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Author

Noelle, David C.

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Computational Cognitive Neuroscience Modeling Using Leabra In PDP++

David C. Noelle (dnoelle@ucmerced.edu)
University of California, Merced, 5200 North Lake Road
Merced, CA 95344 USA

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Overview

Computational cognitive neuroscience involves the fabrication, analysis, and evaluation of computational models that attempt to bridge the gap between brain function and overt behavior. The Leabra modeling framework provides an integrated collection of conceptual tools for the construction of such models. Leabra incorporates important biological features of neural systems, such as membrane potential dynamics, rapid shunting lateral inhibition, and biologically realistic mechanisms for synaptic plasticity, while incorporating computationally efficient approximations of aggregate network behavior, allowing model simulations to scale up to tasks of psychological relevance. Thus, Leabra spans a middle ground between biophysically detailed neural simulations and cognitive models, including abstract connectionist models, that are grounded in psychological theory. Leabra has been implemented in the `PDP++` simulator: an open source software package that includes support for a variety of connectionist frameworks in addition to Leabra. `PDP++` provides a graphical point-and-click interface for constructing, executing, and analyzing computational models, but it may also be easily extended through the incorporation of additonal `C++` code. This tutorial will provide an overview of the Leabra framework, as well as hands-on experience with Leabra models of perception, attention, learning, memory, and cognitive control.

Expected Background of Participants

This tutorial will introduce participants to the Leabra framework, including the generation and manipulation of Leabra models using the `PDP++` software system. This material will be presented so as to be accessible to researchers with no background in cognitive modeling, connectionism, or computational neuroscience, though participants who have had some exposure to these topics will find many new insights over the course of the tutorial. Attendees are expected to have some background in cognitive psychology, cognitive neuroscience, or artificial intelligence, and they are expected to have a basic understanding of differential calculus, linear algebra, probability, and statistics. The mathematics used in this tutorial should not be challenging to graduate students with a scientific background, but those who quake at the sight of equations may not appreciate this material. The ability to navigate the graphical computer environments provided by modern Windows® XP, Mac OS® X, or Linux® systems will be needed in order to complete the simulation exercises. While `PDP++` can be extended using `C++` code, no knowledge of `C++` programming will be needed to benefit fully from this meeting. In short, very little specialized background knowledge will be expected of participants.

Preparation for the Tutorial Session

No preparatory activities are required for participation in this tutorial. Participants may opt, however, to download and install the `PDP++` implementation of Leabra, along with most of the simulation exercises that will be used during the tutorial session, prior to arrival. These may be freely downloaded from the "Download Exploration Simulations" link at:

`psych.colorado.edu/~oreilly/comp_ex_cog_neuro.html`

There are `PDP++` executables at this web site for Linux®, Microsoft® Windows® (using Cygwin™), Mac OS® X (using Darwin), and various flavors of Unix®. The `PDP++` system is an open source project, with source code available at:

`psych.colorado.edu/~oreilly/PDP++/PDP++.html`

Installation of this software prior to arrival at the tutorial site will allow more time to be spent on matters of substance.

