Entropy, Order Parameters, and Complexity

Graduate Statistical Mechanics 6562 / 4488
MWF 10:10-11:00
Jim Sethna sethna@lassp.cornell.edu PSB 412, 5-5132,
office hours Monday 11-12.
sethna.lassp.cornell.edu/Teaching/562/
TA: TBA, TBA@cornell.edu, PSB TBA
Other Key Personnel: Stephen Thornton, TBA

- Random Walks and Emergent Properties
- Microcanonical ensemble
- Phase-space Dynamics and Ergodicity
- Entropy
- Free Energies and Ensembles
- Quantum Statistical Mechanics
- Computational Stat Mech
- Order Parameters, Broken Symmetry, and Topology
- Correlations, Response, and Dissipation
- Abrupt Phase Transitions
- Universality and the Renormalization Group

Aimed at grads in Physics, Computer Science, Biology, Engineering, Chemistry, Math, and the Social Sciences:
Flipped Classroom Format

Text: Statistical Mechanics: Entropy, Order Parameters, and Complexity *Second Edition,* Oxford Univ. Press
Available on the Web at
https://sethna.lassp.cornell.edu/StatMech/EntropyOrderParametersComplexity20.pdf

Typical exercises that you will solve in this course

Random matrix theory	Stock prices and random walks
Taste and smell and chemical potential	Jupiter! and the KAM theorem
2D turbulence and Jupiter's great red spot	Heat death of the Universe
Cat map	Rubber bands
Card shuffling	Shannon entropy
Aging, entropy, and DNA	Dyson sphere
Arrow of time and nucleosynthesis	Epidemics and zombies
White dwarfs, neutron stars, and black holes	Fruit flies, Markov matrices, and free energies
Kinetic proofreading in cells	Topological defects
Cosmic microwave background radiation	Pandemic
Crackling noise	Onset of Chaos
Fingerprints	Conformal invariance
Quantum measurement and entropy	Beer and rigidity

Idiosyncrasies of our class

- *Flipped format:* Read the material *before class*. We will spend class time on exercises, projects, and discussion. National research says that this 'flipped' format can be remarkably effective.
- *Unorthodox topics:* We emphasize topics of broad utility; less about atoms, thermodynamics, and quantum systems.
- Prerequisites: sophistication and interest. Quantum will be needed only for ~2 weeks, no quantum on the 4488 exam.
- *Effort:* This course historically demands around 15 hours of out of class work per week. (Physics grads work hard.)
- *Homework:* Each week has one exercise in common, and then specialized exercises of your choice. Those in 6562 should do one or two specialized exercises each week, with a total of 10 before the prelim and 10 after the prelim. Those in 4488 should do 10 total, at least 5 before the prelim. Pick the ones that fascinate you – not the familiar ones.
- *Grades:* Median grades in this course are typically A-. If you are following the material and enjoying the class, don't be alarmed if you find others are doing well.
- 6562: HW 45%, pre-class 5%, prelim 20%, final 30%
- 4488*:* HW 40%, pre-class 10%, prelim 20%, final 30%
- *Consider traditional alternatives:* Chemistry 7960 (Baker 119, MWF 9:05-9:55, Loring) and Physics/A&EP 4230 (Fall) are more traditional.
- 2022 staff: Stephen Thornton, sjt95@cornell.edu, PSB 425 is the TA. Matt Signorelli and Matthew Dykes are other key personnel.
- Homeworks are due the first day each week in class (usually Monday); solutions will be handed out the next class. *If you cannot turn it in by then*: notify TBA (TBA@cornell.edu), cc me, and do not consult the solutions until you turn in your assignment.
- The exams will be take-home. March 9-12 for the prelim.
- *Integrity:* Do not use the solution sets from previous years. It defeats the purpose of taking the course, as well as being unfair.

Routine

- All exercises are from the second edition of the text: https://sethna.lassp.cornell.edu/StatMech/EntropyOrderParametersComplexity20.pdf

Wednesday

Read: Chapter 1, What is Statistical Mechanics?

