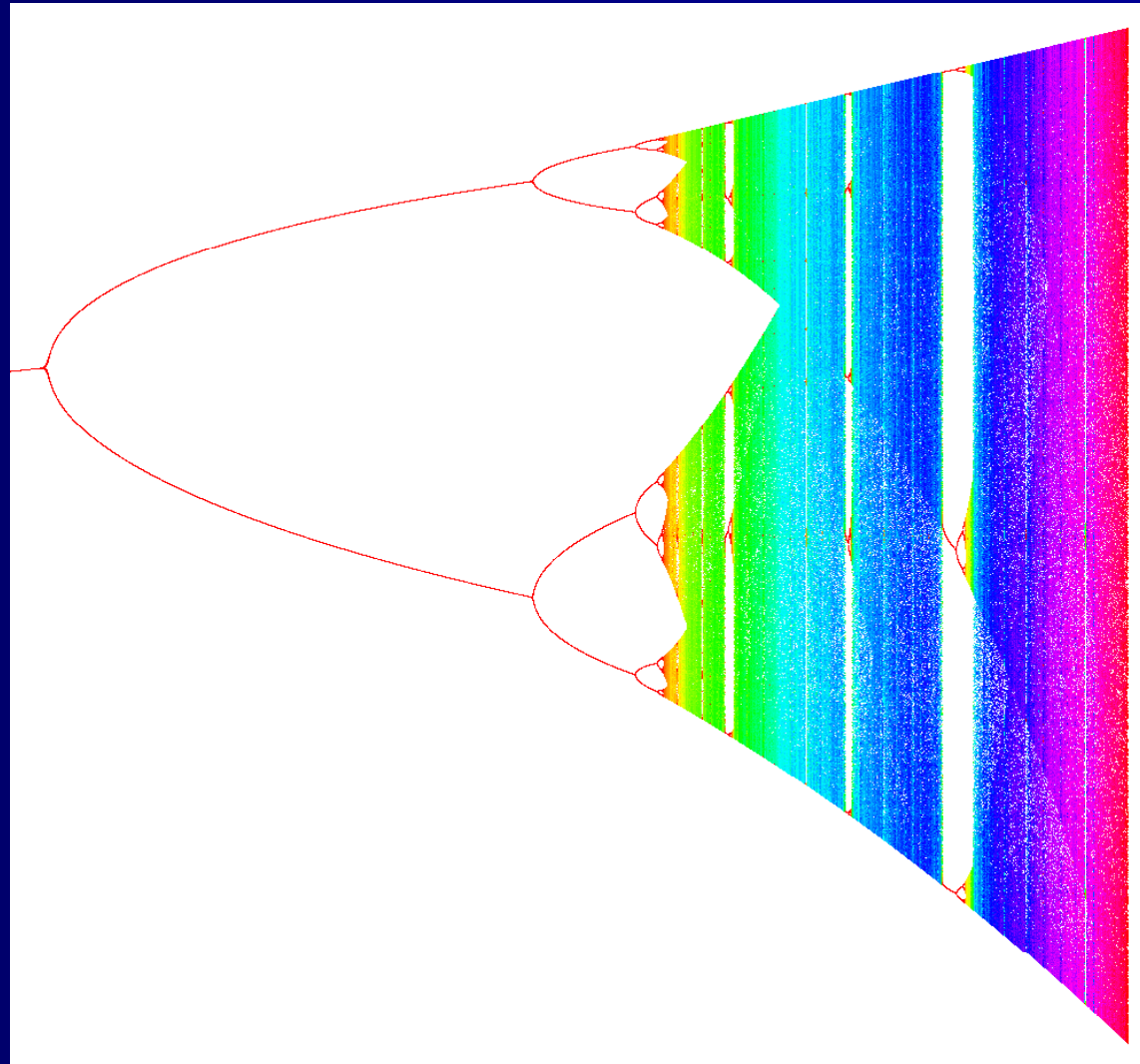


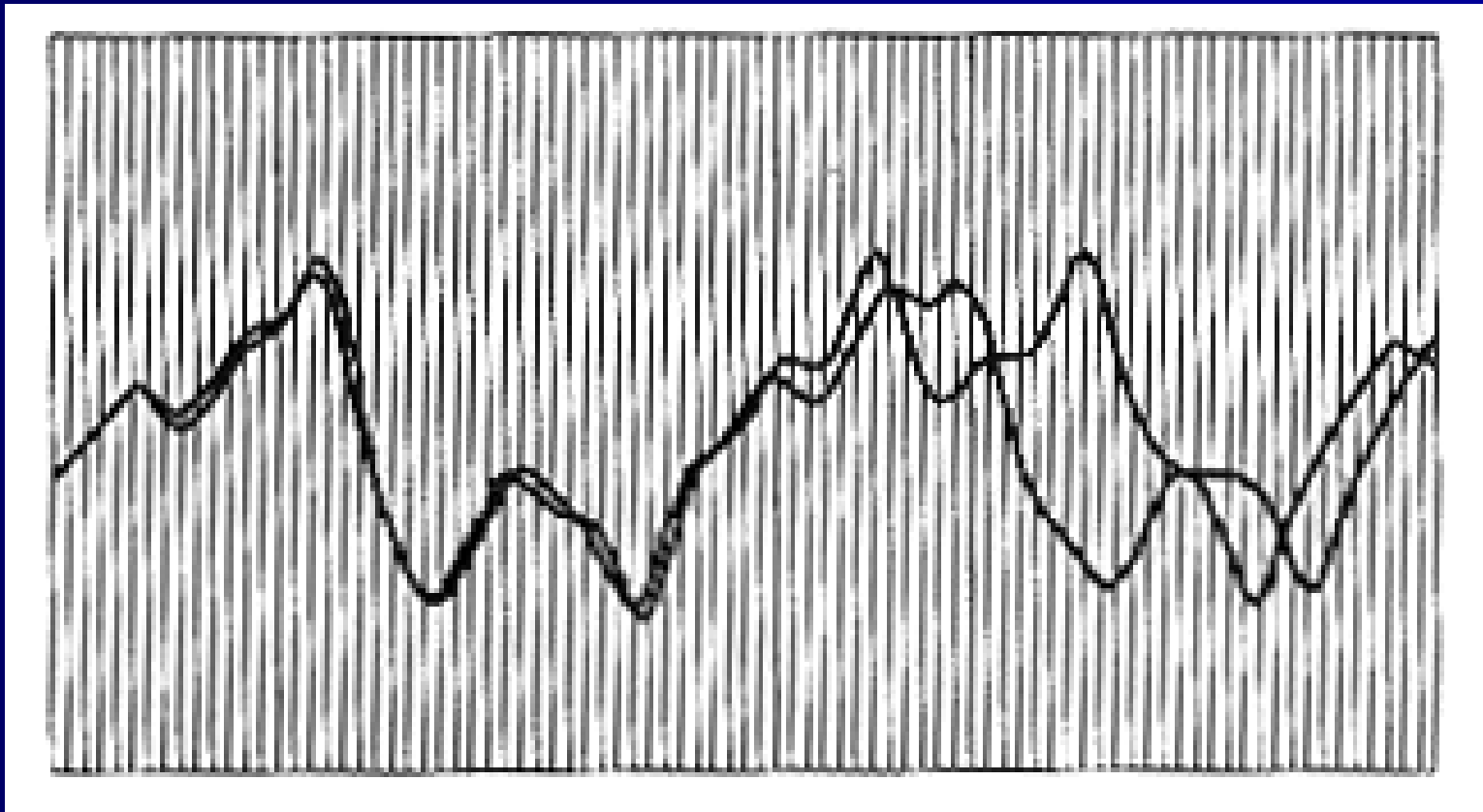
FIGURA 9A *Diagrama de dispersão conectada da taxa de desemprego na Alemanha, 1960-93*

