Chaos/Complex Systems Theory Learning Progression

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Imagine a Freshman, non-science, general education student. How do we introduce them to chaos and complex systems theories, . . . in 3 to 5 classes; in a way they really get it, and can use the principles to understand real systems? This is what this learning progression is about.

The human mind is built to think in terms of narratives, or stories. Chaos/complex systems theories are such narratives. They are not a series of unconnected or disconnected equations or models. If we present our students with a complex system. but do not systematically develop the narrative that holds it together, or makes sense of how all the pieces are interrelated, their ability to understand it will be hindered.

Over the past 10 to 15 years we have experimented with and developed a variety of narratives or rubrics that systematically introduce the three mechanisms of evolution and chaos/complex systems ranging from short several day stints like this here, to semester long treatises. They are developed in a specific order to achieve specific ends of understanding.

The learning progression to the right are a series of 12 models leading to 19 learning outcomes that encompass most of the universality properties that characterize chaos/complex systems. We do not necessarily use all the models in all the classes, but pick and choose what works best for the time available and the goals of the class. It is the progress on that that is important more than the specific models chosen to illustrate the principles.

Chaos theory studies why and how the behavior of simple systems — simple algorithms — become more complex and unpredictable as the energy/information the system dissipates increases. Complex systems theory studies how systems with many agents ("agent" refers to the individual units that are interacting, like birds in a flock, sand grains in a ripple, or the individual units of friction along a fault zone) that are already at high energy/information dissipation interact and behave. Complex systems possess virtually all the properties of chaos systems, which is why we study them first, but add their own properties and behaviors.

What complexity theory demonstrates is that, by following simple rules, all the agents end up coordinating their behavior so that what emerges is not vernacular chaos, but deterministic chaos.

Complex systems are commonly described as self-organizing, and although many are, self-organization is not the only way complex systems behave. A natural outcome of the dynamics of complex systems is that, beginning with a random or chaotic initial condition, the system increase in complexity, diversity, order, and/or interconnectedness with time—that is, it evolves. There are, however, three distinct mechanisms by which this evolution takes place: self-organization, elaboration, and fractionation. The development of the complexity principles in the learning progression are aligned with these three mechanisms, with a different set of models to explore the strategies of each.

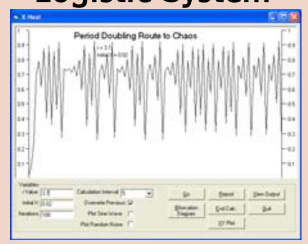
The strategies and rubrics laid out here are only an introduction to complex systems thinking and modeling. Depending on the goals of a course, the learning objective can be applied to an understanding of many other complex systems, such as oscillating chemical reactions (reaction-diffusion and activator-inhibitor systems), autocatalytic networks, hysteresis (bistable) systems, network theory, the rise and collapse of complex societies, and economic collapses. We use these and other complex systems concepts in various classes to talk about the origin of life, ecosystem organization, game theory, extinction events, rise and collapse of complex cultures, and a variety of other systems. The applications are almost endless.

Detailed rubrics at:
http://www.jmu.edu/geology/ComplexEvolutionarySystems/

Chaos Theory

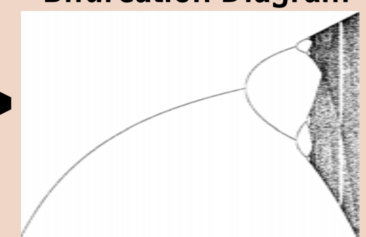
Chaos Theory (a.k.a. deterministic chaos) specifically studies why and how the behavior of simple systems—simple algorithms—becomes more complex and unpredictable as the energy/information the system dissipates increases.

