SYDE 730 Topic – Complex Systems
Winter 2021

Instructor: Paul Fieguth

Nonlinear interacting dynamic systems represent a fascinating domain in systems engineering. Although a rigorous analysis of such complex systems can be tremendously difficult, at a systems level there are quite common themes which emerge, and which can offer a significant degree of conceptual understanding.

This seminar/reading course seeks to explore advanced topics in the understanding and high-level properties of complex systems, particularly as motivated by an exploration of societal and environmental systems, particularly the interaction of people with their physical environment. Examples of such problems are all around us, including global warming, water dead zones, soil desertification, food production, and poverty, none of which can be understood or solved on the basis of examining single pieces of an interlocking puzzle.

This course will examine the mathematics of complex and nonlinear systems, focusing on the following topics:

1. Systems theory
2. Nonlinear systems
3. Non-Gaussian / heavy-tailed / power-law distributions
4. Complex and self-organizing systems

Proposed focus areas / mini-project topics for students to work on (highlight indicates difficulty):

- Measures of complexity – how do we measure or quantify complexity?
- Better nonlinear fluid flow examples — vortex shedding, cloud patterns, whistling
- Game theory / Nash equilibrium, particularly those equilibria which are problematic / troubling
- Nonlinear dynamics in layer-by-layer deep networks
- Decoupling of nonlinear systems?
- Simple model or explanation of instability of spinning tops (e.g., rounded paperweights)
- Some sort of nonlinear circuit example; ideally one parameterized, so that nonlinearity disappears, for example having a diode (or maybe milder nonlinear element) in parallel with a resistor: linear at R=0, nonlinear for R>0
- Social systems: their fixed points and other dynamics
- Simple simulations of emergence, beyond sand-pile and forest-fire models already in place?
- Universality of Tracy-Widom distributions and complex systems
- Third-order phase transitions (related to Tracy-Widom distributions)
- Practical examples of non-normal behavior
- Cascading failures --- simulation, models, analytical results
- Criticality – better definition?, examples?
- Simple discontinuous system?

Grade:

- 10% In-class participation, discussion, contribution
- 75% Three mini-projects, each at 25%:
  - 5% Presentation to class
  - 5% Written submission
  - 15% Elegance / clarity / simplicity / depth of insight
- 15% Assignment questions taken from Complex Systems textbook

Class Arrangement:

SYDE 532 Asynchronous lectures – Two per week (recommended)
SYDE 532 Learn page

SYDE 532 Synchronous lectures (optional)
Mondays 12-1pm
Thursdays 3-4pm

SYDE 730 Synchronous lectures
Mondays 1-2pm
Thursdays 4-5pm