2-15-2004

Collaborative Research: A Dynamic Atlas of the Cricket Cercal Sensory System

Sharon M. Crook
Principal Investigator; University of Maine, Orono

Annual Report for Period: 07/2003 - 07/2004
Submitted on: 02/25/2004
Principal Investigator: Crook, Sharon M.
Award ID: 0091117
Organization: University of Maine
Title:
Collaborative Research: A Dynamic Atlas of the Cricket Cercal Sensory System

Project Participants

Senior Personnel

Name: Crook, Sharon

Worked for more than 160 Hours: Yes

Contribution to Project:

This award paid for two months of summer salary for Sharon Crook in July and August of 2002. She is overseeing all aspects of this research that are being conducted at the University of Maine including software development, computational modeling and simulations, and the development and mathematical analysis of reduced neural models.

Post-doc

Graduate Student

Name: Qi, Weihong

Worked for more than 160 Hours: Yes

Contribution to Project:

Weihong was a graduate student in computer science supported by a research assistantship under this grant. The grant also paid for her tuition. She completed her Master's Degree in December of 2002. Her role on the project was to aid in the design and development of a neural simulator environment for future investigations of the biophysical mechanisms that contribute to encoding of sensory information. She completed several of the modules of this environment including an XML application for storing neural morphology data and a java tool for converting existing neural data to the XML format.

Name: Diaz Eaton, Carrie

Worked for more than 160 Hours: Yes

Contribution to Project:

Carrie is now a graduate student in mathematics. She has been working on reduced mathematical models for interneurons in the cricket cercal sensory system. The currents in these models are based on published data from electrophysiology experiments. The mathematical analysis involves a study of the underlying mathematical properties of the models including bifurcation analysis.

Name: Peshlov, Boyan

Worked for more than 160 Hours: No

Contribution to Project:

Boyan has been working on this project by contributing to computer programming and data visualization using MATLAB. He is a graduate student but is working on the project as an employee, not as a research assistant.

Undergraduate Student

Name: Sewall, Jason

Worked for more than 160 Hours: Yes

Contribution to Project:

Jason is an undergraduate student in mathematics and computer science. His participation is a great asset to this project. He has been involved in computer system administration, model development and the development of complex matlab programs for data analysis and network simulations. Jason is paid by the hour to work on the project as a student employee. Once again some of those funds came from a student merit grant of $1000 from the University of Maine to work on this project and the remainder was provided by this grant.

Name: Flynn, Megan

Worked for more than 160 Hours: No

Contribution to Project:

Megan is working on an undergraduate research project using Genesis and Neuron to build computational models of interneurons in this system. She is paid an hourly wage in support of her research.

Technician, Programmer

Name: Svitak, Joseph

Worked for more than 160 Hours: Yes

Contribution to Project:

Joseph helped design the schema for an updated version of MorphML. This new version will be included in NeuroML as the method of representing morphology data as part of the XML application. He also developed an application program interface for creating and reading MorphML documents.

Other Participant

Research Experience for Undergraduates

Organizational Partners

Montana State University

This is a collaborative research grant with a co-submission by personnel at Montana State University. I visited MSU for an extended period of time during the summer of 2002 in order to collaborate closely with the research group there. We have also met electronically using the Access Grid Nodes at both locations.

University of Edinburgh

Our work on a seamless simulation system led us to contribute to an international effort to establish an XML application for neurobiological data and modeling called NeuroML. We have worked Goddard, Cannon, and Howell at the University of Edinburgh on this project and contributed a stand-alone application that can be included in NeuroML called MorphML.

Other Collaborators or Contacts

In developing the XML application for neural morphology data, we have been communicating extensively with several groups who are interested in using and distributing these products. One of these groups is the NEUROML Developer Group including Nigel Goddard, University of Edinburgh and Robert Cannon, University of Edinburgh who are distributing our MorphML application as part of NeuroMl. We have also collaborated with future users other than those at Montana State University including Laszlo Zaborszky, Rudgers University and Zoltan Nadasdy, Caltech.

