CN550  Spring 2008
Neural and Computational Models of Recognition, Memory, and Attention

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Office hours: Monday noon (before class); and by appointment.

Classes:  Mondays, 1:00 PM - 5:00 PM, 677 Beacon Street (Basement)
January 28 – April 28, 2008

Schedule notes:  There will be no class on February 18 or April 21 (holidays) or on March 10 (spring break).
CN550 will meet Tuesday Feb 19 and Wednesday April 23 (BU Monday schedule these days).

Course description:  CN550 develops neural network models of how internal representations of sensory events
and cognitive hypotheses are learned and remembered, and of how such representations enable recognition and
recall of these events. Various neural and statistical pattern recognition models, and their historical development
and applications, are analyzed. Special attention is given to stable self-organization of pattern recognition and recall
by Adaptive Resonance Theory (ART) models. Mathematical techniques and definitions to support fluent access to
the neural network and pattern recognition literature are developed throughout the course. Experimental data and
theoretical analyses from cognitive psychology, neuropsychology, and neurophysiology of normal and abnormal
individuals are also discussed. Course work emphasizes skill development, including writing, mathematics,
computational analysis, teamwork, and oral communication.

Class project:  CN550 includes a class project, as described in the accompanying materials. Part of each class is
devoted to discussion of the class project and planning for the coming week. Each student will work in a group with
approximately three other students. Groups should plan to meet during the weekly discussion session and at other
times, as needed.

Computational workshops:  Each class will conclude with a computational workshop.

Course materials:
Lecture notes will be given out in class and made available as PDF files on the wiki.
See p. 3 for textbook information.
Other readings are available from the CN550 wiki. Please use ACS to print articles.

Evaluations:  Your grade will be based on work totaling 400 points:
60  reading journals  weekly
30  article & lecture essay  due April 7
70  class project  weekly; essay due May 12
70  computational workshops  weekly
70  midterm exam  March 24
100  final exam  May 12

Your CN550 grade will also reflect your overall performance, progress, and participation.


CN550 wiki:  http://cns.bu.edu/cn550/
CN710 wikis:  Fall 2007  http://cns.bu.edu/cn710/Fall2007/
CN520 site:  http://www.BUCN520.com
CN550 LECTURES and EXAMS

Jan 28 1. Overview, history, philosophy, benchmark database studies

Feb 4 2. Supervised learning methods: Memory-based algorithms (KNN),
model-independent supervised learning methods (validation & cross-validation,
c-index, ROC curves, resampling, combining classifiers, component analysis),
statistical pattern recognition

Feb 11 3. Unsupervised learning: Clustering (leader, K-means), competitive learning, ART

Feb 19 (Tues) 4. Dimensional analysis, competitive networks, phase plane analysis

Feb 25 5. ARTMAP

March 3 6. Associative memory networks: Back propagation, multi-layer perceptrons,
radial basis functions, cascade-correlation, higher-order networks

March 17 7. Support vector machines

March 24 8. Mid-term exam (1:00 – 3:00 PM) Movie: Rashamon

March 31 9. Physiology, psychology, and memory models.

April 4 (Fri) 10. Roger Ratcliff, Science of Learning Seminar 2:00PM

April 7 11. Liapunov functions, Cohen-Grossberg theorem

April 14 12. Three-layer feedforward networks: Theory and mathematical foundations

April 23 (Wed) 13. Synapses, signal functions, distributed vs. winner-take-all coding
Course evaluations.

May 12 14. Final exam (1:00 - 3:30 PM)

extra 15. Invariance, spatial preprocessing, oscillations, temporal order information (TOI)
extra 16. Wavelets, genetic algorithms, fuzzy set theory
CN550: TEXTBOOKS & READINGS

Most readings for CN550 are recent and classical research articles, reviews, and book chapters.

Many of the reference books and journals listed below are available in the CNS Library: http://www.cns.bu.edu/library/
Please send me recommendations for additional books you would like to have in the Library.

The following books are sold in the Bookstore as CN550 texts.

**Required:**

CN520 is also using this text.

**Recommended:**

New York: Basic Books. (paper)

Reprints from these texts are not included in the photocopied set of readings, neither are extensive readings from primary texts such as Levine (2000) or Kandel, Schwartz, & Jessell (2000), or some classical (and readily available) papers.

**CN550 REFERENCES BOOKS**


*Annual Review of Neuroscience.*


1. Overview, history, philosophy, benchmark database studies
Course goals, topics, methods, assignments
Historical review of principal neural network modules for learning, pattern recognition, and associative memory
Class project: Comparative studies of supervised learning systems
Benchmark database studies

Overview, history, philosophy


Memory extremes: Audio & video
Unique memory lets woman replay life like a movie
Morning Edition, April 20, 2006 · Neurobiologist James McGaugh, one of the world's experts on human memory, says that a woman he calls AJ has a one-of-a-kind memory. In an interview with NPR, she talks about what life is like for someone who can remember things she’s done and news events from almost every day of her life for the past 25 years. Her life is like a split-screen movie, with the past running almost as vividly as the present.

