James Madison University

Department of Geology
And Environmental Science

Syllabus - Geology 200

GenScience: Package D, Tier 2

http://www.jmu.edu/geology/evolutionarysystems/

EVOLUTIONARY SYSTEMS

Spring, 2002

SECTION NUMBER:	0001		
CREDIT HOURS:	03		
LECTURE:	Miller, Room 209, MW 1:25 -2:15 *(Lab/lecture sessions may switch)*		
Lab:	Miller, Room 224, F 1:25 -3:15 *(Lab/lecture sessions may switch)*		
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OFFICE HOURS:	MW 8-9; T/Th 8- 10		
FINAL EXAM:	Wednesday, May 1, 10:30-12:30		
TEXTS:	Notebook of Lecture Illustrations (JMU Copy Center) Notebook of Laboratory Experiments (Handed out each lab, but get a 3 ring notebook to store them in)		

THERE ARE THINGS ABOUT THE UNIVERSE WE DON'T UNDERSTAND

"Life is often complicated, sometimes exceedingly so. Much of our everyday experience is unexpected, apparently whimsical, seemingly beyond our control. On the other hand, we also commonly take for granted the long-term, reliable functioning of refrigerators, computers, and communication satellites. How is it that some aspects of our experience are regular, predictable, tamable, while others appear to be the outcomes of some cosmic game of chance? Is the universe a crazy patchwork of phenomena, some understandable, some beyond explanation? [1]

Most of intellectual and scientific history are attempts to bring order and predictability to a world seen as chaotic and ungovernable, subject to decay and discord. Ancient myths and epic poems are explorations of how a hero can overcome the dark forces of chaos and dissolution. For Socrates the important questions related to absolute equality, beauty, goodness, justice, and holiness; and the answers were not to be found in nature. For Plato ideal forms existed as an absolute and eternal reality of which the phenomena of the world are an imperfect and transitory reflection. Thomas Aquinas required a logical proof of God. Descarte and Newton tried to hold the universe together with mathematical and logical purity. And Einstein stated that God does not play dice with the universe.

Humans from the beginning have struggled to make sense of this sometime capricious universe, but for most of history we have been stunningly unable to do it. Even today there are powerful urges to keep the world from flying apart. Fundamentalist religion and absolutist regimes (whether political, or intellectual) with their rigid rules and intolerance for dissent are attempts to restrain what the believers experience as chaos.

Yet, throughout history the evidence all around is that the world is not under our control, and that security and predictability are an illusion. Exhibit some mundane examples, our attempts to predict the weather, and the stock market. Even with powerful computers and sophisticated intellectual tools these systems, one natural and one human, continue to defy our attempts to reign them in. Or, imagine a large city, like New York, or London, or Paris: millions of customers, tens of thousands of merchants, thousands of suppliers, all working more or less independently, each looking after their own selfish interests. The suppliers and merchants just want to make as much money as they can, as fast as they can. And the customers just want to buy what they want to buy when they want it, at the lowest price possible. And they can! The shelves are always full, and the prices are always low.

But how? Who is in charge? Who has organized this marvelous system?
The not so simple answer is, No One!

The truth is, until recently we have not had the means to explore and understand the world in all its complex and chaotic behavior. The shear number-crunching necessary was not available until the advent of computers. But clearly there is also a powerful psychological force working here. Fear of the unknown makes us feel weak and vulnerable, out of control, careening down a dark passage to oblivion.

Yes, the world is chaotic, but not as we once understood the term (*utter disorder and confusion*). And yes, the really interesting phenomena in this world (cities, economies, political systems, brains) are inherently unpredictable. But, where we used to think this chaos and unpredictability hovered precariously on the edge of dissolution and decay, we now understand that it instead lies as much if not more on the edge of creativity and wonder, of beauty. The purpose of this course is to explore this new, and relatively recent view, to come to understand those things we don't understand.

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[1] Chaos Under Control, 1994, The Art and Science of Complexity by David Peak, Michael Frame, Rhonda Roland Shearer, Benoit B. Mandelbrot: 408 pages, W H Freeman & Co.; ISBN: 0716724294 quote on p 1

WHAT IS EVOLUTIONARY SYSTEMS ALL ABOUT?

