Boston University, Spring 2009

BE570: Introduction to Computational Vision

Syllabus

Instructor(s): Professor Lucia M. Vaina
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Office Hours: Friday 9:30-10:30am + by appt

Lectures (time & place): 2-4pm, Monday and Weds ERB705

Goal. The purpose of this class is to provide an introduction to the study of visual processing and perception in the brain. We will discuss a variety of topics including attention, how vision links to action, contrast and motion perception, and visual navigation from three perspectives: (a) neuroanatomy and –physiology, (b) psychophysics, and (c) computational modeling/mechanisms. The class will emphasize the application of vision science to imaging, clinical neurology, computer vision and robotics. We will discuss importance and relevance of understanding how the human visual system works to the medical field, and the impact on society context. Students will use matlab to solve fundamental vision problems.

Course Material. At the beginning of each section you will receive a list of required and optional readings. I will try to have most of the readings as pdf papers placed on Course-web. All lecture-slides will be placed on the Course-web. When pdf material is not available, it will be placed on reserve in the Science & Engineering Library under the course section (BE570). You are encouraged to xerox them. If there are any discrepancies between the readings list and those available in the library please inform me immediately.

Collaboration policy: I encourage interaction both inside and outside class. We will all learn more by talking over ideas and problems. Students may collaborate *in discussions* on any homework, the project, the readings, but each student is expected to hand in his/her own answers. You may ask people for help with general concepts and Matlab programming but your work (including your Matlab code) must be your own. We do not want to find identical texts and/or algorithms. *Be careful not to take code or text from the web. Anything you get from anywhere else should be scrupulously cited.*
If you are ever unsure about what are appropriate interactions, please discuss the situation with me.

Grading policy: Homework, exams, and other requirements. (Maximum 100 points)

a. Two homeworks will be assigned throughout the course. (*) **15% of the final grade** the design and implementation of a project using Matlab; run simulations of computational models and discus them, and (**) **5% of the final grade** a computer-based ethics quiz (http://cme.cancer.gov/clinicaltrials/learning/humanparticipant-protections.asp) and read the Dana Foundation document "Neuroscience at War" (on the Course Web).

b. 20% of the final grade There will be an in class midterm exam.

c. Incremental work in collaborative groups: 22% of the final grade The class will split in sub-groups and each group will have a project that involves measurements (design experimental paradigms and data collection), quantitative data analysis, data interpretation within the neurophysiological and computational vision frameworks. Each student in the group will take ownership of a part of the project, but must be familiar (understasnd) with the all aspects of the project. Every student in the class will participate in the data acquisition- this should take no more than 3 hours/ throughout the semester. Progress will be presented by each group, three times: 1. Set up the problem and experimental paradigm; 2. Results; 3. Interpretation of results.

d. Final exam. **15% of the final grade** The write up of the project (roughly 5 pages), the neurophysiological, psychophysical, and computational context and interpretation of results constitutes the final exam/requirement.

d. 15% towards the final grade During the semester each student will be required to make three presentations based on a subset of papers relevant to the topics being discussed at that time. Presentations will be

approximately 20-30 minutes each and will be conducted during the second hour of class on Weds. Details regarding the general format of the presentations will be discussed prior to the first set of presentations.

e. **8% of the final grade**. class participation, during the discussion sessions

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NOTE-1: The class will consist of lectures on Monday and the first hour on Weds, or both hours on Weds. Several times during the second hour on Weds there will be student-papers/work presentations, discussion of the reading material or progress on the project. Discussion of the readings will be lead by students in the class (assigned a priori).

NOTE 2: All the materials that you hand in must be typed.

"Late" assignment policy

Late assignments will not be accepted without prior approval. Get prior approval. No exceptions. I am ruthless.

A tutorial in Matlab

http://www.mathworks.com/academia/student_center/tutorials/launchpad.html

Schedule of class topics

January 14: Course Overview

(a) Discussion of course requirements - class material, students' background, homework, projects, and grading policy.
(b) Overview and Sampling of course topics

Please visit this page of optical illusions and visual phenomena. **http://www.michaelbach.de/ot/**
"Illusions of the senses tell us the truth about perception" (Purkinje, cited by Teuber, 1960)

January 19: NO CLASS

January 21: Introduction

The computational approaches to vision (discussions of the different paradigms). Levels of understanding, historical perspective, need for interdisciplinary study, overview of topics to be covered and their relevance in computational neuroscience and potential applications.

Brief discussion of the illusions you have looked at. Every student is expected to comment on 2 "illusions"

January 26&28&Feb 2 (first hour): The anatomical, physiological and computational basis for the representation of visual information in the retina.

(a) The micro-circuitry and functional architecture of the retina.
Retinal sampling by the photoreceptors;
Performance limits of vision (acuity and hyperacuity).
Receptors; horizontal, bipolar, amacrine, and ganglion cells.
(b) Computations in the Retina: Contrast sensitivity.
(c) Visual Fields; Retinal disease; Plasticity?
(d) Retinal Implants. Do they work?