BIFURCATIONS IN DYNAMIC NON-LINEAR EQUATIONS



Mathematics by Experiment and
Prigogine, Kauffman, Coveney, Gödel

SENSITIVITY TO INITIAL CONDITIONS- LORENZ "ACIDENTAL" DISCOVERY



-Lorenz error revealed the dependence on initial condition of a set of dynamic nonlinear equations by accident widely known, as reported in detail by Grace Conyers (2009)

- "...the utilization of advanced computing technology in mathematical research – is often called **experimental mathematics**"

- The mathematician will perform experiments like in a laboratory, as chemists and physicists do.
Experimental mathematics uses computation

Experimental mathematics uses computation for:

- * Gaining insight and intuition;
- * Discovering new patterns and relationships;
- * Using graphical displays to suggest underlying mathematical principles;
- * Testing conjectures; exploring a possible result to see if worth formal proof;
- * Suggesting approaches to formal proof;
- * Replacing lengthy derivations with computer-based derivations;
- * Confirming analytically derived results

Intensive use of visualization is essential

The evolution in the last 50 years established the need to incorporate a wide range of relatively new language, new terms, concepts, knowledge, some hardly or never mentioned in undergraduate teaching, and, most importantly, reaching from the hard sciences to humanities – the work of Prigogine builds this bridge.

Complexity and Political Structures

“Democracy may be far and away the best process to solve the complex problems of a complex evolving society, to find the peaks on the coevolutionary landscape where, on average, all have a chance to prosper”.

Kauffman

Peter Coveney and Roger Highfield (1995), mention *Gödel theorem*, stating that "...the logistic doctrine, according to which all mathematics may be deduced from the axioms of logic, was demonstrated to be incorrect". And quoting John Barrow (on page 28), say Coveney and Highfield (1995): "If we define a religion to be a system of thought which contains unprovable statements, so it contains an element of faith, Gödel has taught us not only is mathematics a religion able to prove itself to be one.

NEW SCIENCE: A NEW WORLDVIEW

Kathleen Gordon

Queensland Department of Education
Australia

in "TEACHING FOR A SUSTAINABLE WORLD:
INTERNATIONAL EDITION "

<

[http://www.environment.gov.au/education/publications/ts
w/modules/module10.html#oht2](http://www.environment.gov.au/education/publications/ts
w/modules/module10.html#oht2) >

"New science', sometimes called postmodern science, is the convergence of thermodynamics, quantum physics and chaos theory."

The Modern Scientific Paradigm

- . reductionism (seeing things only in terms of their mechanistic parts)

- . objectivism (claiming science and scientists are objective, neutral and unbiased)

- . determinism (asserting that time is reversible and thus all future events can be accurately predicted)

- . dualisms of mind/body, subject/object, humans/nature

The New Scientific Paradigm

- . **holism** (seeing all things as inter-connected and the whole being more than the sum of the parts)

- . a recognition that **science is subjective** and doesn't have all the answers

- . a belief that **time is irreversible and thus we can't predict future events**

- . a recognition of the **dynamic nature of the world**

- . a **valuing of diversity**

- . a realization that **resources** including energy **are finite and running down**

CONCLUDING

THE NEW ALLIANCE

-The emergence of 'new science' has become apparent with the publication of numerous articles and books and the appearance of many conferences and programmes on the topic

-Coined the 'new science' by Prigogine and Stengers in their revolutionary book, *Order Out of Chaos*, this trend is often referred to as postmodern science

-An historical period yet to be created - where human beings exist in harmonious relations with nature, each other and their own selves'

-The 'new science' has been defined as an ecological science, viewing nature, people and their relationships in an holistic manner.

-Proponents of holistic education view this movement '...from the mechanistic industrial age to a global, ecological age... as part of a larger transformation in western civilization'

...A theory is more impressive the greater is the simplicity of its premises, the more different are the kinds of things it relates and the more extended its range of applicability... It [thermodynamics] is the only physical theory of universal content which I am convinced, that within the framework of applicability of its basic concepts will never be overthrown.

(Einstein in Rifkin, 1989, p. 59)