Three-Stage Neurocomputational Modelling Using Emergent and Genesis Software

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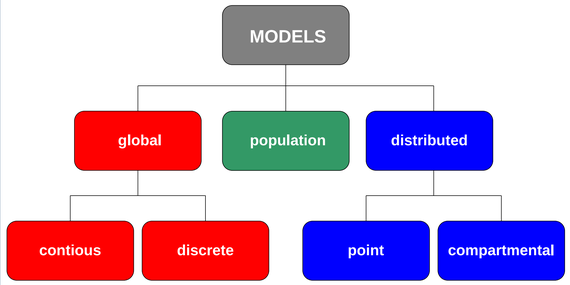
Introduction

Synergy of the natural and technical sciences leads to the needs of simulation-based research in medicine. Understanding cognitive functions and complex dysfunctions requires integration of research results involving bioinformatics, neurobiology, bio- and neuro-cybernetics, cognitive science and biomedical engineering.

Proper simulations of biological processes can help in:
- generating new hypothesis for experimental research and linking them with theoretical research;
- understanding underlying causal mechanisms at molecular, cellular, systems and behavioral levels;
- capturing essential aspects of complicated biological processes;
- learning about system dynamics as a function of lower level processes;
- understanding limitations of biological systems;
- saving time, money and effort focusing on the most interesting and promising ideas.

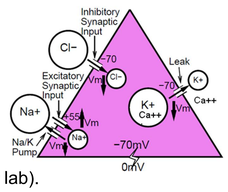
It is essential for computational models of cognitive functions to be entirely grounded in current knowledge in neuroscience. Unfortunately it is very difficult to provide computational model fitted in the best way to simulated phenomenon. Main limitations of the computational models are as follows:
- simple models are comprehensible, but may miss important details of the process;
- complicated, detailed models are difficult to study, hard to implement and develop;
- model have restricted applicability, it is very hard to build general models, useful at all levels relevant to biology.

Simulations of human nervous system suffer from the lack of research standards, difficulties with integration or even comparison of simulation results achieved using different simulation environments. In our current research two neural simulation environments, Emergent and GENESIS, are used and compared.



Emergent

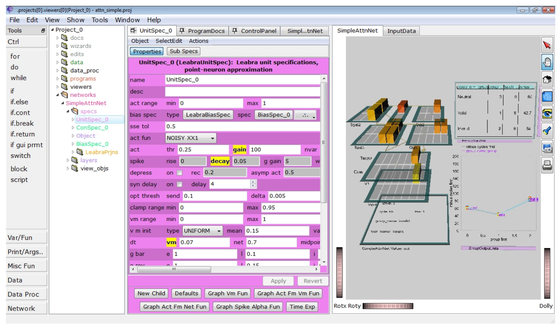
Emergent simulation environment (previously, to the 3.x version: PDP++) has been developed since 1995 at the Carnegie Mellon University, and since 4.x version at the University of Colorado in Boulder (Randal O'Reilly lab).



Emergent provides environment to build complex models of the brain cognitive functions using biologically-inspired neural models.

More on Emergent

Main features of the Emergent software are as follows:
- cross-platform: MS Windows, MacX, Unix/Linux (GPL),
- open source, modular, object-oriented, based on C++,
- various forms of visualization,
- dedicated LEABRA algorithm (Local, Error-driven and Associative, Biologically Realistic Algorithm), combining Hebbian learning and error-driven learning,
- models include 3 basic types of ion channels (K^+, Na^+, Cl^-), different types of noise (including synaptic noise) and the accommodation (neural fatigue) mechanism (Ca^{++} levels), allowing for larger–scale simulations than those possible with more realistic neural models.



GENESIS

GEneral NEural SImulation System (GENESIS) has been developed since 1988 by J.M. Bower at the California Institute of Technology, based on compartmental neurons (in contrast to point-neurons). GENESIS was created to support simulations of neural systems ranging from sub-cellular components to complex models of single neurons, simulations of large networks and systems-level models. It works under Unix/Linux OS.
Main features of the GENESIS software are as follows:
- modular component-based approach based on a "building blocks", provides generality and flexibility;
- modules that receive inputs, perform calculations on them, and then generate outputs;
- models of neurons constructed from basic components (dendritic compartments, variable conductance ion channels, etc.), linked together to form multi-compartmental neurons;
- easy exchange and reuse of models or model components.