- Pre-class question: 1.11 *Emergent vs. fundamental*

In-class question: 1.1 *Quantum dice and coins*

Exercises for everyone

1.13 *The birthday problem.* New law emerges for large classes.

Select zero – one (4488) or one – two (6562)

1.14 *Width of the height distribution.* (Statistics) A modern view of the $1/\sqrt{N-1}$ factor in the standard deviation formula.

1.5 *Stirling and asymptotic series.* (Mathematics,Computation) Do the lowest couple of orders in part (d) by hand, or use the hints file.

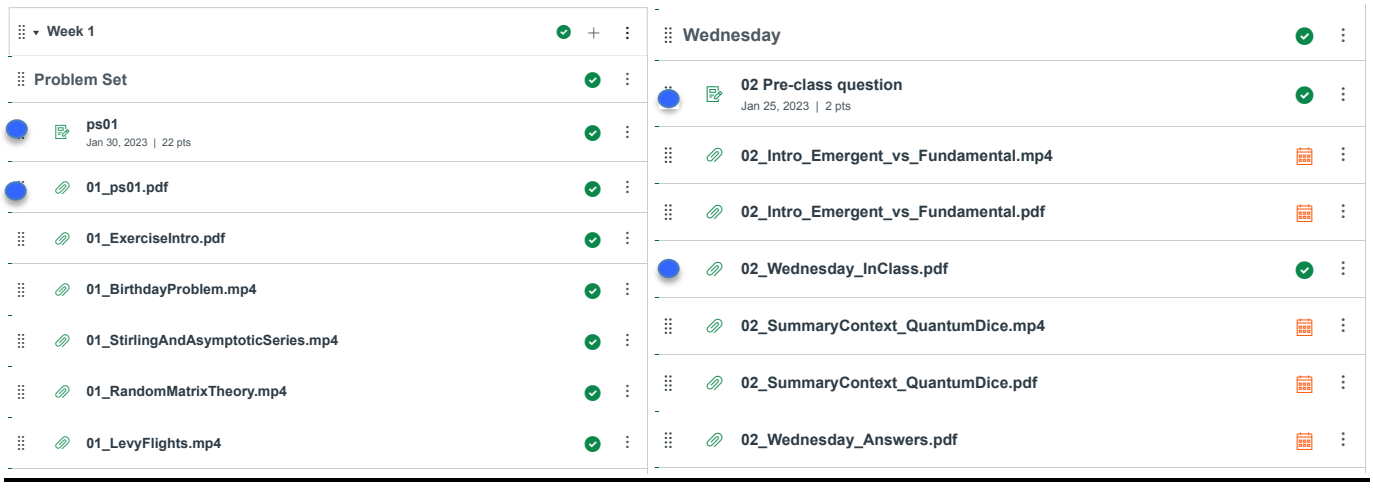
1.6 *Random matrix theory.* (Mathematics, Quantum, Computation). Use the hints file!

2.21 *Lévy flight.* What happens when our random steps can have very large jumps?

1.9 *First to fail: Weibull.* (Mathematics, Statistics, Engineering) Extreme value statistics.

1.12 *Self-propelled particles.* (Active matter) Self-propelled particles and the onset of flow.

Modules



Class Day Routine

Evenings Tu,Th:

- Do the reading
- Write up the pre-class question
- Turn in the pre-class question to the Canvas site

Sunday before class Monday:

- Do the reading
- Do the pre-class question; include in homework
- Finish the homework for the week, upload to Canvas

Physics Education Research (Holmes) tells us that effective learning is optimized by (1) addressing a new challenge individually,
(2) working in a group to establish a consensus and exchange insights, and then (3) a discussion by the expert of the expected approach and context of the problem. Each class will attempt to implement this strategy.

Again, if you are uncomfortable without lectures, or uncomfortable working in groups in class, feel free to consider one of the alternatives. Different people learn best in different ways.