CN/NE 330
Arash Yazdanbakhsh

CN/NE 330
Introduction to Computational Models of Vision

Course Director: Arash Yazdanbakhsh
Office: 677 Beacon Street, Room 213
Office hours: Tuesdays, 1:00 – 2:00pm (by email appointment)

Email: yazdan@bu.edu

Prerequisites: CN/NE 204 or the consent of the course director

Overview: This course will take you step by step through the basic physiological, psychological, mathematical, and computational basis of visual system. Readings and lectures combined with lab sessions and assignments provide an examination of the main topics related to different brain visual areas. Examining and simulating a few neural and computational models in lab sessions offer a better understanding of the architecture and dynamics of the visual system.

Required Textbook: Palmer, S. E. (1999). *Vision science: From photons to phenomenology***.** Cambridge, MA: MIT Press. (Referred to below as PALMER)

Optional Textbook for looking up: Kandel, E. R., Schwartz, J. H., and Jessell, T. M., Principles of Neural Science, Edition 4

Course Grading

MID-TERM EXAM	30% of grade
FINAL EXAM	30% of grade
LAB EXERCISES	30% of grade
ATTENDANCE	10% of grade

The course will offer three hours of lecture and one hour of computer lab each week. Students are required to attend lectures and labs. Students are required to complete weekly lab assignments, a midterm exam, and a final exam. All lab exercises and exams will be based on the assigned readings, lecture materials, and technical concepts covered in lab sessions.

Lab: The first four weeks of the computer lab will cover enough introduction in MATLAB to equip you with necessary skills to simulate small-scale neural models in vision. The rest of the 9 weeks will be divided into three Vision-Labs. Each Vision-Lab is composed of three weeks to apply your earned MATLAB skill into a basic concept in neural modeling in vision. Example of such concepts are contrast detection and normalization, and real time and equilibrium state of multiple neurons related to motion processing.

CN/NE 330
Arash Yazdanbakhsh

Lab Exercises and Assignments: Lab exercises should be completed by the end of each lab session. Teaching fellow (TF) will be around to assist students during and at the end of each weekly lab session. In each weekly lab exercise, students will explore in greater detail the mathematical materials presented in the lectures. Through the lab sessions, students have access to personal computers with MATLAB. Students can collaborate and TF will be assisting, however, at the end of the session, each student should complete her/his own version of the exercise. At the third session of each Vision-Lab, students should provide a written summary and printed plots related to the exercises they have completed throughout the three sessions.

Prepare for each lecture: Read the suggested readings for each week *before* the lectures. This helps you ask questions in class and follow the materials well.

Course Schedule

Week 1

a) Fundamental problems of vision
Motivated by visual examples, we review the challenges faced by the primate visual system in segmenting, grouping, and registering the visual input.

Reading: PALMER Sections 1.1 through 1.2.3, pp. 3-23.

b) Styles of explanation in computational vision
A survey of major historical traditions of theories of visual perception

Reading: PALMER Section 2.1 and 2.2, pp. 45-67

Lab-Intro (1): General introduction to MATLAB

Week 2

a) Survey of "information processing" approaches to vision
Survey of the recent history of information processing approaches to vision

Reading: PALMER Sections 2.3 and 2.4, pp 70-93.

b) Representation in early vision
Introduction to center-surround receptive fields, Difference-of-Gaussians model

Reading: PALMER Sections 2.1 and 2.2, pp. 45-67 and Section 4.3, pp. 171-192

Lab-Intro (2): Implementing basic functions and operations in MATLAB

Week 3

a) Input dynamic range and contrast gain control
An introduction to the *noise-saturation dilemma* in vision and the need to supplement retinal adaptation (bleaching) with cortical background adaptation
Reading: PALMER. Section 4.1.1, pp. 145-151 and Section 4.3, pp. 171-188

b) Introduction to integrate and fire neurons and shunting competitive networks
Divisive normalization for pattern processing in feedforward shunting networks as introduced in CN/NE 204 is reviewed and the analysis deepened to consider the shift-property of automatic gain-control

Reading: Grossberg, S. (1982). Why do cells compete? UMAP Unit 484, The UMAP Journal, Vol. III, No. 1.

Lab-Intro (3): Introduction to MATLAB programming techniques

Week 4

a) Stimulus contrast, contrast sensitivity, and brightness contrast
Key concepts in stimulus contrast and perceptual brightness contrast

Reading: PALMER Sections 4.11, pp. 145-150 and 4.2, pp. 158-170

b) Shunting networks, contrast and constancy
Ratio processing, contrast processing, and “center-surround” networks with distance-dependent kernels
Reading: PALMER, Section 4.2, pp. 158-170

Lab-Intro (4): Implementing basic programming functionality in MATLAB

Week 5

a) Early visual pathways
Overview of main receptive field characteristics of retina, LGN, and V1

Reading: PALMER, Sections 4.1.2 through 4.1.4, pp. 151-157

b) Oriented receptive fields and edge processing
Simple and complex cells

Reading: PALMER, Section 4.4, pp. 193-198

Vision-Lab (1.1): Simulating a one-layer shunting network

Week 6

a) Nonlinear cortical processing: Short-range competition
End-stopping, understood as a competition among orientation-sensitive cells, and cross-orientation inhibition

Reading: Yazdanbakhsh, A. and M. S. Livingstone (2006). "End stopping in V1 is sensitive to contrast." *Nature Neurosci* 9(5): p.697-702.

b) Nonlinear cortical processing: Long-range processing
Cortical visual processes embedding much larger visual field than a single neuron's view filed: inter- or intra-areal?