Nature of the Course Content

Evolutionary Systems are rooted in complex systems, complex systems are rooted in complexity theory, complexity theory is rooted in chaos theory, and chaos theory is rooted in non-equilibrium thermodynamics.

The study of Evolutionary Systems seeks to explain how complex system such as geochemical cycles, organisms, ecosystems, and economies organize, grow, and evolve by bottom-up processes; that is, without central planning or control.

The experimental methods include mathematical modeling in Artificial Life, SOC (self organized criticality), autocatalytic networks, and neural networks, among others. All of these are based on the computational viewpoint which argues that the behavior and evolution of complex systems cannot be deduced from first principles but must be discovered by watching the system evolve in real time.

The heart of the course is Robert May's population model $X_{next} = rX\ (1-X)$. This deceptively simple equation exhibits the most amazing and wonderful behavior and allows us to explore question such as, "What makes populations stabilize? What makes them fluctuate? Are populations in complex ecosystems more stable than populations in simple ecosystems?

Using a computer program that calculates X_{next} under any conditions, we come to understand that even simple systems may exhibit complex and unpredictable behavior. We also come to understand how to read the behavior of a system, to know when it is stable and boring, when it is poised to evolve in unpredictable ways, and when it is about to self destruct.

From this foundation the course uses a variety of other computer based models and experiments to systematically explore concepts such as local rules/global behavior, sensitive dependence on initial conditions (the butterfly effect), and emergent behavior (the whole is more than the sum of the parts).

Accompanying the experimental labs are lectures/discussions that explore the theoretical underpinnings of evolutionary systems, and their relationships to other phenomena, such as the chaotic behavior of a simple oscillator (the pendulum, or an electronic circuit), and the dynamics of oscillating chemical reactions, such as the BZ ((Belousov-Zhabotinsky) reaction.

The concepts we explore are not abstract and impractical, however, but have wide application to all branches of science as well as to everyday life. For example:

1. How complex patterns evolve out of originally disordered and chaotic patterns by applying simple rules. These studies have application to the origin of life, the functioning of the brain, and to most other complex evolutionary systems.
2. How natural selection evolves order from initially random conditions (the proverbial room full of monkeys with typewriters writing the Gettysburg address.)
3. Why natural selection by itself cannot explain the evolution of complex systems, whether they be life, a society, or an economy, and what other principles are operating to produce the complexity we observe.
4. How complex systems interact, compete, and mutually evolve using programs that exploring flocking behavior in birds, fish, etc., the behavior of electronic "ants" in computer-based ecosystems, as well as a number of other complex adaptive systems.
5. The course culminates by examining how chaos/complexity strategies can and have been used to explain the dynamics of cooperation and competition in interpersonal relationships, the marketplace, and public policy issues. The final issue is a demonstration that freedom, properly constrained by wise laws, is capable of producing the best outcomes.

THE GOALS OF EVOLUTIONARY SYSTEMS

The course has three interrelated goals. First, to develop in you the knowledge and experience to recognize any self-organizing, complex system for what it is when you see it, even if it is now "frozen in time." Second, to develop in you the knowledge and experience so you can observe any complex system - physical, chemical, biological, social, economic, etc. - and not only deduce the general rules by which it is operating but also be able to describe the modes and patterns of its behavior.

Third, to enable you to put your finger on the pulse of those systems, and deduce from their behavior their "r" value ("r" = rate of growth, or how hard the system is being pushed) at any point in time, and describe their resulting attractor state, potential for change, and the possible direction and predictability of that change.

To achieve these goals we spend the semester exploring both theoretically and practically a host of concepts central to complex evolutionary systems, including among others, a fresh definition of chaos (not *utter disorder and confusion*, but *a quantitative study of unstable aperiodic behavior in determinist nonlinear dynamical systems*), emergent behavior, bifurcations, avalanche behavior, sensitive dependence, local rules/global behavior, self organized criticality, and complex adaptive agents.

TEXTS

Each subject we examine this semester in Evolutionary Systems is an enormous subject all its own with entire books, or college courses devoted to it. In some areas you can even get a degree studying it. Plus, these higher degrees are spread across the disciplines: math, economics, biology, etc.