GENESIS / NESSIE

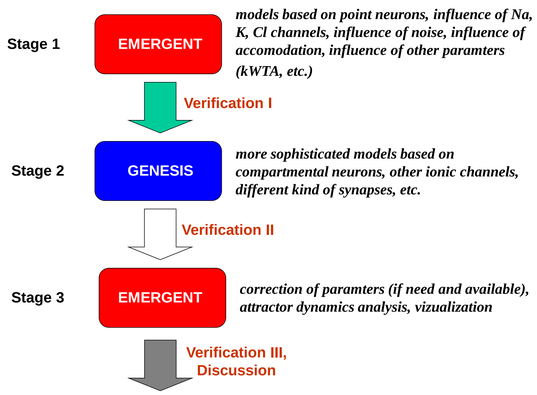
In our research GENESIS was supported by NEuroinformatic System for Science, Industry and Education (NESSIE), developed at the Institute of Computer Science, Maria Curie-Sklodowska University in Lublin, Poland, focused mainly on a large-scale simulations of mammalian brain cortex. NESSIE is a website which allows for modification of parameters of existing models, runs simulations and collects results without the need to know details of GENESIS implementation, difficult process of simulator compilation, and even the necessity of using Linux OS installation.
NESSIE is residing on the local cluster Lomond.

Usability

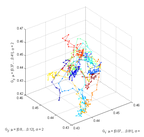
Emergent and GENESIS both can be useful to support the simulation of neural systems ranging from sub-cellular models to simulations of large networks and systems-level using different kind of single neuron model. But structures which have complexity of human brain (10^{11} neurons, 10^{15} connections) cannot be simulated even with the use supercomputing. Some biological model parameters cannot be used directly in simpler Emergent simulations. Sophisticated simulations will be conducted in the parallel version of GENESIS. Even simulation of our relatively simple model requires high computational powers. Initial experiments have been already successfully completed on the local cluster, however, in future, for larger models we will have to rely on the support of the Polish Grid Project (PL-Grid).

Three stages of the research

Methodology of simultaneously developing, comparing and assessing models created in the Emergent and GENESIS environments used in our "Spectrum of autism – integrated theory" project involves a three-stage process:
- creation of general models based on point neurons (Emergent);
- more sophisticated and detailed model based on compartmental neurons (GENESIS);
- return to the model based on point neurons (Emergent), taking into consideration findings from previous models (particularly based on compartmental neurons in GENESIS), and neural dynamics analysis to provide all aspects of the network functionality.



Attractor analysis limitations



Our research in the area of attractor dynamics visualization of Autism Spectrum Disorders models was made using Fuzzy Symbolic Dynamics (FSD) and has been based on models in Emergent. Attractor dynamics of two models implemented in the Emergent simulator have been studied to verify this hypothesis. Unfortunately not every model build using Emergent software can be analyzed in this way.

Problems and solutions

Both Emergent and GENESIS have their own specificity. In larger research projects an interdisciplinary team experienced in simultaneous use of both environments will be useful. Knowledge about advantages and disadvantages of the two approaches can help in appropriate planning of modeling. The main technical problems in simultaneous use of Emergent and GENESIS are as follows:
- GENESIS does not allow for simple visualization of results, including the simultaneous activity of neurons in network layers;
- implementation of inhibitory neurons in GENESIS is difficult;
- implementation of noise influence in GENESIS is not easy;
- analysis of attractor dynamics using FSD or recurrence plots may not be difficult to comprehend for some models.

This points out to the need of extending GENESIS and steps to add some visualization capabilities have already been made. The three stage strategy, starting from simpler models in Emergent, followed by more detailed GENESIS models and finally by extensions to Emergent models seems to be fruitful. Simplicity of the presented solution should provide better insight into the most important general processes of controlling the dynamics of biological neural systems.

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