Clive Wearing: Living without memory YouTube (BBC – The Mind): Pt2a Pt2b Pt2c Pt2d
Wikipedia: Clive Alex Wearing (born 1938) is a British musicologist, conductor, and keyboardist suffering from an acute and long lasting case of anterograde amnesia. Specifically, this means he lacks the ability to form new memories, dubbed the "memento" syndrome by laypeople and the media, after a film based on the subject of the same name.
Class project databases

CN710 wikis – including financial database reports and results
- Fall 2007  http://cns.bu.edu/cn710/Fall2007/

Financial prediction
Versace, Massimiliano, Bhatt, Rushi, Hinds, Oliver, & Shiffer, Mark (2004) Predicting the exchange traded fund DIA with a combination of genetic algorithms and neural networks. Expert Systems with Applications, 27(3), 417-425. [This paper, by four CNS students, began with the CN550 class project.]

UCI Repository

Response plots

Writing
2. Supervised learning methods: Memory-based algorithms (KNN), model-independent supervised learning methods (validation & cross-validation, c-index, ROC curves, resampling, combining classifiers, component analysis), statistical pattern recognition

Memory-based algorithms: K-nearest neighbors (K-NN)
Approaching supervised learning problems fairly and systematically
Training, testing, validation, and cross-validation
ROC curves and the c-index
Resampling: bootstrapping, boosting, bagging
Combining systems: mixing models and voting
Data preparation: component analysis
Brief introduction to statistical pattern recognition and Bayesian estimation

Memory-based algorithms  http://en.wikipedia.org/wiki/KNN


Training, testing, validation, and cross-validation


C-index and ROC curves  http://en.wikipedia.org/wiki/Roc_curve


9.4.1 Jackknife  http://en.wikipedia.org/wiki/Resampling_%28statistics%29#Jackknife

9.5.1 Bagging  http://en.wikipedia.org/wiki/Bootstrap_aggregating
9.5.2 Boosting  http://en.wikipedia.org/wiki/Boosting

[CONTINUED ON THE FOLLOWING PAGE]
Mixing models and voting

Section 9.7: Combining classifiers, pp. 495-499.


Component analysis

Section 3.8: Component analysis and discriminants, pp. 114-124
3.8.1 Principal component analysis (PCA) [http://en.wikipedia.org/wiki/Principal_Component_Analysis](http://en.wikipedia.org/wiki/Principal_Component_Analysis)
3.8.3 Multiple discriminant analysis


3.1 Introduction
3.2 Maximum-likelihood estimation (MLE) [http://en.wikipedia.org/wiki/Maximum_likelihood](http://en.wikipedia.org/wiki/Maximum_likelihood)
3.4 Bayesian parameter estimation: Gaussian case
3. Unsupervised learning: Clustering (leader, K-means), competitive learning, ART

Clustering algorithms: Leader clustering and K-means clustering
Norms and metrics
Competitive learning
Adaptive resonance theory - 1970s
ART 1: Binary pattern learning
ART 2-A: A fast, algorithmic version of ART 2
Freud's neural networks

Clustering  http://en.wikipedia.org/wiki/Data_clustering


Competitive learning

    Chapter 4: Competition, lateral inhibition, and short-term memory, pp. 95-154.
    Chapter 6: Coding and categorization, pp. 198-279.


Adaptive Resonance Theory - 1970s


ART 1


ART 2-A algorithm


[CONTINUED ON THE FOLLOWING PAGE]


4. Dimensional analysis, competitive networks, phase plane analysis

Dimensional analysis
Dynamics of on-center off-surround shunting competitive networks
Phase plane analysis of competitive networks


Chapter 6: Simplification, dimensional analysis, and scaling, pp. 185-224

  - Section 4.3: Formulating a model
  - Section 4.4: Saturating nutrient consumption rate
  - Section 4.5: Dimensional analysis of the equations

**Phase plane analysis**  [http://en.wikipedia.org/wiki/Phase_plane](http://en.wikipedia.org/wiki/Phase_plane)

Sections 5.2-5.9: Phase-plane methods and qualitative solutions, pp. 171-193.

