Study Guide # 1: 2002 Version

The Origins of Order

(The Search for Meaning and Evolutionary Processes)

GenSci 102 - Environment Earth
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Topics to Be Covered and General Objectives:

The universe we live in is a mysterious and wondrous place, and from our beginnings we humans have hungered to understand it.

What stories we tell ourselves,
Of origins and endings,
Of form and transformation,
Of gods, the word, and law.

All people, at all times,
Must have created
Myths and stories to sketch
A picture of our place under the sun.

Any survey of the histories of the world's peoples, past and present, show that we have been richly inventive with the myths of our beginnings, and the searchings for some meaning to it all. They are the imaginative fabrics which give significance to our lives, bind societies together, and make us human.

But a problem lies at the core of beliefs, for they quickly evolve from tentative attempts to satisfy our curiosity to assuming the trappings of absolute Truths. They become the beliefs that not only bind us together, but tear us apart too into warring factions, a certain sign of just how much we need our beliefs, and how important they are to us. (Of course, the beliefs of others are "myths"; our beliefs are the Truth.)

We believed ourselves to be at the center of the universe.

But millennia by millennia, and century by century our most sacred beliefs have had to face the onslaught of new ideas and theories, from which we perpetually recoil, regroup, and come forward again. A sign of our resiliency, if not our sensibleness.

For some, the worst of these onslaughts is science. Yet science has not always been the antithesis of mystery and faith. From the 15th through the 18th centuries the discoveries of science were the handmaid of Christianity, giving insights into God's mind at work. But still, many discoveries are discomforting, and caused a lot of soul searching and reevaluation of the dogma of belief.

But somewhere along our path, paradise has been lost,
Not to sin, but to science.
The story of our loss of paradise is familiar:
Copernicus, Galileo and Kepler, Newton, Darwin.

Copernicus, Galileo, and Kepler were bad enough, removing the earth from the center of the solar system, and demonstrating that Plato's world of perfect circles was not the real world. And Newton created a completely mechanical world, even if it did come from the mind of God. But in the 19th century it really began to unravel as the early geologists confronted the Biblical myths of Genesis and Western civilization as an explanation for the earth (the earth was created 6000 years ago, in six days, and fossils were artifacts of the Devil to tempt man into sin.)

And then from among their number comes Darwin, who questioned the very uniqueness of man at the center of God's universe. And into the 20th century it has not gotten any better. Some think that science (and if truth be told, mathematics) has systematically removed the sacred and mysterious from the world.

Yet, a spiritual hunger remains, and the central issue
We face is to reinvent the sacred.

The hunger to know does not and will not go away. It is one of the most central features of what it means to be human. And the onslaught of new, and often disturbing ideas will not stop. It is the outcome of that curiosity that needs to know. That is also what it is to be human. At best we can learn, as we have in the past, to adapt.

Where then, does this order come from,
This teaming life I see from my window?
The order is not accidental, and vast veins
Of spontaneous order lie at hand.

Stuart Kauffman

But where then does this order come from? Why, and how do we live in this marvelous, sometimes frightening, and always mysterious universe? Can science offer no explanations for this order, *"this teaming life I see from my window?"*

The problems of understanding are formidable, and the tasks that lay before us are numerous. Science cannot offer magic, or the supernatural, but it does advance ideas so deeply mysterious we could not have imagined them. And we are beginning to find explanations. Spontaneous order does lie at hand.

Prospectus

Our earth, what we see, what we live on, what we have to study, is the result of cyclical transformations of Matter by the dissipation of Energy. The earth is an ***open system***; that is, energy of many kinds continuously passes through the matter of which it is made and transforms that matter into the earth, the sky, and the life teeming on it. Beginning with the simple, the world has become ever more elaborate and complex with time, often in ways which still seem mysterious. But our abilities in the past to find explanations were hobbled by the need for determinism, the need to have complete explanation and predictability, the conviction that there did exist a God's eye view we could attain. But the universe ***is*** much more mysterious than that, and will not yield to our child-like needs to have complete control and explanation.

