Georgia Institute of Technology
School of Electrical and Computer Engineering
ECE8833/BMED8813: Special Topics (Spring 2011)
Information processing models in neural systems

Instructor

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Office hours: Tuesday 1:30pm-3:00pm or by appointment
Course meeting: Tue/Thu 3:05-4:25 in Van Leer C340

Overview

Neural systems are adept at leveraging the statistics of the complex natural world to understand and navigate their environment with great efficiency and effectiveness. These neural systems are very complex, and have been studied at many different levels of abstraction ranging from molecular interactions to human psychophysics. Modeling approaches that seek to describe the input/output relationship of a neural system in terms of computational primitives from a lower level of abstraction (i.e., a "bottom up" modeling approach) are commonly used, but do not always illuminate the underlying computational goal of that system. This course will instead examine "top down" modeling approaches, where an optimal computational principle used in engineering (e.g., information theory, Bayesian inference, resource allocation, control theory) can account for the observed information processing strategies in a neural system. The potential contributions of these top-down models will be explored in levels of abstraction ranging from the anatomy of single neurons to human sensory perception and motor control.

The necessary neurophysiology and mathematics background material will be largely self-contained, making this course appropriate for students with a background in either the biosciences or engineering who are interested in learning how the tools of modern information processing can help us understand the function of neural systems.

Prerequisites

Background in probability/statistics, linear algebra, signal processing/linear systems, and the use of Matlab (we will use Matlab extensively). Courses such as ECE2025 and ECE3075 (or similar) will be likely be sufficient if the student is willing to work hard catching up on some of the materia. Please see the instructor if you have any questions about whether you have the appropriate background material.

Course website

The T-Square website will have the current version of the syllabus (it may change as the course progresses), the course calendar (including lecture schedule and due dates), PDFs of required readings, PDFs of additional readings, homework assignments, and information about the course project. Check the website often!

Textbook

Natural Image Statistics: A Probabilistic Approach to Computational Vision, by A. Hyvarinen, J. Hurri and P. Hoyer, Springer (2009). Note that the full preprint version of this book is available as a PDF online. Supplemented heavily by the course notes and relevant research papers. See the "course matierals" section of the course website for more details.

Assignments

In addition to the course project at the end of the term (which will be discussed in detail elsewhere), the main graded assignments during the term will take the form of *homework sets* and *case studies* (approximately 4-5 of each). The intention is to use homework to exercise your knowledge of fundamental concepts as they are introduced near the beginning of the course, but phase the homework out over time to give you more time to work on your project. Case studies will exercise your ability to read, comprehend, summarize/describe and critically evaluate a research paper (probably the single most important skill for a graduate student).

In all assignments in this course, a significant portion of your grade will be determined by your ability to communicate technical information. One of the most important skills you will develop in graduate school is the ability to effectively communicate about your research. I have seen far too many papers that were useless because, despite the potential quality of their technical content, they were unreadable. In your writing of homework solutions and case study summaries, please give careful consideration to what you can do to make your presentation clear to the reader. If you are not already using LaTeX to prepare your technical documents, this would be a great time to learn.

Homework sets: In general, assignments are due in class on their due data and no late assignments will be accepted. If you have an extreme extenuating circumstance, please contact the instructor at least 2 days before the assignment is due to discuss possible solutions. I strongly encourage discussion among the students in the course about the assignments, as I believe that this interaction will help everyone understand the material better. However, because you must all be evaluated on your understanding of the material, you must each independently write up your own solutions for the course assignments (including Matlab code and problem solutions). In a similar vein, you are bound by the Georgia Tech honor code not to use any type of homework solutions from a previous semester that you may encounter. Many of the homework assignments (and your projects) will require Matlab, which is available in on-campus labs (student versions are also very affordable).

Case Studies: Case study teams will be assigned randomly at the beginning of the semester (~2 people per team). For each case study, each team will be assigned a component of one paper (e.g., 2-3 figures). The team will need to write a short summary of the whole paper. This summary should be abound two paragraphs. The first paragraph should be a summary of the approach and conclusions. A great approach to this would be to hide the original abstract and see if you could write one yourself after reading the paper. The second paragraph should be your own analysis. What did you think was especially creative, or what especially bothered you? What could you do (analysis or experiment) to validate the results of the paper, or how would you build on the author's results? The team will get a single grade for this summary.

Additionally, one member of each team (randomly chosen) will need to explain their assigned component (e.g., 2-3 figures) to the class. Everyone will get an individual grade for their presentation. Presentations should be no more than 10 minutes long. Not everyone will have read the same papers, so this is an important opportunity to practice your teaching abilities.

Projects: Projects will be done in teams of 2-3 (depending on final enrollment). Details about appropriate topics and the deliverables are on the course website.

Grading

The course grade is based on the following metrics:
Class participation – 10%
Homework – 25%
Case studies – 25%
Projects (and presentation) – 40%

Students with disabilities

Georgia Tech offers accommodations to students with disabilities. If you need a classroom accommodation, please make an appointment with the ADAPTS office (see http://www.adapts.gatech.edu).

Topical outline:

1. **Introduction and background**
   - The types of modeling: Descriptive, mechanistic, and functional/interpretive
   - Review of mathematical preliminaries: linear systems, probability and statistics
   - Basic neurophysiology: Cell physiology, electrical potentials, and synaptic transmission
   - Basic system structure and function: Early visual pathway, auditory periphery, and characterization of individual cell responses
   - Natural sensory statistics and system efficiency
2. **Information theory**
   - The mathematical theory of information
   - Synaptic structure and function
   - Single unit responses in the visual pathway
   - Adaptive gain control maximizes information?
   - Independent component analysis (ICA) and information maximization
3. **Optimal inference and decision theory**
   - Optimal statistical inference and decision theory
   - Inference in perception and cue integration
   - Motion illusions and conditional perception as Bayesian inference
   - The generic viewpoint as inference: how to deal with irrelevant parameters
   - Optimal (sequential) decision making and evidence accumulation
   - Inference in neural codes incorporating sparsity
   - Compressed sensing in learning and memory
4. **Control theory and dimensionality reduction in the motor system**
   - Optimal control theory
   - Open and closed loop control for motor system function
   - Inferring muscle synergies (dimensionality reduction)
   - Sensorimotor integration and adaptation
5. **Achieving invariance**
   - Hierarchical models for phase smoothness
   - Hierarchical models for capturing correlations
   - Hierarchical models for predictive coding
   - Slow feature analysis
6. **Resource optimization**
   - Optimizing energy consumption
   - Optimizing wiring length