Some Foundations in Complex Systems:

Tools and Concepts

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Comments about my series of lectures

1. I am trained as a theoretical physicist. So my approach will be somewhat physics-centric.
2. There is a lot of material that I'm trying to cover, so I'll move quickly and at times will skip some topics that I really shouldn't skip.
3. There will be times when the lectures seem to slow, and other times when they seem too fast. This will probably be the case for all the lectures this month.
4. Please, ask questions during (and after) the lectures!
5. I'd also welcome comments, critique, and conversation.
6. My aim is to give a somewhat selective and opinionated survey of tools, methods, and ideas from complex systems.
7. We can't cover anything, so I've chosen what I think is most important and what you're less likely to get elsewhere.

Complex Systems?

I'm not interested in a strict definition of complex systems. However, it seems to me that most things we'd think of as a complex system share many of the following features:

1. Unpredictability. A perfectly predictive theory is rarely possible.
2. Emergence: Systems generate patterns that are not part of the equations of motion: *emergent phenomena*.
3. Interactions: The interactions between a system's components play an important role.
4. Order/Disorder: Most complex systems are simultaneously ordered and disordered.
5. Heterogeneity: Not all the elements that make up the system are identical.

Phenomena and Topics

- Another way to approach a definition of complex systems is to list the things that people think are complex systems:
  - Immune system, ecosystems, economies, auction markets, evolutionary systems, the brain ...
  - Critical phenomena/phase transitions, chaotic dynamics, fractals and power laws, complex networks, natural computation ...
- This amounts to saying: complex systems are what complex systems people study.
- This does have a nice internal consistency.
- In my opinion, what gets included as part of a discipline is often a frozen accident.

Tools

Most tools and techniques for complex systems will need to:

1. Measure unpredictability, distinguish between different sorts of unpredictability, work with probabilities
2. Be able to measure and discover pattern, complexity, structure, emergence, etc.
3. Be inferential; be inductive as well as deductive. Must infer from the system itself how it should be represented.
4. Be interdisciplinary; combine methods, techniques, and areas of study from different fields

Models

We will need model systems upon which to try out tools and techniques: "fruit flies" and "lab rats" for complex systems. Many are commonly used

1. Logistic equation
2. Random networks
3. Ising models
4. Cellular automata
5. etc.

- Also, one usually has to build a model, or choose a representation, of a phenomena before one can study it.
- It is important to choose model classes carefully.
- We will also need to think about how to infer models from data.
- Models, by definition, ignore many aspects of the phenomena being modeled.
- There are always choices (sometimes hidden) made when building a model.

Complexity: Initial Thoughts

- The complexity of a phenomena is generally understood to be a measure of how difficult it to describe it.
- But, this clearly depends on the language or representation used for the description.
- It also depends on what features of the thing you're trying to describe.
- There are thus many different ways of measuring complexity. I will aim to discuss a bunch of these in my lectures.
- Some important, recurring questions concerning complexity measures:
    1. What does the measure tell us?
    2. Why might we want to know it?
    3. What representational assumptions are behind it?

Outline

1. Introductory remarks.
2. Introduction to Dynamical Systems and Chaos, Part I. Terminology, definition of chaos.
3. Introduction to Dynamical Systems and Chaos, Part II
4. Information Theory, Part I: Basic Definitions
5. Information Theory, Part II: Entropy Convergence and Complexity
6. Computation Theory, Part I: Automata and Computational Hierarchy
7. Computation Theory, Part II: Universal Turing Machines and Computational Complexity
8. Measures of Complexity, Part I: Computational Mechanics
9. Measures of Complexity, Part II: Survey of other Complexity Measures
10. Conclusions

Goals

1. Present some tools, models, paradigms that are useful in complex systems.
2. Discuss the applicability and un-applicability of these various tools.
3. Provide references and advice so you can learn more about these topics if you wish.
4. Present some thoughts about what makes the study of complex systems similar to, and different from, other types of science.
5. Provide some background which may help you get more out of other lectures.
6. Have fun.