Psychology 5618

Introduction to Computational Cognitive Neuroscience

Course Announcement, Autumn 2014

Credits:	3
Times:	Tuesdays and Thursdays 9:35–10:55 a.m.
Room:	Psychology Building, Room 219
Prerequisites:	Graduate standing OR Neuroscience major OR Psych 2220 and Psych 2300 and (Psych 3313 or Psych 3513) OR Permission by instructor. (Psych 5612 is strongly recommended at all levels, but not required.)
Textbooks:	**1.** Trappenberg, T. P. (2010). *Fundamentals of Computational Neuroscience* (2nd Ed.). Oxford, UK: Oxford University Press. **2.** McClelland, J. L. (2011). Explorations in Parallel Distributed Processing: A Handbook of Models, Programs, and Exercises (2nd Ed., in preparation). PDF available free of charge at http://www.stanford.edu/group/pdplab/pdphandbook/
Instructor:	Dr. Alexander Petrov, apetrov@cogmod.osu.edu

Course Overview

How does cognition emerge from the brain? This course introduces you to the exciting interdisciplinary field of Computational Cognitive Neuroscience (CCN) that provides important pieces of the answer to this question. We focus on simulations of cognitive and perceptual processes, using neural network models to bridge the gap between biology and behavior. We first consider briefly the basic physiological and computational properties of individual neurons and networks of neurons, as well as their idealized model counterparts. We discuss basic processing mechanisms such as spiking, dendritic integration, temporal filtering, spreading activation, inhibition, and multiple constraint satisfaction. We introduce concepts and techniques from dynamical systems theory, information theory, and control theory and illustrate their utility in understanding neural systems. We then discuss learning mechanisms that allow networks of neurons to build internal models of their environments and perform complex tasks. Models illustrating these ideas will be demonstrated in class and explored in homework assignments. The emphasis is on biological plausibility and psychological adequacy rather than on machine learning considerations. Hands-on exploration of neural network models is an integral component of this course. Each student will need access to a computer with a licensed copy of the Matlab software environment (http://www.mathworks.com/products/matlab/). (All OSU students have access to a university-wide license for Matlab installations on personally owned computers for academic use; https://ocio.osu.edu/software). The explorations are based on open-source software that comes with the textbooks and implements various neural network models in the Matlab programming language. No prior knowledge of Matlab is required and most models can be explored via a point-and-click user interface. We complement these simple demos with a few case studies of research-grade models of various aspects of perception and memory. Finally, we turn to big-picture issues and outline two connectionist proposals of cognitive architectures and their plausible neural substrate.

Topics

The following is a list of some of the topics that will be covered in the course. The list is preliminary and provided for illustrative purposes only.

- Neurophysiology review: membrane potential, ion channels, synaptic currents
- Gentle introduction to ordinary differential equations. Matlab demos
- Gentle introduction to the Hodgkin-Huxley equations of spike generation
- Integrate-and-fire model neuron, Izhikevich model neuron, hysteresis, bursting
- Gentle introduction to dynamical system theory, phase portraits, attractors
- Firing rates and population averages, activation functions. Connectionist models
- Feedforward networks, population codes, encoding, decoding, transformations
- Standard model of simple and complex cells in primary visual cortex
- Inhibition, gain control (Heeger), surround suppression in primary visual cortex
- Interactive activation and competition (IAC) model. Constraint satisfaction
- Pattern associator network. Review of linear algebra. Linear separability
- Synaptic plasticity, long-term potentiation and depotentiation, Hebbian learning
- Perceptron. Error-correcting (task) learning. Delta rule. Cerebellum
- XOR problem, multi-layer perceptron, backpropagation, gradient descent
- Machine learning, generalization, overfitting, cross-validation, regularization
- Winner-takes-all networks. Competitive learning. Self-organizing maps
- Simple recurrent (Elman) networks. Backpropagation through time
- Is error-correcting learning biologically plausible? Contrastive Hebbian learning
- Deep networks. Invariant object recognition. Semi-supervised learning
- Recurrent autoassociative memory. Pattern completion, content addressability
- Complementary learning systems in the hippocampus and neocortex
- Neuromodulation: dopamine, norepinephrine, etc. Tonic and phasic timescales
- Reinforcement learning, actor-critic architecture, exploration/exploitation tradeoff
- Temporal difference learning. Dopamine and prediction error.
- Executive control. Stroop. Production systems. Gating in the basal ganglia
- Activation-based memory in the prefrontal cortex. Working memory
- Relational reasoning, propositions. Binding problem and proposed solutions
- Holographic reduced representations, semantic pointers (Eliasmith), cleanup
- Cognitive architectures. Tripartite architecture (O'Reilly). SPAUN (Eliasmith)
- Synthetic brain imaging: Modeling the MRI BOLD signal using neural networks

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