Yet, if we cannot have complete control, what we are discovering through the study of chaos and complexity theories and the open systems of universe is that they are spontaneously self-evolutionary - producing *"order for free"* as Stuart Kauffman says. What we are discovering is that deep general laws of evolution exist which apply to all open systems: physical, chemical, and biological. Evolutionary processes consist of three components:

- Processes of ***self-organization*** where "adaptive systems" spontaneously arise out of the chaos in an open system.
- (Natural) ***Selection*** of the adaptive systems, where they "compete" with each other on "adaptive landscapes" to find the optimum solution to the existing conditions.
- And, ***Historical accident (contingency)***, where what has already evolved constrains what can evolve in the future.

Furthermore, we discover that not only do adaptive systems evolve, but the structure of the landscapes they explore also evolves.

Our task this semester is to explore these systems and the principles behind them and construct a plausible history of the earth and life on it from their origins to the present. This will take us the entire semester, but we begin with an exploration of two themes:

- The human need to explain the origins of things, from ancient mythology to modern science, and:
- The principles of non-equilibrium thermodynamic systems (chaos and complexity theory) that help us find answers to such questions.

Topics to Be Covered

- The origins of myths in the human brain, and how those myths make us so human.
- The kinds of "truth" and their historical origins.
- The scientific strategy for finding "truth."
- Open and closed thermodynamic systems and their behavior.
- Chaos and Complexity theory.
- Biological evolution as an example of the application of Chaos/Complexity theory to evolutionary systems.

I hope you gain an appreciation for the human and scientific struggle to understand and make sense of this planet we live on. I hope you also gain an appreciation for the processes of spontaneous

self-organization and evolution which characterize the universe, and of the fundamental order which has emerged from that.

On the exam you should be able to demonstrate your understanding of these principles by providing answers to the questions below. On a test you may be asked to demonstrate your understanding either in short answers or short essays to specific questions, the interpretation of charts or diagrams, or the solution of critical reasoning problems; see the syllabus for further information on the tests. Note that in a test question two or more of these may be combined in one question.

Note that these guides are often stated as if you should be able to do something, write something, explain something. This is in fact a good way to study. If you can understand these ideas well enough to explain them, as if to someone else if not yourself, then you will do ok. Also, remember that test questions commonly ask you to identify, recognize, or interpret diagrams and illustrations in the Lecture Notebook.

SPECIFICALLY YOU SHOULD BE ABLE TO:

THE INTELLECTUAL FRAMEWORK

1. Describe the cognitive imperative:
   - ” What it is?
   - ” Why it is important?
   - ” What are the ways it can be satisfied?

2. Describe what a myth is (as myth holders use and understand the term), and the purpose it serves.

3. Describe the location of each of d’Aquili’s neural operators in the brain, and how they process information.
   - ” How does the left hemisphere of the brain (esp. the binary and value operators) analyze the problem the myth presents?
   - ” How does the right hemisphere (holistic operator) solve the problem of the myth?
   - ” What is the role of the limbic system in the myth process?

3. Campair and contrast the differences among mythical truth, empirical truth, and analytical truth, giving examples or demonstrations of how each kind of "truth" is confirmed true.
   - ” Be able to explain the forms of deductive logic we explored (dialectic and syllogism).

4. Compare and contrast in writing Platonism [Idealism] and Aristotelianism [Empiricism] in human thought processes, and describe their origins historically, provide illustrating examples, and explain their relationships to mythical, empirical, and analytical truths.

5. Be able to briefly describe the contributions made by St. Augustine, St. Thomas Aquinas, Francis Bacon, Rene Descartes, and Isaac Newton to the human search for truth.

6. Describe and explain the flaws of induction as laid out by David Hume.

7. Describe and explain the flaws of deduction (the syllogism), distinguishing between validity and truth, with cogent examples.

8. Briefly recognize by name, and describe the four ways in which 20th century science has undermined our ability to find Truth (capital **T**).

THE SCIENTIFIC METHOD

The traditional view of science is that it describes things truthfully, that the criteria for a scientific theory is its truthfulness. Yet that is what Karl Popper said was exactly the problem.

9. Describe Karl Popper's criticisms of "verification" and truthfulness as the criteria for the validity of a scientific theory.

