CN550: Spring 2006  
Neural and Computational Models of Recognition, Memory, and Attention

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Office hours: Tuesdays after class; and by appointment.

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(617) 353-6180  
Office hours: Tuesday 3:30-4:30 PM (before class); and by appointment.

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Classes:  
Tuesdays, 5:00 PM - 9:00 PM, 677 Beacon Street (Basement)  
January 17 - May 2, 2006

Schedule notes:  
There will be no class on Tuesday February 21 (Monday schedule that day) or on Tuesday, March 7 (spring break).

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. Each class begins with a quiz, followed by a lecture/discussion. The last part of class is devoted to discussion of the class project and planning for the coming week. Each student will work in a group with approximately 3-4 other students. Groups should plan to meet during the 8-9PM discussion hour and at other times, as needed.

Course materials:  
Lecture notes will be given out in class and made available as PDF files.  
See p. 3 for textbook information.  
You may purchase a package of the readings marked CC in the syllabus.  
$50.00 due by Wednesday, January 18, 3:00 PM (cash, or check to Gail Carpenter).

Evaluations: Your final grade will be based on weekly quizzes (100 points), the reading journal (100 points total), your work on the class project (100 points), and a final exam (100 points). Your final grade will also reflect your overall performance, progress, and participation.

Exams (closed book):  
Quizzes (weeks 2-12) - Tuesdays at 5:00PM in the CNS Auditorium  
Final (2 1/2 hours) - Tuesday, May 2, 5:00 - 7:30 PM

Syllabus on the web:  

Related CNS courses:  
CN 510: http://cns.bu.edu/~guenther
CN 520: http://cns.bu.edu/~shinn/pages/CN520/syllabus.html

CN550 Wiki:  
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<th>Topic</th>
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<td>Jan 17</td>
<td>1. Overview, history, philosophy</td>
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<td>Jan 24</td>
<td>2. Supervised learning methods: Memory-based algorithms (KNN), model-independent supervised learning methods (validation &amp; cross-validation, c-index, ROC curves, resampling, combining classifiers, component analysis), statistical pattern recognition</td>
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<td>Jan 31</td>
<td>3. Unsupervised learning: Clustering (leader, K-means), competitive learning, ART</td>
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<td>Feb 7</td>
<td>4. Dimensional analysis, competitive networks, phase plane analysis</td>
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<td>Feb 14</td>
<td>5. ARTMAP</td>
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<td>Feb 28</td>
<td>6. Associative memory networks: Back propagation, multi-layer perceptrons, radial basis functions, cascade-correlation, higher-order networks</td>
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<td>March 14</td>
<td>7. Support vector machines</td>
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<td>March 21</td>
<td>8. Physiology, psychology, and memory models</td>
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<td>March 28</td>
<td>9. Content-addressable memories (CAM), active network design</td>
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<td>April 4</td>
<td>10. Liapunov functions, Cohen-Grossberg theorem</td>
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<td>April 11</td>
<td>11. Three-layer feedforward networks: Theory and mathematical foundations</td>
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<td>April 18</td>
<td>12. Synapses, signal functions, distributed vs. winner-take-all coding</td>
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<td>April 25</td>
<td>13. Invariance, spatial preprocessing, oscillations, temporal order information (TOI). Course evaluations, class party.</td>
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<td>May 2</td>
<td>14. Final exam (5:00 - 7:30 PM)</td>
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CN550: TEXTBOOKS & READINGS

Most readings for CN550 are recent and classical research articles, reviews, and book chapters. Papers in the CN550 readings package are marked in the syllabus by CC.
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.
You are welcome to use materials in the Library, but you may not remove books or journals.
Many journals are accessible via the web from BU IP addresses: http://www.bu.edu/library/ejournals/index.html

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

**Required:**


**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, and Jessell (2000), or some classical (and readily available) papers.

**CN550 REFERENCES BOOKS**


*Annual Review of Neuroscience*.


