CS 420/594
(Advanced Topics in Machine Intelligence)

Complex Systems and Self-Organization

Bruce MacLennan

http://www.cs.utk.edu/~mclennan/Classes/420

Contact Information

- Instructor: Bruce MacLennan
  maclennan@cs.utk.edu
  Claxton Complex 217
  Office Hours: 2:00-3:30 MW (or make appt.)
- Teaching Assistant: Yifan Tang
  ytang@cs.utk.edu
  Claxton Complex 124
  Office Hours: 5:00-6:00 W (or make appt.)

CS 420 vs. CS 594

- CS 420: Undergraduate credit (but graduate students can count one 400-level course)
- CS 594: Graduate credit, additional work

Grading

- You will conduct a series of computer experiments, which you will write up
- Some of these will be run on off-the-shelf simulators
- Others will be run on simulators that you will program
- Graduate students will do additional experiments and mathematical exercises
- No exams

Prerequisites

- CS 420 & 594: None per se, but you will be required to write some simulations (in Java, C++, or whatever)
- CS 594: Basic calculus through differential equations, linear algebra, basic probability and statistics

Textbooks

- CS 420 & 594: Flake, Gary William. *The Computational Beauty of Nature*. MIT Press, 1998
- CS 594: Bar-Yam, Yaneer. *Dynamics of Complex Systems*. Perseus, 1997. This book is available online in pdf format

Contents of Flake CBN

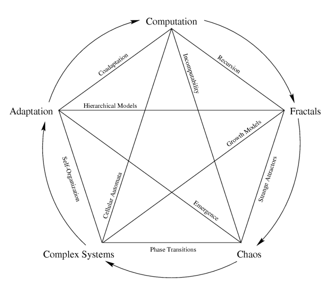

Figure 1.1 An association map of the contents of this book

What We Will Cover

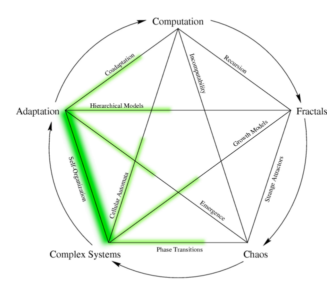

Figure 1.1 An association map of the contents of this book *that we will cover*

Reading for Next Week

- Flake: Ch. 1 (Introduction)
- Flake: Ch. 15 (Cellular Automata)
- 594: Bar-Yam:
  - Secs. 0.1 – 0.5 (Overview)
  - Sec. 1.5 (Cellular Automata)

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Course Web Site

- www.cs.utk.edu/~mclennan/Classes/420
- Syllabus
- Link to Flake *CBN* site (with errata, software, etc.)
- Link to Bar-Yam (CS 594) online text
- Links to other interesting sites
- Handouts:
  - assignments
  - slides in pdf formats (revised after class)

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Discussion

- What is a *complex system*?
- What is an *emergent property*?
- What is *self-organization*?

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Weaver's Stages in the Progress of Science

- Simple systems
- Disorganized complexity
- Organized complexity

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Complex vs. Simple Systems

- Have many parts
- Parts are interdependent in behavior
- Difficult to understand because:
  - behavior of whole understood from behavior of parts
  - behavior of parts depends on behavior of whole

Examples of Complex Systems

- government
- family
- person (physiology)
- brain
- world ecosystem
- local ecosystem (desert, rainforest, ocean)
- weather
- corporation
- computer
- ant colony
- university

