Computation and Physics

Proposed Syllabus

Time: Spring 2012, Tue-Thu 9:00am-10:30am
Instructors: Prof. Aram Galstyan (galstyan@isi.edu) and Greg Ver Steeg (gregv@isi.edu)
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Course Introduction

During the last decade there has been a dramatic increase in the intensity of cross–disciplinary research between theoretical computer science and machine learning, statistical physics of disordered systems, and information theory. At the root of these convergent trends are probabilistic graphical models, which describe a potentially large number of random variables coupled with each other through some dependency mechanism. The proposed inter-disciplinary course has twofold objective: to introduce CS and engineering students to methods and approaches used in statistical physics of disordered systems; and to introduce physics students to problems in computer science and machine learning. The course will cover three broadly defined topics: combinatorial optimization, error correcting codes, and inference in probabilistic graphical models.

Prerequisites: This course is designed for students that have taken at least one advanced course in computer science, machine learning **or** statistical physics. Examples include CSCI-567 (Machine Learning), PHYS-518 (Thermodynamics and Statistical Mechanics), and EE-599 course on *Large Scale Systems and Message Passing*.

Course Requirements

- **Format** Classroom lectures, assigned reading, 4 homework assignments, and a final project.
- **Textbooks**
    - Marc Mezard and Andrea Montanari, "Information, Physics, and Computation", preliminary draft available online: http://www.stanford.edu/~montanar/RESEARCH/book.html
    - M. Mezard, Giorgio Parisi, M. Virasoro, "Spin Glass Theory and Beyond" (<u>optional</u>, equivalent papers can be provided).
- **Review Articles and Research Papers**
    - K. Binder and A. P. Young, "Spin glasses: Experimental facts, theoretical concepts, and open questions", Rev. Mod. Phys. 58, 801–976 (1986).
    - O. C. Martin, R. Monasson, and R. Zecchina, "Statistical mechanics methods and phase transitions in optimization problems", Theor. Comput. Sci. 265, pp. 3-67, August 2001.

- N. Sourlas, "Spin-glass models as error-correcting codes", Nature 339, 693 – 695, 1989.
- J. Reichardt and M. Leone. "(Un)detectable cluster structure in sparse networks", Phys. Rev. Lett. 101, 078701 (2008)
- A. Allahverdyan and A. Galstyan. "On Maximum a Posteriori Estimation of Hidden Markov Processes", UAI 2009.

Grading
The grade will be based on 4 homework assignments (60% of the grade) and the final class project (40% of the grade).

Course Outline
Week 1: Introduction to statistical physics, basic concepts, Gibbs distribution, free energy, entropy. [Chs. 1-2]
Week 2: Ising model: critical phase transitions; Computational approaches: simulated annealing, extremal optimization. [Chs. 4-5]
Week 3: Disordered systems, replica trick, spin glasses [Ch. 8, BY review] *(HW1 released)*
Week 4: Combinatorial Optimization: terminology, examples (random K-SAT, graph bi-partitioning, etc.), phase transition in average-case complexity. [Ch. 3, MMZ review]
Week 5: Statistical physics solution to number partitioning. [Ch. 7]
Week 6: Statistical physics of (sparse) graph partitioning problem. [RL paper]
Week 7: Project proposal review *(HW1 discussion, HW2 released)*
Week 8: Introduction to graphical models: Markov property and representations. [Ch. 9 & 13]
Week 9: Exactly solvable models: Binary symmetric HMM, statistical physics of Viterbi decoding [AG paper]
Week 10: Inference in graphical models: MAP, mean field, variational methods [Ch. 14]
Week 11: Belief propagation and cavity approximation [Ch. 15] *(HW2 discussion, HW3 released)*
Week 12: Information theory concepts: noisy channels and error-correcting codes [Ch.6 & Sourlas paper]
Week 12: Statistical physics of LDPC codes [Ch. 11] *(HW3 discussion, HW4 released)*
Week 13: Project updates
Week 14: Advanced topics: replica symmetry breaking, survey propagation [Selections from Chs. 19-22] *(HW4 discussion)*
Week 15: Project presentations, course wrap up.

Class project
The class project requires independent research on extending one of the models discussed and analyzing the result numerically. Examples could include solving a Potts model using belief propagation for partitioning graphs into K clusters, or developing statistical physics formalism for MAP decoding of multi-state and/or

multi-channel HMMs. Project should be picked in consultation with the instructor, teams of 2-3 will be allowed.

Statement on Academic Integrity
USC seeks to maintain an optimal learning environment. General principles of academic honesty include the concept of respect for the intellectual property of others, the expectation that individual work will be submitted unless otherwise allowed by an instructor, and the obligations both to protect one's own academic work from misuse by others as well as to avoid using another's work as one's own. All students are expected to understand and abide by these principles. Scampus, the Student Guidebook, contains the Student Conduct Code in Section 11.00, while the recommended sanctions are located in Appendix A: http://www.usc.edu/dept/publications/SCAMPUS/gov/. Students will be referred to the Office of Student Judicial Affairs and Community Standards for further review, should there be any suspicion of academic dishonesty. The Review process can be found at: http://www.usc.edu/studentaffairs/SJACS/.

Statement for Students with Disabilities
Any student requesting academic accommodations based on a disability is required to register with Disability Services and Programs (DSP) each semester. A letter of verification for approved accommodations can be obtained from DSP. Please be sure the letter is delivered to me (or to TA) as early in the semester as possible. DSP is located in STU 301 and is open 8:30 a.m.–5:00 p.m., Monday through Friday. The phone number for DSP is (213) 740-0776.