Activities and Findings

Research and Education Activities:

The general goals of this research project are 1) to characterize the representation of dynamic sensory stimulus parameters at two processing states within a mapped sensory system, and 2) to examine the mechanisms through which the representation is transformed at the interface between these two processing stages. This is a collaborative proposal and the specific objectives of the proposal that are to be carried out here at the University of Maine are: 1) to create new simulation software that can be used to model

interneurons using a variety of dynamic, naturalistic sensory stimuli, 2) to collaborate with the Miller/Jacobs Lab at Montana State University to create detailed compartmental models of primary interneurons, and 3) to create reduced interneuron models for analyzing the roles of nonlinear interactions in sensory information processing.

Item 1: The simulation software design phase has been completed. The simulation software will include a well-thought-out data format called MorphML for storing neural morphology data for use in analysis and models. This has been implemented in XML and is available on our webpage or through the NeuroML development group. We also have developed and made available software for converting our former data format (binary branch trees) to MorphML. A user interface for performing data analysis using Matlab routines are currently under development. We are also collaborating with the NEURON group on developing software for converting MorphML files to the format used by NEURON (Hines and Carnevale, Yale and Moore, Duke University).

Item 2: Compartmental models for several primary sensory interneurons have been developed and simulations have been conducted using the NEURON neural simulator for bi-directional stimuli. These studies are the subject of the results reported in the journal articles listed in the next section. A summary of findings is given below.

Item 3: Some reduced modeling studies have been performed. Carrie Diaz Eaton is performing these studies as her Master's thesis research under the direction of Sharon Crook. This work has been presented at the Computational Neuroscience Meetings and some of the results have been published.

Findings:

Interneuron models:
Realistic, biophysically-based compartmental models were constructed for several primary sensory interneurons in the cricket cercal sensory system. A dynamic atlas of the afferent input to these cells was used to set spatiotemporal parameters for simulated stimulus-dependent synaptic inputs. We examined the roles of dendritic morphology, passive membrane properties, and active conductances on the frequency tuning of the neurons. The sensitivity of narrow-band low-pass interneurons can be explained entirely by the electrotonic structure of the dendritic arbors and the dynamic sensitivity of the spike initiation zone. The dynamic characteristics of interneurons with higher frequency sensitivity required models with voltage-dependent dendritic conductances.

Channel modeling:
We are revising these models to include more realistic ion channel dynamics and calcium-handling. This work will be based on the development and analysis of channel models for interneurons in the cercal system. Past modeling studies of primary sensory interneurons in the cricket, Acheta domestica, have used two ion channels û a transient sodium channel and delayed-rectifier type potassium channel û to model the spike-producing

mechanism in these cells. The spatial structure of these compartmental models is based on morphological data, and the parameters for the Hudgkin-Huxley type equations for ionic currents were chosen in order to match the shape of simulated action potentials to physiological data. However, other ion channels are known to be present in these cells. We have developed channel models based on the physiology data obtained by Kloppenburg and H÷rner (1998), used the channels to construct a model neuron, and provided an analysis of the underlying mathematical structure of the excitable. We also examined the frequency sensitivity of the model neuron. This work provides a first step toward developing biophysically-based models of primary sensory interneurons with more accurate current dynamics.

Simulation environment:
In order to distribute our models and develop a common data format for various applications, we have developed an Extensible Markup Language (XML) application for the storage of neuronal morphology data. The application, MorphML, is consistent with current neuronal digitization methods and is also compatible with existing simulation software environments for creating model neurons based on morphology data. We also describe a tool, nemo2xml, which generates MorphML documents corresponding to digitized neuronal morphology files for one particular data format, the Nevin or Binary Branch Tree (BBT) format.

Training and Development:

Weihong Qi: Weihong's graduate studies were supported entirely by this grant. She has completed her Master's Degree in computer science and is now working as a postdoc in bioinformatics. (She previously obtained a PhD in Biology.)