10. Diagram the "To and Fro" model of science [derived from work of Jacob Bronowski and Karl Popper] and/or be able to explain any step in the model.

11. Why is scientific truth *[though flawed]* preferable to empirical *[inductive]* or analytical *[deductive] [not to mention mythical]* truth alone. That is, what are the weaknesses mythology, and inductive and deductive logic.

12. Models: One of the essential tools of science is the use of models. In terms a layperson would understand, define or describe what a scientific model is, what they might look like or what form they might take, and why they are valuable.

13. Describe the differences between "top-down" strategies and "bottom-up" strategies for investigating the world. How do they fit into the "To and Fro" model of Bronowski?

THE PROBLEM OF PROBLEMS AND THE 2ND LAW

14. Describe the "problem of problems" and its relation to the 2nd law.

15. Describe the core positions of Vitalism, Finalism, and Naturalism.

16. Define, describe the meaning of, apply, or give or recognize pertinent examples of the terms in the table below [listed alphabetically]. Or be able to use these terms meaningfully in other descriptions outlined below [See "A Glossary of Terms and Concepts Associated with Non-Equilibrium Thermodynamic Systems"]

” Closed System	” Non-equilibrium thermodynamics
” Determinism	” Open [dissipative] System
” Dissipative Structure	” Positive Feedback
” Entropy	” Recursive
” Linear/Non-linear	” Self Referencing
” Negative Feedback	” Stratified Stability

CHAOS AND COMPLEXITY THEORIES

17. Chaos Theory #1: One definition of chaos theory we used was ***"The quantitative study of unstable aperiodic behavior in deterministic nonlinear dynamical systems."*** Be able to take this definition apart and describe the meaning of each component, and then put it back together again to explain what it all means to someone unfamiliar with it.

18. Describe what the ***computational viewpoint*** is, why it is necessary, and why it is important.

19. **Chaos Theory #2:** A second definition of chaos theory we used was the equation $X_{next} = r X (1-X)$. Be able to describe or diagram how this equation illustrates and defines chaos theory, or be able to answer questions about this equation or its graphic output using the following the terms and concepts [listed alphabetically] in the table below, or, where appropriate, those in the above table. [See ***"The Period Doubling Route to Chaos"***, and others.]

20. Define, describe, explain, or illustrate the meaning of the terms in the table below [listed alphabetically], giving pertinent examples. Or be able to use these terms meaningfully in other descriptions.

” Bifurcation [diagram]	” Local Rules/Global Behavior
” Edge of chaos	” Period Doubling
” Emergent property	” Self Referencing
” Iteration (Iterated)	” Sensitive dependence on initial conditions (butterfly effect)

21. The concept of bifurcation is especially important in understanding complex systems. Describe, explain, apply, or recognize an example of the concept.

22. **Attractors:** Strange and Otherwise:
    - ” In mathematical terms, describe what an attractor is, including a definition or drawing illustrating a phase space.
    - ” Describe, define, illustrate, recognize, and give examples of Fixed Point, Limit Cycle, and Strange attractors.
    - ” Describe in terms a lay person would understand what makes a Strange attractor strange.
    - ” In vernacular (non-mathematical) terms, describe what an attractor is and give or recognize any example.

24. **Complexity Theory:** like chaos theory, has many definitions or descriptions. We used two.
    - ” Describe how complexity theory is related to chaos theory, including its relationships to the $X_{next} = r X (1-X)$ equation and bifurcation diagrams.

25. **SOC Systems** (Self Organized Criticiality): Self Organized Criticality is Per Bak's term for the phenomena of complex systems (a.k.a. complexity theory). The terms below describe some of the behavior or properties of complex systems. Be able to define or apply any of them.

” Adaptive Landscape	” One-Over-F (1/*f*) noise
” Complex Adaptive Agent	” Power Law Distribution
” Avalanche behavior	” Universality
” Fitness Landscape	” White Noise

26. Describe ***Euclidean geometry***. Describe ***fractal geometry***. Explain in ways a layperson would understand the most salient distinguishing features between them. Or, be able to recognize an example of an Euclidean figure and a fractal figure.
    - ” Recognize or list some examples of phenomena that exhibit fractal geometry.