Reading: PALMER Sec. 6.4.2 to 6.4.4, pp 292-300

Vision-Lab (1.2): Simulating simple and complex cells

Week 7

a) Surface perception and its temporal dynamics
Electrophysiological and perceptual demos related to perceiving uniform surfaces and summary of arguments for and against cortical mechanisms supporting filling-in representation of a surface.

Reading: Rossi AF, Paradiso MA. (1999). Neural correlates of perceived brightness in the retina, lateral geniculate nucleus, and striate cortex. *J Neurosci.* 15;19(14):6145-56

b) Illusory contours, water-color effect, and neon color spreading
Overview of how concepts introduced to date, with a few supplementary ideas, can explain illusory contours and neon color spreading

Reading: PALMER. Sec. 3.3, pp. 122-136

Vision-Lab (1.3): Computing edges, surfaces, and discounting the illuminant

Week 8

a) Mid-term exam

b) Cortical magnification factor
Primary visual cortex looks non-uniformly at the visual world!

Reading: E.L. Schwartz, Spatial mapping in the primate sensory projection: analytic structure and relevance to perception, *Biol. Cybern.* 25 (4) (1977) 181–194.

Vision-Lab (2.1): Simulating oscillatory behavior in neural cell populations

Week 9

a) Temporal dimension of receptive fields
Temporal variation of cell response

Reading: Gregory C. DeAngelis, Izumi Ohzawa, and Ralph D. Freeman (1995) Receptive-field dynamics in the central visual pathways. *Trends Neurosci*. 18: 451-458.

b) Inter– versus intra– areal cortical connections
Exploring the temporal and spatial limits of the connectivities between and within visual cortical areas and their impact in visual processing, plus reviewing the modeling implications

Reading: Bullier J. (2001). Integrated model of visual processing. *Brain Res Brain Res Rev.36*(2-3):96-107

Vision-Lab (2.2): Simulating different types of model neurons, including Integrate and Fire, Hodgkin and Huxley neurons, and cell populations

Week 10

a) Figure-ground segregation
How does our visual system segregate objects against their background?

b) Border-ownership
How does visual system figure out that objects rather than their background own the separating borders?

Reading: Zhou, H., H. S. Friedman, et al. (2000). "Coding of border ownership in monkey visual cortex." *J Neurosci* 20(17): 6594-6611

Vision-Lab (2.3): Simulating border-ownership cells

Week 11

a) Visual short-range motion and suggested models
Phenomena of short-range motion, and correlational and gradient models

b) Motion induced contours, figure-ground segregation, and border-ownership

Reading: PALMER, Sec. 10.1.1, 10.1.2, and 10.1.4 pp. 465-470, and 481-483, and also, Sec. 10.1.5, pp. 484 -486

Vision-Lab (3.1): Simulating motion-selective neurons

Week 12

a) Visual long-range motion and aperture problem

Phenomena of long-range apparent motion. Traveling Gaussian waves as models of long-range apparent motion

Reading: PALMER Sec. 10.1.3, pp. 471-480

b) Frame of reference and induced motion
Perceptual phenomena associated with moving and stationary visual backgrounds further constraint models of visual motion

Reading: Léveillé J., Yazdanbakhsh A. (2010). Speed, more than depth, determines the strength of induced motion, *Journal of Vision*, 10(6): 10, 1-9

Vision-Lab (3.2): Simulating short- and long-range motion processes

Week 13

a) Visual depth, monocular cues
Occlusion, transparency, perspective, and beyond…

b) Visual depth, binocular cues
Absolute disparity, relative disparity, da Vinci stereopsis, and correspondence problem

Reading: DeAngelis GC. (2000). Seeing in three dimensions: the neurophysiology of stereopsis *Trends Cogn Sci* 4: (3) 80-90

Vision-Lab (3.3): Simulating disparity sensitive neurons

Week 14

a) Introduction to eye movements
Different types of eye movements and their impact on retinal image and visual perception

Reading: Martinez-Conde S, Macknik SL, Hubel DH. (2004). The role of fixational eye movements in visual perception. *Nat Rev Neurosci*. 5(3): 229-40

b) Visual attention

Phenomena including innatentional blindness, attentional blink, and change blindness

Reading: PALMER Secs 11.2.1, 11.2.2, and 11.2.3, pp. 531-548, also Fries P, Reynolds JH, Rorie AE, Desimone R. (2001). Modulation of oscillatory neuronal synchronization by selective visual attention, *Science,* 23;291(5508):1560-3.

Vision-Lab: Review and discussion