MATH 991-Spring 2002
Computational and Mathematical Methods in Neuroscience: Vision

Number of Credits 1-3. Final grade is based on a term project.
Course URL: http://www.lmcg.wisc.edu/bioCVG/ for Spring 2002. URL for past offerings: www.cms.wisc.edu/~cvg and go to Courses
Math Dept Home Page: www.math.wisc.edu/~assadi

Texts: Visual Space Perception, Maurice Hershenson. Pub. MIT Press
(2) Selected Chapters from: Understanding Vision, Edited by Glyn Humphreys. Pub. Blackwell Sci. Pub. This text is out-of-print, so copies of the chapters will be distributed, pending publisher's permission.
Recommended Reading. Additional materials will be recommended from the following:

For neuroscience background: A Vision of the Brain, by Srmir Zeki. Blackwell Scientific Publications;
For computation and mathematics: Computer Vision, by Reinhard Klette et al, Springer;
For Learning Theoretic Vision: Shree Nayar and Tomaso Poggio, Oxford Press.

Pedagogical objectives of the course. Explore current findings and do research on topics related to the following grand challenge problems in human vision:

- How does the human brain represent space (visual environment)?
- How does the human brain represent form (of objects)?
- How does the brain perceive form (of objects)?
- How does the brain perceive space (spatial location, place, …)?

All four questions are related. Our task is to learn: (I) how to approach these questions as ***interdisciplinary research problems***; and (II) implement the key steps necessary for success in research.
(A) In the computation/mathematics lectures, we will discuss background materials in the context of an example project that incorporates the items above.
(B) In the science (biology, cognitive science, engineering,…) lectures, we will study the background from current research on visual system and its computational implementations.
(C) The main topics in the course are: visual perception of textured surfaces, perception of motion, and applications to visual perception of natural scenes and face recognition.
In (A), we begin with a review of basic concepts from analysis of data (Principal and Independent Components Analysis, Singular Value Decomposition and reduction of dimensionality,…). Our emphasis throughout the course will be on approximate reasoning based on probability and statistical learning from data. We will provide background on information theory (Shannon's theory of communication, Fisher information, Kullback-Leibler metric,…), Hidden Markov models, Regularization Theory and Support Vector Machines,… . We will also introduce background from Scientific Computation as needed, such as large-scale numerical computation in linear algebra, optimization and genetic and other evolutionary algorithms, neural networks for pattern recognition, feature extraction,…. From these topics, only the most relevant aspects are introduced only for the purposes of the applications in the context of the lectures. Additional materials are available for the students who wish to learn the mathematical topics in more depth, and as part of the student projects. My style is to combine lectures and mentoring development of research skills based on individual background and interest. This has proved quite successful to train students from outside of mathematics to learn the relevant mathematics and computation.
In (B), we begin with a very basic review of the biology of the visual system and in general, biological neural networks. Then we formulate several concrete questions related to visual perception of form and space. Next, we chart a map through the jungle of research material in biological and cognitive aspects of the visual system related to our problems. Finally, in the process, we arrive at some new mathematical/computational problems that we did not anticipate in the beginning. These are mainly geometric problems that we need to formulate in the context of visual perception, and preferably study them via neural networks, genetic and other evolutionary algorithms and other methods.