Logistic System



1. Computational Viewpoint
2. Positive/Negative Feedback
3. 'r' Values
4. Deterministic is not Predictable

Bifurcation Diagram



5. Bifurcation = change in behavior
6. Instability increases with 'r'.

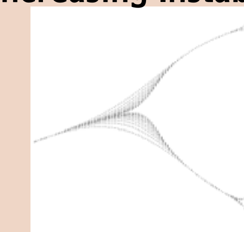
Self-Similarity/Fractals

7. Self Similarity
8. No typical/average size of events/objects
9. Non-whole number dimensions

Feigenbaum Ratios

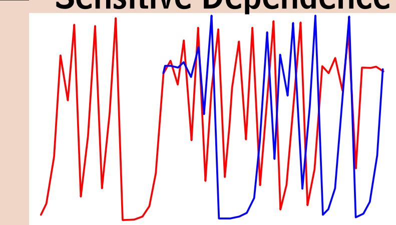
10. All complex systems accelerate rate of chage at the same rate.

Increasing Instability



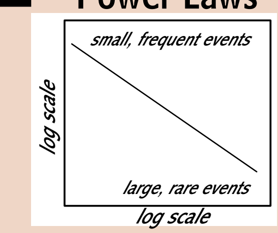
11. All changes (bifurcations) preceeded by increasing instability

Sensitive Dependence



12. Miniscule changes in 'r' can result in dramatic changes in behavior.

Power Laws



13. Small - low energy - events very common; large - high energy - events very rare.

Strange Attractors

14. Behaviors have recognizable large scale patterns but never repeat the same path.

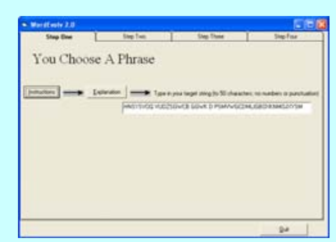
Complex Systems Theory

Complex systems theory studies how systems with many "agents" (individual interacting units, like birds in a flock, sand grains in a ripple, or individual units of friction along a fault zone), existing far from equilibrium, interacting through positive and negative feedbacks, to form interdependent, dynamic, evolutionary networks . . . leading to increasing complexity, diversity, order, and/or interconnectedness

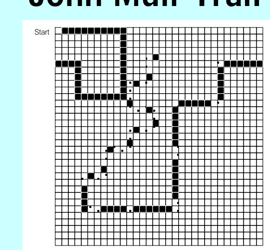
Elaborating Evolutionary Mechanisms

Word Evolv

15. The general evolutionary algorithm—1) differentiate, 2) select, 3) amplify, 4) repeat—is an extremely efficient and effective method of natural selection.



John Muir Trail



Tierra/Avida

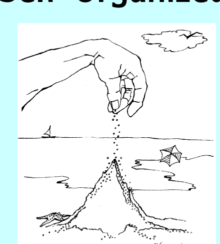
Ancestral Program - consists of three 'genes'

Self-Organizing Mechanisms

Boids

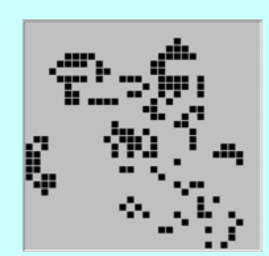
16. Local Rules lead to Global Behavior, self organization arises spontaneously without design, or purpose, or teleological mechanisms.

Self-Organized Criticality



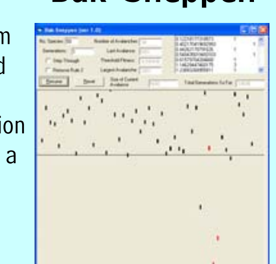
17. All open systems dissipating sufficient energy evolve—self-organize—to critical, sensitive dependent states which lead to avalanches of change that follow a power law distribution.

Cellular Automata



18. In a complex system everything is connected with everything else. Nothing exists in isolation from the rest, sitting in a protected niche, independent and self-sufficient.

Bak-Sneppen



19. In a complex system no one can be completely safe, with complete control over their fate.

Fractionating Evolutionary Mechanisms

We are unaware of any experimental models or computer based experimental programs that explore principles of fractionating evolution as a complex system, either in the spirit of the General Evolutionary Algorithm for elaborating evolution, or comparable to the many specific self-organizing evolutionary algorithms. That is, an agent-based model with simple rules that can be tuned to explore how different conditions result in different outcomes.

On to next poster