Multi-level Simulation Methodology: A Computational And Experimental Approach to Neural Systems

Alfredo Weitzenfeld
Instituto Tecnológico Autónomo de México
Michael Arbib
University of Southern California
Francisco Cervantes
Instituto Tecnológico Autónomo de México
Pablo Rudomin
Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional
Amanda Alexander
University of Southern California

Biological neural systems are studied at a number of levels: behavior, networks of neurons, single neurons and synapses. These studies involve behavioral data modulated by learning processes, anatomical and physiological data at the neural and neural network level, and receptor and neurotransmitter data at the synaptic level. The goals of this joint U.S.-Mexico research project are to develop a multi-level simulation methodology to answer some of the questions arising in complex neural systems which single level models cannot. These results are then applied to technological applications. This research effort is tied together by a number of software tools: ASL, at the behavior level, NSL, at the neural network level, and other tools for single neuron and synaptic levels.

Objectives: An in-depth understanding of the computational methodology needed for multi-level simulation of highly complex systems with respect to three different levels of analysis: behavior, multiple arrays of neural elements, and subneural modeling. In particular, the modeling goal is to understand the underlying mechanisms for sensorimotor integration in living animals.

Approach: The collaborative research is depicted in Figure 1. The upper triangle emphasizes the collaboration on a multi-level simulation methodology; the lower triangle emphasizes the collaborative development of neuroscience databases.

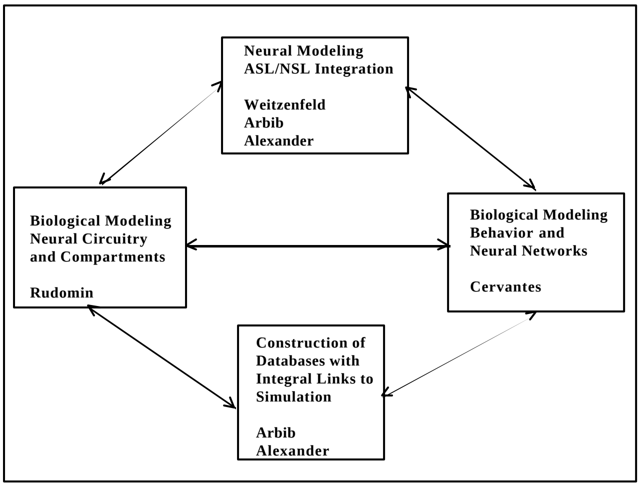

Figure 1

Neural models are developed at: (1) the behavioral level in terms of schemas [1] with ASL [2]; (2) neural networks level with NSL [3]; and subneural level with GENESIS [4] and NEURON [5], as shown in the following table. To enable multi-level integration, these software simulation tools are integrated to provide the multi-level simulation platform.

Databases are built to provide a linkage between experimental data and simulation data at the different levels.

Levels of Analysis	Theoretical Approach or Simulation Tool
1. Behavior	Schemas: ASL (ITAM)
2. Multiple arrays of neural elements	Layers as neural nets: NSL (ITAM-USC)
3. Subneural modeling	Compartmental models, Cable Theory, Hodgkin-Huxley, ion channels: GENESIS, NEURON (CINVESTAV-ITAM-USC)

Accomplishments-to-date: Work up to date has been in terms of (1) the extension and integration of software tools, and (2) development of new models based on experimental data at the different analysis levels. We have developed a heterogeneous distributed implementation of ASL [6], integrated NSL with ASL [7], and we are near completion on a schematic editor and a scripting language to graphically specify modular decomposition of complex models and to control their performance. We have developed a neural model, corresponding to the control of the synaptic effectiveness of muscle spindle and tendon organ afferents as described in [8]: a leaky integrator neural network model simulated in NSL; and a detailed compartmental and synaptic model in GENESIS, simulating the effects of presynaptic inhibition mediated by different types of receptors [9]. At the behavior and neural network levels, we have developed a schema theoretic model for prey acquisition modulated by learning processes; and extended a retino-tectal-pretectal model to include neural circuitry responsible for habituation [10].

Acknowledgements: This research is supported by the National Science Foundation in the U.S. (Grant #IRI-9522999) and CONACyT in Mexico (Grant #546500-5-C018-A).

References:

[1] Arbib, M.A., "Schema Theory", in the Encyclopedia of Artificial Intelligence, 2nd Edition, Editor Stuart Shapiro, 2:1427-1443, Wiley, 1992.

[2] Weitzenfeld, A., "ASL: Hierarchy, Composition, Heterogeneity, and Multi-Granularity in Concurrent Object-Oriented Programming", Proceedings of Neural Architectures and Distributed AI: From Schema Assemblages to Neural Networks Workshop, USC, 1993.

[3] Weitzenfeld, A., Arbib, M.A., "NSL - Neural Simulation Language", in Neural Networks Simulation Environments, Editor J. Skrzypek, Kluwer, 1994.

[4] Bower, J.M., Beeman, D., "GENESIS", Telos, Springer-Verlag, 1995.

[5] Hines, M., "NEURON", in Neural Network Simulation Environments, Editor J. Skrzypek, Kluwer Academic Publishers, 1994.

[6] Calderas, C., Mármol, S., "Diseño e Implementación de un Sistema Distribuido Heterogéneo para la Extensión del Lenguaje de Modelos Teórico Esquemáticos ASL", ITAM Undergraduate Thesis, CANNES-TR-96-01, ITAM, México, Octubre 1996.

[7] Weitzenfeld, A., Arbib, M., Alexander, A., "NSL - Neural Simulation Language: System and Applications", MIT Press, to appear in 1998 (in preparation).

[8] Eguibar, J.R., Quevedo, J., Jiménez, I., Rudomin, P., "Selective cortical control of information flow through different intraspinal collaterals of the same muscle afferent fiber" *Brain Res.* 643: 328-333, 1994.

[9] Rodriguez, G., "Modelado y Análisis del Fenómeno de Inhibición Presináptica", ITAM Undergraduate Thesis, CANNES-TR, ITAM, México, 1997 (in preparation).

[10] Flores, L.R., "Modulación de Tiempo variable de la Elicitación de la Conducta de Captura de Presas en los Anfibios Anuros", UNAM Master Thesis, CANNES-TR-97-01, ITAM, Mexico, DF, Agosto 1997.