CS 346U

Exploring Complexity in Science and Technology

Instructor: Melanie Mitchell
• Note: All slides for a lecture will be available on the class webpage before each lecture:

http://www.cs.pdx.edu/~mm/ExploringComplexityFall2013
What are Complex Systems?
What are Complex Systems?

Large networks of simple interacting elements, which, following simple rules, produce *emergent*, collective, complex behavior.
Insect colonies

https://www.youtube.com/watch?v=DXaaTQztoI0
Brains

http://www.youtube.com/watch?v=FZ3401XYYww
Immune system
https://www.youtube.com/watch?v=HUSDvSknlgl (+47sec.)
Economies

https://www.youtube.com/watch?v=Lx-pRkp7pM8

Schweitzer et al., Science, 325, 422-425, 2009
http://www.sciencemag.org/cgi/content/full/325/5939/422
World-Wide Web
https://www.youtube.com/watch?v=MjC7jse49W
Cities

Data from 360 US metropolitan areas show that metrics such as wages and crime scale in the same way with population size.

http://www.nature.com/nature/journal/v467/n7318/full/467912a.html

http://cognitivocities.com/
Do these systems have anything in common?
Core Disciplines

Dynamics: The study of continually changing structure and behavior of systems

Information: The study of representation, symbols, and communication

Computation: The study of how systems process information and act on the results

Evolution: The study of how systems adapt to constantly changing environments
Goals:

- Cross-disciplinary insights into complex systems
- General theory
Methodologies
Methodologies

\[ e^x = \sum_{n=0}^{\infty} \frac{x^n}{n!} = \lim_{n \to \infty} (1 + x/n)^n \]

\[ \int_0^1 x \, dx = \left[ \frac{1}{2} x^2 \right]_0^1 = \frac{1}{2} \]
Methodologies
How this class will work

- “Flipped” class
- Complexity Explorer site
- Syllabus
- Textbook & Readings
- Math and Programming
- Assignments / Assignment 1
- Online Tests
- Final Project
- Grading
- Teaching Assistant
- Mailing list
Notes

• Don’t do the “homework” on the Complexity Explorer site – just do the assignments I hand out.
Class Rules

• Turn off cell phone

• During class, please don’t use computers for mail, chatting, web surfing, etc.

• While you’re here, make it worth your while. Pay attention.

• In return, class will be interesting enough to hold your attention! (I hope…)
Introduction to NetLogo

• Developed by Uri Wilensky, at the Center for Connected Learning and Computer-Based Modeling, Northwestern University

• Based on the “Logo” and “StarLogo” programming languages from MIT

• Used extensively in education on computer modeling, from elementary school through graduate school

• Also used in complex systems research

• Written in Java

• Motto: “Low threshold and no ceiling”
Examples:
Modeling Self-Organizing Systems

Birds flocking

Fireflies synchronizing their flashes

Ants foraging for food
Birds Flocking and Fish Schooling
• Why do they do it?

• How do they do it?
Why Flock or School?

Some hypotheses

– Predators will think that flock or school is single (large, threatening) organism

– Predators won’t be able to target individuals in the flock or school

– The flock or school will be more efficient at catching prey (via cooperative hunting) than individuals alone

– The flock or school will increase the individuals’ aero/hydrodynamic efficiency (like a peloton in bicycling)

Many hypotheses! Possibly all are correct.
How to Flock or School (without a leader, with only local information)?

“Boids” model, Craig Reynolds, 1987

Craig Reynolds
Boids rules of flocking (or schooling), in order of relative importance:

1. **Collision Avoidance**: avoid collisions with nearby flockmates

2. **Velocity Matching**: attempt to match velocity with nearby flockmates

3. **Flock Centering**: attempt to stay close to nearby flockmates
Boids Simulation of Fish Schooling

http://www.youtube.com/watch?v=hWcOTLtnm0Y
Netlogo Flocking Model

Rules for each bird:

• If I’m too close to nearest neighbor, separate

• Otherwise:
  – **Align**: Turn so I’m headed in the same direction as the average of my neighbors
  – **Cohere**: Move closer to my nearest neighbors
Speculation

As you **increase** the vision range, will the group flocking behavior become stronger (converging more quickly on larger flocks) or weaker (converging more slowly, with smaller flocks)?

A. Stronger

B. Weaker
Netlogo

Free, easy to use, easy to learn to program!

http://ccl.northwestern.edu/netlogo/
Fireflies Synchronizing Their Flashes
Why Synchronize?

Again, multiple hypotheses!

- Makes males’ location more visible to females
- Makes small groups of males appear larger, more attractive to females
- Reduces “noise”: males can more easily spot females in the dark between flashes

Perhaps all of these are correct...
How to synchronize?

Assumptions:
- No leader.
- Each individual firefly only sees neighbors flashes.

Each firefly is a natural “oscillator”, with a natural flashing frequency of about 1 second.

“Excitation” builds up in firefly’s neurons, reaches a threshold, leading to flash.

However, if the firefly sees flash from a neighbor, this speeds up its cycle and it flashes sooner.

Result of interacting group: synchrony! (via “coupled oscillators”)
Netlogo Fireflies Model

- Each firefly cycles through its own clock, flashing at beginning of each cycle, then resetting clock to zero once it reaches the maximum.

- All fireflies have the same cycle length.

- Each firefly starts out at a random point in its cycle.
• As fireflies perceive other flashes near them (within radius of one patch), they use this information to reset their own clocks.
Fireflies model
Speculation

As you increase the number of fireflies, will the synchronization become faster or slower?

A. Faster

B. Slower
Ants Foraging for Food
Ant Foraging

• Ants move randomly in many different directions.

• When an ant encounters a food source, it returns to the nest, leaving a pheromone trail.

• Ants encountering this trail are likely to follow it, also leaving pheromone if they find food on this trail.

• The pheromone continually evaporates, so the trail disappears if it is not reinforced by ants.
Netlogo Ant Foraging Model

- Each ant leaves the nest and moves around at random

- If an ant finds a piece of food, it picks it up and carries it back to the nest, leaving a pheromone trail.

- If an ant senses pheromone nearby, it goes to a nearby spot with the highest concentration of pheromone.
Speculation

How much faster will the ants eat the food if they are allowed to leave pheromone trails?

A. Same speed

B. Twice as fast

C. Ten times as fast