Hundreds of books have been written dealing with the subjects of chaos theory, complexity theory and evolutionary systems, including both general explorations and highly technical treatises. We have read and incorporated in this course ideas from many of these books, but none of these books by themselves make a good textbook. All of the books either explore a subject in more detail then we have time for, or they do not begin to explore the breadth of the subject matter we have in mind. During the semester we recommend many books to you as good explorations of some deeper aspect of what we are studying, but if you were to buy every book worth reading to understand evolutionary systems you would purchase a small library.

On the other hand, many of the subjects we work with are very visual, and judging with your educated eye is an important part of studying evolutionary systems. We have gathered these illustrations, as well as other materials, into a notebook reprinted by the JMU Copy Center. It is your primary text book.

For the laboratory portion of the course we have gathered a wide diversity of programs from many sources, and written lab guides to help you explore and understand the models the programs calculate out. These lab guides will eventually exist in a second notebook reprinted by the JMU Copy Center, but for this first semester the lab guides are handed out one experiment at a time. We recommend that you get a three ring notebook binder to keep them in.

THE IMPORTANCE OF A LAB

One of the core concepts of evolutionary systems is that the phenomena we are studying are incompressible. Or as Stuart Kauffman says, "*The theory of computation is replete with deep theorems. Among the most beautiful are those showing that, in most cases by far, there exists no shorter means of predicting what an algorithm will do than to simply execute it, observing the succession of actions and states as they unfold. The algorithm itself is its own shortest description.*"

Or, simply, you have to see it, you have to experience it, to understand it and to know it. More, you have to experience it many times to come to understand its range of variability, because commonly the "answer" is not quantitative but qualitative. This is because these systems are inherently sensitive dependent, slight changes in the initial conditions result in a markedly different evolutionary trajectory of the system. Thus, what we have to learn and understand is to evaluate the different behaviors of the system and find what is common to them.

Experimenting with the models in computer simulations is the only way to do that. Therefore, a major requirement of the course is that every laboratory experiment must be completed in order to receive credit for the course.

EVOLUTIONARY SYSTEMS REQUIREMENTS, EXAMS AND GRADING

Course work includes a mid-term exam, a final exam, writing assignments of various sizes and types (but mostly short), participation in discussions/seminars, and completion of computer experiments.

GRADING:

There are two lecture exams, the second being the final. Grading is based upon the following schedule. Because this course is actively developing the system below may change, but any changes will be discussed with the class and decided by majority vote.

- Midterm: Principles of Chaos/Complexity . . . . 30 %
- Final: Evolutionary Systems . . . . 30 %
- Writing Assignments *(in class, our of class, large and small)* . . . . 20 %
- Laboratory Summaries . . . . 20 %

100%

MIDTERM: The midterm evaluates your understanding of basic concepts in chaos/complexity theory. It is computer graded and consists of multiple choice and True/False questions dealing with understanding of definitions, concepts, and the great variety of charts, diagrams, and graphs used to illustrate or demonstrate these phenomena. A study guide is provided to prepare for the test.

FINAL: The final deals with the application of chaos/complexity principles to evolutionary systems - such as biological evolution, economic systems, social systems, the Prisoner's Dilemma, etc. It will be principally essay in format. A study guide is provided.

WRITING ASSIGNMENTS: A wide diversity of generally short writing assignments occur throughout the semester. Their purpose is to clarify concepts, or solidify you understanding of concepts, or give you practice thinking about a certain type of problem. Each of these is graded individually. At the end of the semester total points are calculated and a curve drawn on those points. Since these exercises are meant more for practice and gaining insight rather than evaluating your knowledge the curve is generous. The requirement of the course is that all these be completed before the final exam is taken.

LABORATORY SUMMARIES: There are two purposes for the laboratory summaries. One, to evaluate the experiment itself and how well it works. Two, to evaluate your understanding of the principles behind the experiment. The purpose here is more for us to keep our finger on the pulse of your understanding than to evaluate your performance. At the end of the semester total points are calculated and a curve drawn on those points. The curve is generous. The requirement of the course is that all these be completed before the final exam is taken.

FINAL GRADES **-** Final grades are based on the percent scale, with plus and minus grades distributed as follows:

97-100 = A+	87- 89 = B+	77- 79 = C+	67-69 = D+
94- 96 = A	84- 86 = B	74- 76 = C	60-66 = D
90- 93 = A -	80- 83 = B -	70- 73 = C -	NO D- GRADES EXIST