February 2 (second hour) **Probing the functional properties of the visual system: analytic measurements of visual perception**

(a) Psychophysics: What is it and how is it measured?
Psychometric function.
Basic methods (Threshold, Constant stimulus, Staircase)

February 4:

(discussion) Retina: a. Computational models. b. Retinal Implants. c.Contrast sensitivity.

(second hour) Visual Psychophysics. **Establish the working groups and discuss class semester-project.**

February 9&11 Low level representation of image structure in cortex.

(a) The visual pathway in primates from the retina to the brain (Retinal projections)
Thalamus (LGN): Parvocellular and magnocellular layers

(b) The Neocortex and the Anatomy of Vision.
Cytoarchitectonic maps; Lamination;
Thalamus (LGN); Parvocellular and Magnocellular layers;
Topographic arrangement of the retina replicated in the LGN and the Primary Visual Cortex.
Topographic organization in the human visual cortex.
The role of the LGN in visual processing.

(c) Primary Visual Cortex.
Receptive fields;
Visual computations in the primary visual cortex.
Forms of representation in the cortex: coding information (distributed coding, sparse coding)
Blindsight and unsconscious vision

February 16: No class

February 17 (substitution for Feb 16): Class presentations: selected papers on the visual cortex

February 18: Low level vision (cont)

a. Edges and edge detection (brief discussion of computer vision methods). Here are some useful matlab commands for image filtering: http://www.math.hkbu.edu.hk/~cstong/sci3710/filter_tutor.html
Theory, algorithms, detecting intensity changes, removing noise, zero-crossings.
b. Orientation and spatial frequency analysis (contrast sensitivity; hyperacuity); simple and complex cells; neural circuitry underlying orientation selectivity.
Contrast sensitivity (psychophysics and physiology)
c. Computational models of motion measurement in the primary visual cortex.
d. Functional neuroimaging in the primary visual cortex and beyond
e. Human early levels of visual perception

February 23 Midterm Exam
February 25-no class/ Prof. Vaina will be at NIH

March 2: Introduction to neurophysiological and computational networks and neural coding
Visual Networks architectures. Learning Processes (How biological are they?)

March 4: Ethics: The Belmont Project. The HIPAA rules. Research with human subjects. Societal, health, economic impact. Medical Applications. Military application. Industry applications.

Spring break (March 7-15)

March 16&18: Extrastriate Visual Areas and Functional Specialization

(a) Identification of visual areas. Visual areas related to the occipital, parietal, and temporal lobes.
(b) Processing Streams
(c) Hierarchical Processing
(d) Crosstalk between streams at successive stages of processing.
(e) Computations of the Posterior Parietal Neurons (motion, etc)
(f) Mirror Neurons
(g) Functional Imaging in the posterior parietal cortex.

March 23: Visual Psychophysics: Measurements of visual perception II. Signal Detection and the ROC

Experimental design. Discussion of progress on class project by each group.

March 25, 30&April 1 Visual perception of motion.

(a) The correspondence problem
(b) Physiological basis of motion perception
    Visual areas in the dorsal pathway: Receptive fields and visual topography – areas V5 (MT) and MST in the macaque and their function. Where is MT in the human brain? Another motion pathway in the anterior temporal lobe: motion recognition?
    Local and global motion systems
(c) Single cell Physiology, microstimulation and the impact of perception measurements. What electrical microstimulation has revealed about the neural basis of vision? Local Field Potentials in area MT.
(c) Motion measurements and the integration of motion measurements: Motion detection, the aperture problem, motion transparency, local and global motion computations.
(d) Physiology and psychophysics. Seeing neurons discriminate. Complex motion: Radial, circular, and spiral motion.
(e) Function neuroimaging and motion perception. Localization of cortical areas responsive to visual motion.
(f) Biologically motivated computational models of motion processing (V1-MT). (you will run the simulations found here **http://www.cns.nyu.edu/~lcv/MTmodel/)**
(g) Context dependent changes in the functional circuitry of MT.
(h) Deficits of visual motion in neurological patients

April 6: Low level vision algorithms applications to automated medical diagnosis
-Automated segmentation of brain/heart structures in MR images,
Building and implementing models.

April 8: Algorithms applied to vision-based biometric (person identification) systems

April 13&15: . **Optic flow and visual navigation.**

(a) Motion and Optic Flow: Computational models of Velocity field and optic flow. Computational models: Horn & Schunk model. Hildreth's model.
(b) Computing Heading (neurophysiology, psychophysics, and fMRI).
(c) Time to Collision (TTC): neurophysiology, psychophysics, fMRI
(d) Biological Motion: neurophysiology, psychophysics, fMRI
(e) Deficits of high level motion: impaired visually guided navigation.

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April 20: No class

April 22: Visual attention and memory.

April 23 (substitute for April 20): a. Mechanisms of decision making; Linear-nonlinear Poisson modeling of primate choice dynamics; **b**. papers discussion

April 27&29: **Class Presentations. Written final projects are due (4-5 pages).**
Discussion/Review: The role of mathematics, engineering and computer science methods in Vision Science. Biological Vision: where are we? Techniques.