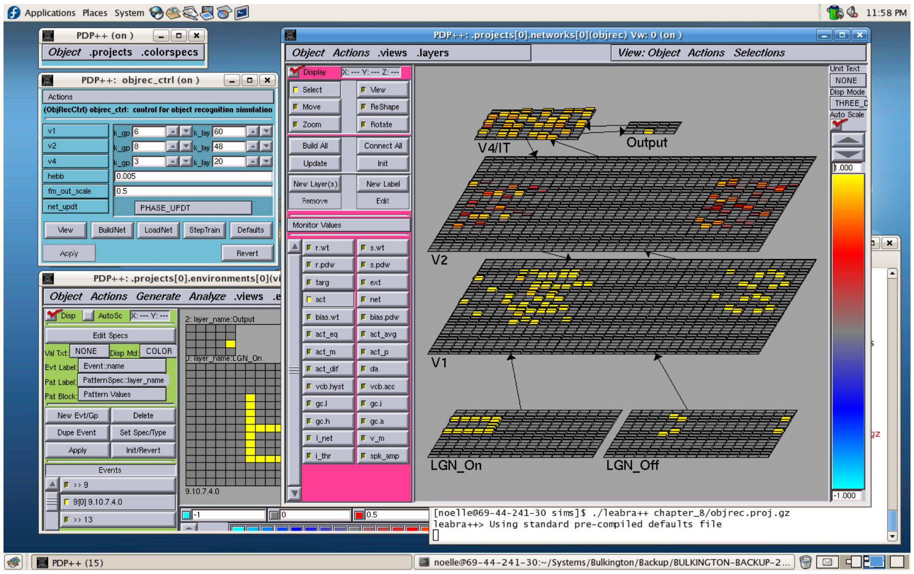
Learning Goals

Attentive participants will leave this tutorial with a foundational understanding of Leabra, as well as the ability to execute, manipulate, and examine `PDP++` simulations. While the tools needed to construct completely novel Leabra models from scratch will be introduced, it is unreasonable to expect participants to become fluent in such skills over the course of this short tutorial. Each participant will also receive a copy of `PDP++` (if they brought a laptop computer), extensive slides, and step-by-step notes for the simulation exercises.

Topics to be Covered

This tutorial is divided into roughly two parts. During the first half, the basics of the Leabra framework are introduced and simulation demonstrations using `PDP++` are used to drive home the central principles of the modeling approach. In particular, this section includes material on:

- the dynamics of membrane potentials
- Leabra's point-neuron approximation
- Leabra's spiking model and its firing rate approximation
- the dynamics of bidirectional excitation
- the dynamics of fast feedforward and feedback inhibition
- Leabra's efficient approximation of shunting inhibition



```
[noelle@69-44-241-30 sims]$ ./leabra++ chapter_8/objrec.proj.gz
leabra++> Using standard pre-compiled defaults file
```

Figure 1: View of a Leabra simulation in the PDP++ system.

- using activation dynamics to satisfy constraints
- associative learning in Leabra
- biologically realistic error-correction learning in Leabra
- dopamine-based reinforcement learning in Leabra

Most of this initial section involves lecture presentations, though simulation demonstrations will be used to communicate concepts, and participants will be welcome to follow along with such demonstrations on their own computers. The second half of the tutorial is more hands-on, and involves an examination of several selected models of cognitive performance. These models are "prepackaged" and designed with pedagogy in mind. After a brief introduction to the general tripartite cognitive architecture often used to guide Leabra models (involving slightly different processing mechanisms in the frontal cortex, in the medial temporal lobe, and in the rest of neocortex), specific cognitive models from a number of focal psychological domains will be examined, including:

- classical conditioning
- visual perception and attention
- the hippocampal memory system
- the prefrontal cortex in cognitive control and flexibility

Each of these models is quite rich, providing ample opportunities for exploration and the garnering of insights. A brief wrap-up session will be used to address general questions from the attendees.

Biography of Instructor

David C. Noelle is an Assistant Professor at the University of California, Merced, with appointments in Computer Science and Cognitive Science. Until recently, he was Assistant Professor of Computer Science and Psychology at Vanderbilt University. He received his Ph.D. in Cognitive Science and Computer Science from the University of California, San Diego, and did postdoctoral work at the Center for the Neural Basis of Cognition, a joint project of Carnegie Mellon University and the University of Pittsburgh. His research primarily involves the design, analysis, and evaluation of computational cognitive neuroscience models of rule learning and rule use, with a focus on the role of prefrontal cortex in the learning and production of rule-guided behavior. Along with an international team of collaborators, he is currently investigating the development of hierarchical control representations in frontal cortex, employing computational models using the Leabra framework. One of these fellow scientists is Randy O'Reilly, the principal architect of Leabra, with whom Noelle has been collaborating for almost ten years.

Acknowledgments

Some material for this tutorial is drawn from *Computational Explorations in Cognitive Neuroscience* (O'Reilly & Munakata, 2000), and thanks are due to the authors of this excellent volume for their permission to use these resources. Thanks are also due to Ashish Gupta for his work developing the conditioning simulation exercise.

References

O'Reilly, R. C., & Munakata, Y. (2000). *Computational explorations in cognitive neuroscience: Understanding the mind by simulating the brain*. Cambridge, Massachusetts: MIT Press.