JOURNALS

For a list of journals that are accessible from BU IP addresses see:
http://www.bu.edu/library/ejournals/index.html

Elsevier’s ScienceDirect is a good resource: http://www.sciencedirect.com/science/journals

Most of these journals are in the CNS Library, Room 216: http://cns.bu.edu/library/journallist.html

Behavioral and Brain Sciences http://www.bbsonline.org/bbsprints.html


Cognitive Science, Ablex Publishers

Connection Science, Carfax Publishers

IEEE Transactions on Neural Networks, IEEE

IEEE Transactions on Pattern Analysis and Machine Intelligence, IEEE Computer Society

Journal of Cognitive Neuroscience, MIT Press

Journal of Experimental Psychology - Learning, Memory, and Cognition

Machine Learning, Kluwer Academic Publishers


Memory and Cognition, Psychonomic Society

Nature, Nature Publishing Group

Nature Neuroscience, Nature Publishing Group

Neural Computation, MIT Press

Neural Networks, Elsevier Publications Cambridge

Neural Processing Letters, Kluwer

Neurocomputing, Elsevier Publications Cambridge

Psychological Review, American Psychological Association

Science, American Association for the Advancement of Science

Trends in Cognitive Sciences, Elsevier Publications Cambridge

Trends in Neurosciences, Elsevier Publications Cambridge
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**


**Class project databases**

**Auto-MPG**

**Letter recognition**

**Benchmark databases**

**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


Training, testing, validation, and cross-validation


C-index and ROC curves

Written notes in handout


Resampling: Bootstrapping, boosting, bagging

  9.4.1 Jackknife
  9.4.2 Bootstrap

  9.5.1 Bagging
  9.5.2 Boosting

[CONTINUED ON THE FOLLOWING PAGE]
Mixing models and voting


Component analysis


3.8.1 Principal component analysis (PCA)
3.8.2 Fisher linear discriminant
3.8.3 Multiple discriminant analysis

Maximum-likelihood and Bayesian parameter estimation


3.1 Introduction
3.2 Maximum-likelihood estimation
3.3 Bayesian estimation
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
Fuzzy ART: Generalized ART 1, for analog inputs, using the city-block metric
ART 2-A: A fast, algorithmic version of ART 2
Freud's neural networks

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


[CONTINUED ON THE FOLLOWING PAGE]
Fuzzy ART


ART 2-A algorithm


Freud's neural networks


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

**Dimensional analysis**

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**

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

Section 3.3: Phase planes for linear systems with real eigenvalues, pp. 266-282.
Section 5.2: Qualitative analysis, pp. 457-470.
Section 5.3: Hamiltonian systems, pp. 470-488.
Section 5.4: Dissipative systems, pp. 488-510.
5. ARTMAP

Supervised learning by ART systems
Binary ARTMAP
Analog fuzzy ARTMAP

Supervised learning by ARTMAP systems


Fuzzy ARTMAP and other ARTMAP networks


Carpenter, Gail A. (2003). Default ARTMAP. *Proceedings of the International Joint Conference on Neural Networks (IJCNN '03)*, Portland, Oregon, 1396-1401.  CC
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


Back propagation and cost functions


Associative memory models

Chapter 3: Associative Learning and Synaptic Plasticity, pp. 41-94.

Radial basis functions (RBFs)


Cascade-correlation network


Higher order networks
7. Support vector machines

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

Support vector machines and constrained optimization


8. Physiology, psychology, and memory models

Neural substrates of memory
Cortical organization
Synaptic modification
Long-term potentiation (LTP), NMDA receptors, nitric oxide (NO)
Redistribution of synaptic efficacy
Neuropsychology of memory and amnesia

Schacter, Daniel L. (1996) Searching for Memory: The Brain, the Mind, and the Past. New York: Basic Books. NOTE: This is an optional CN550 textbook. Try at least to skim it, reading sections that interest you.

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


Synaptic modification


Redistribution of synaptic efficacy


Neuropsychology of memory and amnesia


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

The Cohen-Grossberg theorem


Section 9 - Content-addressable memory storage: a general STM model and Liapunov method, pp. 24 - 30. CC
11. Three-layer feedforward networks: Theory and mathematical foundations

Mappings by three-layer feedforward networks: mathematical analysis

Mapping by 3-layer feedforward networks


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


Retrograde messengers and ART 3


Rules of synaptic transmission and distributed outstar learning

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

Course evaluations, class party.

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


Chapter 8: The spatial frequency domain, pp. 298-326 CC

Chapter 8: Pre-processing and feature extraction, pp. 295 - 331. CC

Oscillations in dynamical systems: Hopf bifurcation and singular solutions


Temporal order information (TOI)

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

Buffer models


14. Final exam, 5:00PM - 7:30PM