Tools

In the introduction to my lectures, I said that:

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

I hope to have given you some tools that you can use, apply, modify, and/or reject as you see fit.

Some things I didn't cover

- Two-dimensional systems.
  - Formally, a 2D system can be converted into a 1D string.
  - However, I think this is the wrong way to think about 2D.
  - 2D problems are much harder, conceptually and practically, than 1D problems.
- Non-stationary systems
- Continuous systems and continuous computation
- Parallel computation
- Algorithms and implementational details

Complex Systems Science?

Is there a science or theory of complex systems? Can there be one? My hunch is that the answer is no, at least not in the usual sense of theory.

- Perhaps looking for a unifying theory of complex systems is to forget the message of emergence: that the whole is the greater than the sum of its parts, and that innovation and novelty is the norm.
- On the other hand, I don't think it's the case that every complex system is different. There may be some unifying tools, principles and ideas.
- My strong hunch is that a theory of complex systems will be primarily concerned with **methods** and **tools** as opposed to universal governing principles or equations.

What Good are Complex Systems?

- Complex systems provide a new set of paradigms or exemplars: e.g., logistic equation, random graphs, CAs, Schelling's tipping model, etc.) These serve as stories we tell about what the world is like, and provide an important counterbalance to linear, reductive, "rational" models that still are predominant in many fields.
- The model systems of the sort I've focused on here may have little to say directly about complicated, real-world phenomena. However, these systems provide a very clear setting in which to explore the discovery of pattern, and fundamental tradeoffs between randomness and order. This can hone intuition when considering other, real-world complex systems.

What Good are Complex Systems?, continued

- I believe that there is an aesthetic and perhaps even normative component to the study of complex systems. Part of what the field has in common is a group of people with similar tastes and concerns and a sense of what is interesting:
  - How the world is put together, rather than how it's taken apart.
  - A fascination with patterns and their formation.
  - A fascination with diversity.
  - A willingness to take risks.
  - A recognition of interrelationships and complexity.

Interdisciplinary Challenges

- Interdisciplinary work is hard: it is usually up to *you* to make the connections.

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Some Final Thoughts and Advice, Bit and Small

- Pace yourself—the summer school is long.
- Explore Beijing: it's a great city.
- Keep in touch with CSSS colleagues after the school ends.

Some Final Thoughts and Advice, Big and Small

- Most people I know who are excellent researchers:
  - Know more than they have to know
  - Are good at both math/theory and computation.
- Review literature thoroughly. Use the science citation index.
- Interdisciplinarity is good, but it's a means, not an end.
- For each topic I covered, there are at least several students who are more of an expert than me. Use your colleagues as resources.
- Try not to lose your passion for big questions
  - If you pursue a career in academia, you will be pressured to pursue traditional, safe problems.
  - You will also be pressured to chose a discipline.
  - It is wise to give in to this pressure, but try to do so in a way that lets you keep working on risky, interdisciplinary, BIG problems.
  - Enjoy the uncertainty that comes with BIG questions.

Enjoy the Questions

> have patience with everything unresolved in your heart and to try to love the questions themselves as if they were locked rooms or books written in a very foreign language. Don't search for the answers, which could not be given to you now, because you would not be able to live them. And the point is to live everything. Live the questions now. Perhaps then, someday far in the future, you will gradually, without even noticing it, live your way into the answer.

Rainer Maria Rilke, 1903 in Letters to a Young Poet