MCS 591: Statistical Physics and Applications (Spring 2021)

Instructor: Will Perkins
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Course schedule Class meets Mondays, Wednesdays, and Fridays 10:00am-10:50am CST. To begin the semester the class will meet on Zoom (link sent by email). If UIC allows in-person classes later in the semester, we will meet in-person with all lectures still streamed by Zoom.

Course webpage: `http://willperkins.org/MCS591-2020/index.html`

Lecture notes: Lecture notes will be provided via a dropbox link to a file that will be updated throughout the semester.

Office hours Mondays 9:00-9:50 and Wednesdays 11:00-11:50am on Zoom (link sent by email).

Course description This course is an introduction to statistical physics and the statistical physics way of thinking. We will learn about the fundamental objects and phenomena in the field: Gibbs measures, partition functions, correlation decay, phase transitions. We will then apply the ideas and intuition of statistical physics to problems in combinatorics, algorithms, and geometry. This perspective will yield new methods and results as well as new questions. The course will be structured to introduce students to research problems. Student projects will involve reading recent research papers or beginning a research project of one's own.

Course prerequisites: No previous knowledge of physics or statistical physics is needed. Some background in probability theory is assumed. Some basic knowledge of combinatorics will be useful.

Additional resources In addition to the lecture notes, the following books might be useful.

- *Statistical Mechanics of Lattice Systems*, Friedli & Velenik.
- *The Probabilistic Method*, Alon & Spencer.
- *Probability and Random Processes*, Grimmett & Stirzaker.
- *Markov Chains and Mixing Times*, Levin & Peres.

References to additional lecture notes are provided in the class notes.

Topics

- Fundamentals of statistical physics
- Absence of phase transition
- Counting and sampling
- Phase coexistence
- Cluster expansion
- Abstract polymer models
- Entropy methods
- Occupancy method
- Sphere packings
- Pirogov-Sinai theory
- Spin models on random graphs

Grading

The course is assessed by homework assignments, a class project (in two parts), and class participation. All work should be typed in LaTex.

(1) **Assignments** (50%): there will be several homework assignments. Please try the problems on your own before discussing with others in the class. If you do discuss with others, please note their names on your assignment.
(2) **Project** (30%): the class project will be in two parts:

Part I: In the middle of the semester you will choose 2 or 3 recent research papers, read them, and write a 2 -3 page report summarizing them (I will provide a list of suggested paper, or you can choose your own). At the end of your report you should list several open problems: these can be extensions or generalizations of the results in the papers, or questions inspired by their results or techniques. Your open problems ideally will cover a range of difficulty levels from near exercise to ambitious challenges.

Part II: At the end of the semester you will complete a final project. This can have one of two forms:

(a) A survey of a specific area or problem (5-10 pages).
(b) An original research project.

(3) **Class participation** (20%): full credit for class participation will be given for excellent performance in at least two of the following areas:
(a) Attendance
(b) Class participation in lectures (asking and answering questions)
(c) Participation in class discussions and office hours
(d) Careful reading and proofreading of the course notes (i.e. sending me corrections and suggestions)

Grades will be assigned according to the following scale: A: 90-100; B: 80-89; C: 70-79; D: 60-69; F: 0-59.

Academic honesty

Be sure to submit your own work for assignments and projects and follow all standards of academic integrity. Be respectful and considerate in all of your interactions with fellow students.

Research opportunities

There are a couple of optional opportunities to get involved in research related to the topics of the course.

(1) The UIC Combinatorics and Probability seminar will meet Mondays at 3pm online, starting January 25: `https://www.math.uic.edu/persisting_utilities/seminars/schedule_by_topic?code=CP`. If you are not already on the mailing list for the seminar and would like to join, please email me and I will add you.
(2) With Nicolas Fraiman (UNC) I will be organizing a research working group on Phase Transitions and Algorithms as part of the SAMSI semester-long program on Combinatorial Probability: `https://www.samsi.info/programs-and-activities/semester-long-programs/program-on-combinatorial-probability/`. I encourage you to sign up for the working group if you're interested in learning about research problems in the area and meeting other students, postdocs, and faculty from other universities interested in the same things.