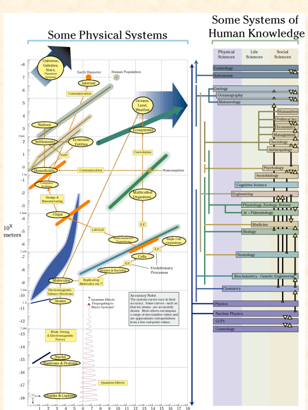

Fig. from

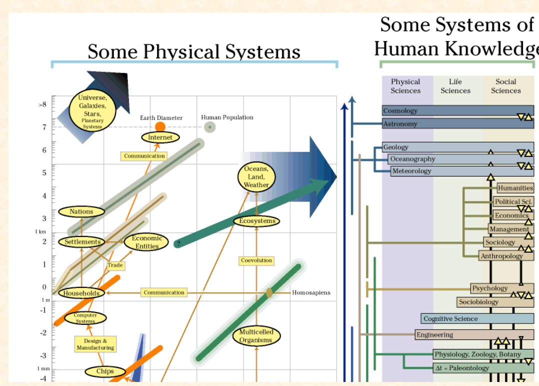

Fig. from NECSI

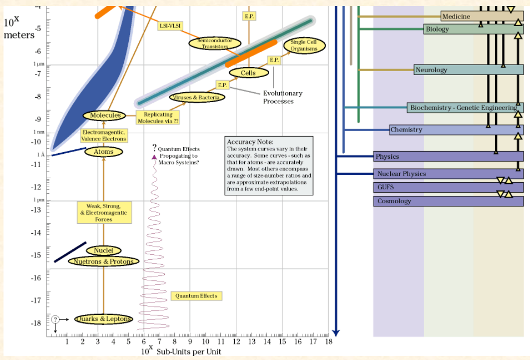

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Fig. from NECSI

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Defining Properties

- Elements (& their numbers)
- Interactions (& their strengths)
- Formation/operation (& their timescales)
- Diversity/variability
- Environment (& its demands)
- Activities (& their objectives)

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What are the *universal properties* shared by all complex systems?

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Ockham's Razor

- *Pluralitas non est ponenda sine neccesitate.*
- "Plurality should not be posited without necessity"
- Advocated by William of Ockham (1285-1347/49)
  - also spelled "Occam"
- A law of economy fundamental to science

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Universal Properties

- By Ockham's Razor:
  - for explaining system properties/behavior…
  - don't make use of particulars of elements unless necessary
- Often discover: properties & behavior of the system are independent of the specifics of the elements
- E.g., ant colonies and neural networks obey similar laws

Emergence

- The appearance of *macroscopic* patterns, properties, or behaviors
- that are not simply the "sum" of the *microscopic* properties or behaviors of the components
  - non-linear but not chaotic
- Macroscopic order often described by fewer & different variables than microscopic order
  - e.g. ant trails vs. individual ants
  - *order parameters*

Self-Organization

- Order may be imposed from outside a system
  - to understand, look at the external source of organization
- In *self-organization*, the order emerges from the system itself
  - must look at interactions within system
- In biological systems, the emergent order often has some adaptive purpose
  - e.g., efficient operation of ant colony

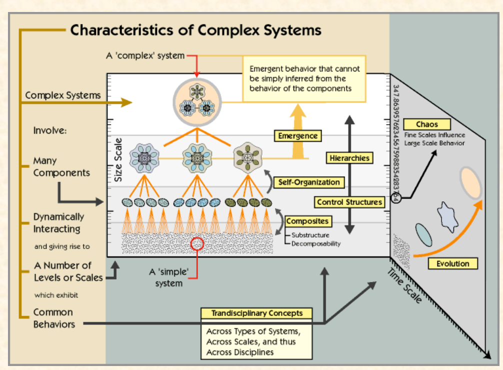

Fig. from NECSI

Why Are Complex Systems & Self-Organization Important for CS?

- Fundamental to theory & implementation of massively parallel, distributed computation systems
- How can millions of independent computational (or robotic) agents cooperate to process information & achieve goals, in a way that is:
  - efficient
  - self-optimizing
  - adaptive
  - robust in the face of damage or attack

Some of the Natural Systems We Will Study

- adaptive path minimization by ants
- wasp and termite nest building
- army ant raiding
- fish schooling and bird flocking
- pattern formation in animal coats
- coordinated cooperation in slime molds
- synchronized firefly flashing
- soft constraint satisfaction in spin glasses
- evolution by natural selection
- game theory and the evolution of cooperation
- computation at the edge of chaos
- information processing in the brain

Some of the Artificial Systems We Will Study

- artificial neural networks
- simulated annealing
- cellular automata
- ant colony optimization
- artificial immune systems
- particle swarm optimization
- genetic algorithms
- other evolutionary computation systems