CS 420/594
(Advanced Topics in Machine Intelligence)

Complex Systems and Self-Organization

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

CS 420 vs. CS 594

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

Contact Information

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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


Contents of Flake CBN

What 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)

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)

Discussion

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

Weaver’s Stages in the Progress of Science

- Simple systems
- Disorganized complexity
- Organized complexity
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
What are the universal properties shared by all complex systems?

Defining Properties

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

Ockham’s Razor

- *Pluralitas non est ponenda sine necesitate.*
- “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
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
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