Boston University Ordinary Differential Equations Project: [http://math.bu.edu/odes/](http://math.bu.edu/odes/)
  - Section 3.3: Phase planes for linear systems with real eigenvalues, pp. 266-282.
  - Section 5.2: Qualitative analysis, pp. 457-470.
5. ARTMAP

Fuzzy ART: Generalized ART 1, for analog inputs, using the city-block metric (L1 norm)
Supervised learning by ART systems
Binary ARTMAP
Analog fuzzy ARTMAP

Fuzzy ART


Supervised learning by ARTMAP systems


Fuzzy ARTMAP and other ARTMAP networks


6. Associative memory networks: Back propagation, multi-layer perceptrons, radial basis functions, cascade-correlation, higher-order networks

Back propagation
Multi-layer perceptrons
(Local) minimization of cost functions
Radial basis functions (RBFs)
Cascade-correlation architecture
Higher order networks

The perceptron  http://en.wikipedia.org/wiki/Perceptron


Radial basis functions (RBFs)  http://en.wikipedia.org/wiki/Radial_basis_function


Higher order networks

7. Support vector machines

Support vector machines (SVMs)
Constrained optimization
Lagrange multipliers
Structural risk minimization
VC dimension

Constrained optimization and Lagrange multipliers


V-C dimension


Additional SVM resources

CN710 Readings re: SVM, especially the Bennett and Campbell paper .

-- Midterm exam. Movie: Rashamon --
8. Physiology, psychology, and memory models

Neural substrates of memory
Cortical organization
Neuropsychology of memory and amnesia
Synaptic modification
Redistribution of synaptic efficacy: What is a weight?

NOTE: This is an optional CN550 textbook. Try at least to skim it, reading sections that interest you.

**Neural substrates of memory**

http://en.wikipedia.org/wiki/Cerebral_cortex

Appendix 1: Basic Facts of Neurobiology, pp. 375-395.


**Neuropsychology of memory and amnesia**

Clive Wearing: Living without memory YouTube (BBC – The Mind): Pt2a  Pt2b  Pt2c  Pt2d


**Synaptic modification**

http://en.wikipedia.org/wiki/Long-term_potentiation


Robert Malenka podcast – Synaptic plasticity: Multiple mechanisms and functions

**Redistribution of synaptic efficacy**


9. Content-addressable memories (CAM), active network design

Content-Addressable Memory (CAM)
Net STM activity of statistical ensembles
Nonspecific modulation and active regulation of STM
Principled construction of neural network models

Competitive networks


STM system design

10. Liapunov functions, Cohen-Grossberg theorem

Liapunov functions and the LaSalle invariance principle
The Cohen-Grossberg theorem

http://en.wikipedia.org/wiki/Lyapunov_function
http://mathworld.wolfram.com/LyapunovFunction.html

The Cohen-Grossberg theorem


Section 9 - Content-addressable memory storage: a general STM model and Liapunov method, pp. 24 - 30.

Additional resource


Sections 5.1 and 5.2.
11. Three-layer feedforward networks: Theory and mathematical foundations

Mappings by three-layer feedforward networks: mathematical analysis

Mapping by 3-layer feedforward networks

http://en.wikipedia.org/wiki/Hilbert%27s_problems
http://en.wikipedia.org/wiki/Hilbert%27s_thirteenth_problem


Reference book: Mathematical analysis

12. Synapses, signal functions, distributed learning

Neurobiology of chemical synapses, neuromodulators, and short-term synaptic plasticity
Retrograde messengers
ART 3: Chemical transmitters, retrograde messengers, and neuromodulators for implementing parallel memory search
Distributed outstar learning and rules of synaptic transmission

Physiology of chemical synapses

http://en.wikipedia.org/wiki/Synapse


http://en.wikipedia.org/wiki/Nitric_oxide


Rules of synaptic transmission and distributed outstar learning

13 [extra]. Invariance, spatial preprocessing, oscillations, temporal order information (TOI)

Invariant pattern recognition
Fourier analysis
Log-polar-Fourier filter
Singular solutions
Hopf bifurcation
Coding of temporal order information for event sequences
Free recall paradigm
Models of TOI: buffer, activation gradient, oscillations

**Image transforms and preprocessing**


**Oscillations in dynamical systems: Hopf bifurcation and singular solutions**


**Temporal order information (TOI)**


- Sections 1, 23-38 (From *Studies of Mind and Brain*, pp. 500-512, 564-591.)

**Buffer models**


- Section 61: Automatic versus controlled information processing (SMB: pp. 626-631)
14 [extra]. Wavelets, genetic algorithms, fuzzy set theory

Wavelets
Introduction to genetic algorithms
Fuzzy set theory: definitions

Wavelets
http://en.wikipedia.org/wiki/Wavelet

Preliminaries and notation, pp. xi - xix.
Chapter 1: The what, why, and how of wavelets, pp. 1 - 16.

http://www.cl.cam.ac.uk/~jgd1000/csvt.pdf

Introduction to genetic algorithms
http://en.wikipedia.org/wiki/Genetic_algorithm

Section 7.5.1: Genetic algorithms, pp. 373-377.


Introduction to fuzzy set theory and fuzzy classification
http://en.wikipedia.org/wiki/Fuzzy_sets
http://en.wikipedia.org/wiki/Fuzzy_logic


Section 4.7: Fuzzy classification, pp. 192-195.

Section 10.4.4: Fuzzy k-means clustering, pp. 528-530.