Carrie Diaz Eaton: Carrie is obtaining training in dynamical systems and biological modeling as well as the use of software to conduct analysis and simulations in these areas. She is working toward a graduate degree in mathematics with research in the general area of neural models and networked cell models. This project is providing her with an opportunity to combine her interests in biology and mathematics. Carrie will finish her studies this summer and graduates in August of 2004.

Jason Sewall: Jason is an exceptionally bright student who is a double major in computer science and mathematics. His participation in this project is exactly the type of experience that he needs in order to learn about opportunities in computational research. He is truly one of the most independent thinkers I have ever encountered and he is a great asset to this project. He is learning a great deal about specific software packages such as XPP and Matlab as well as the general process of software development in a research setting. He also contributes to the details on everything that is going on in our research group and is learning about neurobiology and mathematical modeling in the process. Specifically, he is helping with model development, data analysis and the development of matlab routines.

Megan Flynn is an undergraduate student in biology who is using the Neuron and Genesis simulation environments to model interneurons in this system. She has reported to me that this work has provided a strong preparation for her biophysics courses, has taught her a great deal about using a computer to perform simulations and has stimulated her interest in quantitative methods in biology.

Outreach Activities:

Journal Publications

Crook, S, JP Miller and G Jacobs, "Modeling frequency encoding in the cricket cercal sensory system", Neurocomputing, p. 769, vol. , (2002). Published

Jacobs, G, C Henze, T Ganje, S Crook and J Miller, "Structural and biophysical mechanisms underlying dynamic sensitivity of primary sensory interneurons in the cricket cercal sensory system", Neurocomputing, p. , vol. , ( ). Accepted

Eaton, Carrie Diaz and Sharon Crook, "Modeling ion channels from the cricket cercal sensory system", Neurocomputing, p. , vol. , ( ). Submitted

Qi, Weihong and Sharon Crook, "Tools for neuroinformatic data exchange: An XML application for neuronal morphology data", Neurocomputing, p. , vol. , ( ). Submitted

Books or Other One-time Publications

Web/Internet Site

URL(s):

http://www.umemat.maine.edu/faculty/crook/MorphML.html

Description:

This website provides information, documentation, and software related to our work on a common data format for neural morphology data. This work has contributed to the NeuroML project.

Other Specific Products

Product Type: Software (or netware)

Product Description:

We have enhanced software for converting morphology datafiles from the binary branch tree format used by the NeMoSys neural simulation system to the format needed for the NEURON simulation system. We are in the design phase for all additional software proposed for this project.

Sharing Information:

We are in the initial phases of software design and development but ALL software that we develop will be made available for download on a website that is currently under construction.

Contributions

Contributions within Discipline:

Our modeling studies suggest that although the afferent encoding of information about the stimulus environment (direction and dynamics of air currents) is essentially linear, the interneurons use nonlinear coding schemes that rely on nonlinear biophysical processes.

In developing software products that serve as modules in a simulation environment, we are trying very hard to communicate and collaborate with other groups. We are doing our best to create products that utilize a common data format and provide a broad range of functionality that will be of use in a wide range of applications.

Contributions to Other Disciplines:

Contributions to Human Resource Development:

In the past yeasr, the the research activities funded by this project have provided exceptional training experiences for three graduate students and two undergraduate students--all of whom have interdisciplinary interests. Of these 5 students, three are women, one is hispanic, and one is Asian. All have learned a great deal about the research process, the use of technology

in research, and opportunities that exist at the interface of neurobiology and the computational disciplines of mathematics and computer science.

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

Special Requirements

Special reporting requirements: None

Change in Objectives or Scope: None

Unobligated funds: less than 20 percent of current funds

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Activities and Findings: Any Outreach Activities

Any Book

Contributions: To Any Other Disciplines

Contributions: To Any Resources for Research and Education

Contributions: To Any Beyond Science and Engineering