

## 9.54 Computational aspects of biological learning

### Course Instructors

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Teaching Assistants: Chen Sun

Class Times: M, W 3:00-4:30 pm

Location: 46-5193

starts Wednesday, Sept 4th;

Prereq: 9.40

### Synopsis

Takes a computational approach to learning in the brain by neurons and synapses. Examines supervised and unsupervised learning as well as possible biological substrates, including Hebb synapses and the related topics of Oja flow and principal components analysis. Discusses hypothetical computational primitives in the nervous system, and the implications for unsupervised learning algorithms underlying the development of tuning properties of cortical neurons. Also focuses on a broad class of biologically plausible learning strategies.

# Syllabus

|                           |            |                                                                                                |
|---------------------------|------------|------------------------------------------------------------------------------------------------|
| Class 01                  | Wed Sep 03 | <b>Levels of understanding</b>                                                                 |
| Class 02                  | Mon Sep 08 | <b>Types of learning</b>                                                                       |
| Class 03                  | Wed Sep 10 | <b>Biophysics of Computation</b>                                                               |
| Class 04                  | Mon Sep 15 | <b>Supervised Learning:</b> regression and classification, linear and nonlinear, RBFs and MLPs |
| Class 05                  | Wed Sep 17 | <b>Supervised Learning:</b> local methods+kernels and applications                             |
| Class 06                  | Mon Sep 22 | <b>Supervised Learning:</b> regularization                                                     |
| Class 07                  | Wed Sep 24 | <b>Supervised Learning:</b> online learning and back-propagation                               |
| Class 08                  | Mon Sep 29 | <b>Supervised Learning:</b> associative memories                                               |
| Class 09                  | Wed Oct 01 | Review                                                                                         |
| Class 10                  | Mon Oct 06 | <b>Unsupervised Learning:</b> PCA, background and applications                                 |
| Class 11                  | Wed Oct 08 | <b>Unsupervised Learning:</b> PCA in neurons, Hebb synapses and Oja's rule                     |
| Mon Oct 13 - Columbus Day |            |                                                                                                |
| Class 12                  | Wed Oct 15 | <b>Unsupervised Learning:</b> Introduction to Independent Component Analysis (ICA)             |

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|---------------------------|------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| Class 13                  | Mon Oct 20 | <b>Unsupervised Learning:</b> Clustering, k-means and visual words                                                                                  |
| Class 14                  | Wed Oct 22 | Midterm Review                                                                                                                                      |
| Class 15                  | Mon Oct 27 | Midterm Exam                                                                                                                                        |
| Class 16                  | Wed Oct 29 | <b>Unsupervised Learning:</b> Features for classification                                                                                           |
| Class 17                  | Mon Nov 03 | <b>Reinforcement Learning:</b> Introduction, model-based RL                                                                                         |
| Class 18                  | Wed Nov 05 | <b>Reinforcement Learning:</b> Model-free RL I                                                                                                      |
| Mon Nov 10 - Veterans Day |            |                                                                                                                                                     |
| Class 19                  | Wed Nov 12 | <b>Reinforcement Learning:</b> Model-free RL II, applications                                                                                       |
| Class 20                  | Mon Nov 17 | <b>Reinforcement Learning:</b> Biology of RL: dopamine, RL brain structures                                                                         |
| Class 21                  | Wed Nov 19 | <b>Learning Invariant Representations:</b> Object recognition, Hubel and Wiesel, Fukushima, HMAX                                                    |
| Class 22                  | Mon Nov 24 | <b>Learning Invariant Representations:</b> Unsupervised learning in the ventral stream, invariance and selectivity for compact groups               |
| Class 23                  | Wed Nov 26 | <b>Learning Invariant Representations:</b> Invariance for locally compact groups and non-groups, clutter and hierarchies                            |
| Class 24                  | Mon Dec 01 | <b>Learning Invariant Representations:</b> Spectral theory, Hebb rule, simple cells tuning, models of simple and complex cells, learning the wiring |
| Class 25                  | Wed Dec 03 | <b>Learning Invariant Representations:</b> From invariance to architecture of retina, V1, V2, V4, IT                                                |
| Class 26                  | Mon Dec 08 | Review for final exam                                                                                                                               |

## UNSUPERVISED LEARNING module

- PCA, background and applications
- PCA in neurons, Hebb synapses and Oja's rule
- Introduction to Independent Component Analysis (ICA)
- Clustering, k-means and visual words
- Features for classification

## SUPERVISED LEARNING module

- Supervised learning: memory is trivial, generalization is key: from look-up tables to generalization, from memory to learning: memory-based learning algorithms, shannon, RF (Mallot)
- Gaussian-like tuning, memory-based intelligence and RBF in RKHS Neurons, synapses and supervised online learning algorithms
- Learning Hyperacuity+ learning to recognize
- Associative memories: Willshaw- Longuet-Higgins, Hopfield, Kanerva, Platt
- Deep learning in hierarchical networks, back propagation, Hilbert's problem

## REINFORCEMENT LEARNING module

- Introduction, model-based RL
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- Model-free RL I
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- Model-free RL II, applications
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- Biology of RL: dopamine, RL brain structures

## INVARIANT REPRESENTATION LEARNING module

- Object recognition, Hubel and Wiesel, Fukushima, invariance

- Unsupervised learning in the ventral stream, invariance and selectivity for compact groups
- Invariance for locally compact groups and non-groups
- Clutter and hierarchies
- From invariance to architecture of retina, V1, V2, V4, IT
- Spectral theory, Hebb rule, simple cells tuning, models of simple and complex cells, learning the wiring