ARTIFICIAL LIFE AND CELLULAR AUTOMATA

The study of Artificial Life (or Alife) is a branch of research that works to discover basic principles of life by creating computer-based "life" on which experiments can be easily conducted. Alife systems include cellular automata, genetic algorithms, and artificial neural networks. It is a large, diverse, and rapidly expanding field of study that includes studies in artificial intelligence, the function of social systems, economic systems, political systems, etc. Cellular automata are the most basic Alife systems and so we use them to understand the principles of Local Rules/Global Behavior, self organization, and information flow and its affect on an open system.

27. In terms a layperson would understand, describe or explain what a ***cellular automata*** is.

28. Given a set of rules and a CA grid with starting conditions, be able to calculate a two dimensional cellular automata (on a test this will probably show up as a set already calculated; you will just have to decide if the given outcomes are the correct ones.)

29. In terms a layperson would understand, describe or explain the relationships which exist between information flow and the emergence of complex or interesting patterns in cellular automata.

30. The principles developed above indicate that evolution has three components:
    - Ø Processes of ***Self-Organization*** where “Adaptive Systems” spontaneously arise out of the chaos in an open system.
    - Ù (Natural) ***Selection*** of the adaptive systems, where they “compete” with each other on “Adaptive Landscapes” to find the optimum solution to the existing conditions.
    - Ú And, ***Historical Accident***, or ***Contingency*** where what has already evolved constrains what can evolve in the future.

    You should be able to take points Ø and Ù above and present a convincing argument, in terms a layperson would understand, what they are saying, and the mechanisms, principles, and processes by which they come about. (Point Ú will be dealt with later.)

BIOLOGICAL EVOLUTION AS A DISSIPATIVE STRUCTURE

The record of life is fractal. That is, now matter how much we enlarge the record, no matter how close we look at it, the degree of intricacy and detail remains the same - it never gets simpler. And if the record is fractal then the theory which explains it must be capable of generating those fractal patterns. These theories are Chaos and Complexity.

Our primary focus in this class will be on the physical evolution of the earth, and its relationships to the atmosphere and life - not to the evolution of life . But we need to apply these principles to some system we are familiar with already to see how to apply it. Most of us have more knowledge of biological evolution than planetary evolution, and it will be the easiest to apply there. So we begin with an examination of the principles of chaos and complexity theory applied to biological evolution.

28. Describe, or recognize illustrations of, a few ways that the record of life is fractal.

29. **Darwin** and evolution by means of natural selection.
    1 Write a statement describing Darwin's theory of natural selection.
    2 Be able to identify the statements of positive and negative feedback in the quote from the Origin of Species.
    3 Draw or recognize a diagram illustrating Darwin's evolutionary theory of natural selection. [See "Natural Selection and Gradualistic Evolutionary Models"].
    4 Explain sympatric speciation.

30. The **Modern Synthesis:** Present a model explaining the evolutionary process according to the Modern Synthesis. Include the following concepts. [See *"Founder Populations and the Allopatric Speciation Model"*]

” Allopatric speciation	” Genetic drift
” Founder effect	” Stasis

31. Diagram and explain how the diversity, complexity, and specialization of life increases from a single founder species [See *"Allopatric Models for the Evolution of Species and Clades. . "*]

32. In terms of modern evolutionary theory explain how the flow of information (and energy) can increase and decrease during speciation events.

33. Relate positive and negative feedback mechanisms from chaos theory to biological processes by illustrating and explaining the meaning of positive and negative feedback in the following [you should be able to sketch and label these diagrams].
    - The bifurcation diagram.
    - The logistic equation $X_{next} = r X [1-X]$ and its relationship to biological positive and negative feedback [see "Relationship Between Positive and Negative Feedback . . ."].
    - The flow of information in a reproducing species [see *"Applying Complexity Theory to the Allopatric Speciation Model"*]

34. Given the ***Turnover Pulse Hypothesis*** of Elizabeth Vrba, be able to identify which steps represent positive feedback and which negative. Be able to explain why.