Quantitative Neurophysiology: a Scientific Course for Graduate Students in BME

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Abstract

Neural engineering, an emerging significant branch of Biomedical Engineering, uses approaches and tools of fundamental life sciences, such as neurosciences, to solve biomedical problems. However, the interaction between neural engineers and neuroscientists has not yet reached the level that researchers from both fields would like to see. Graduate students in the Department of Biomedical Engineering at the Case Western Reserve University (CWRU) are required to take the courses Physiological Processes I and II offered by the Department. In addition, students in neural engineering normally take several courses offered in the Departments of Neurosciences and Physiology & Biophysics. In contrast, students from other departments rarely register for biomedical engineering courses.

In the fall of 2000 we ran a pilot course EBME 517 "Quantitative Neurophysiology" offered in the BME department. The idea behind this course is to use modeling tools to illustrate neurophysiological processes. The course differs from "typical" computational neuroscience courses by focusing on computer modeling using NEURON software with a number of models included or publicly available and which does not require special computational skills to create custom models. Thus such a course is well suited for students from the Departments of Neurosciences and Physiology & Biophysics. On the other hand, the course provides deep fundamental background for biomedical engineering students.

In the pilot run of the course proved to be interesting and well evaluated by the students. The projects completed by students were related to their research and well interlaced with fundamentals learnt in the lectures

The strategy in development of the course for the fall of 2002 will include more standard models available for students for practice and fundamental understanding as well as to advertise the course wider to attract neuroscience and biophysics students.

Introduction

Neural engineers – those who design functional electrical stimulation devices or develop novel brain imaging techniques or try to construct reliable nerve regeneration systems – all must have excellent background in fundamental processes governing the function and pathology of the nervous system. The EBME 517 "Quantitative Neurophysiology" course has been introduced into the graduate curriculum in the BME Department to provide detailed and deep understanding of fundamental neurophysiological processes illustrated by the computer simulations and models.

Course structure

The basis of the course is lectures on fundamentals of neuroscience delivered by recognized specialists in the topic. Five instructors teach the course in blocks of 3-5 lectures, with the coordinator (D.E. Kourennyi) present at each lecture and planning the coverage of the topics. The lectures give the students deep understanding of the facts and theories behind neurophysiology of the cell – from molecular to cellular to intercellular level. The material is covered at both quantitative level (which suits BME students well and can be rather stimulating for neuroscience students) and descriptive/explanatory level (comfortable for neuroscience students and very informative for BME students).

The course covers a variety of topics:

- review of quantitative tools, such as differential equations and chemical kinetics
- the laws of physics that govern behavior of ions in solutions
- molecular structure and function of ion channels
- permeability and selectivity of ion channels
- empirical quantitative description of electrical activity of cells (Hodgkin-Huxley model)
- stochastic nature and statistical description of ion channels
- electrically large cells: cable theory
- compartmental model of the neuron
- synaptic transmission
- calcium dynamics in neurons
- cellular and molecular basis of plasticity in the nervous system
- examples and models of abnormal electrophysiology: epilepsy, de-myelinazation, etc.
- extracellular recording and stimulation.

We do not require a particular textbook for this course. Instead, we recommend several textbooks for additional reading, while detailed handouts are provided in the lectures. The recommended textbooks include quantitative[3,4,6,8,9], semi-quantitative[1], and descriptive[5,7] texts, so that students have opportunity to look at the subject from different points of view. The course materials and progress of students is reflected in the course webpage.

Homeworks are designed to stimulate in students thinking and creativity (problem solving). Normally homeworks illustrate the material from the lectures and require additional reading from the recommended textbooks and original scientific papers. We use two types of the homeworks: theoretical and project-oriented. The latter are actually small assignments focused at modeling certain aspects of electrophysiology of neurons, such as passive membrane properties, establishing the membrane potential, generation and propagation of the action potentials, extracellular and intracellular stimulation, etc.

The most significant part of the course is the project and the presentation. Students choose the project in the first half of the semester based on their own research or taking a problem relevant to the scientific paper(s) of their interest. The project is to model a particular system using the NEURON software. As the course proceeds, the students incorporate more complexity into their model. The help from instructors and the teaching assistant is provided continuously. When the projects are completed, students submit them as full-scale reports and present them in front of the class, with students involved in the evaluation of the presentation. The project and the presentation constitute the largest part of the final grade: 40-50%. About 30% are reserved for two intermediate exams and 20-30% to homeworks.

Course outcome

In this course, students obtain fundamental knowledge (science) and problem-solving skills (engineering) related to structure, function and repair of neural systems. In particular, they:

- get quantitative understanding of fundamental principles underlying function of the nervous system, such as generation and propagation of action potentials and synaptic transmission between neurons;
- develop skills in constructing realistic models of neurons, i.e. models that are successfully tested against experimental data. For example, a model of a motor neuron must correctly simulate generation of an action potential in the initial segment of the axon, and not in the cell body or dendrites;
- learn how construct and use neuronal models that have predictive power. In other words, the models are used to predict certain behavior of neuronal system, that can later help in designing the experiment to test such a prediction;
- learn how to combine theoretical and fundamental knowledge with modeling skills to solve problems in neural engineering. For example, students are able to model the effects of different patterns of extracellular electrical stimulation on excitability of neurons or analyze and predict the ability of a neuron to propagate action potential if partial de-myelinization occurs.

Students' evaluation

All 5 students who took the course enjoyed the experience which is reflected in their evaluation: two students graded it as excellent and three as very good. The instructors and the teaching assistant were evaluated also in excellent to very good range.

Conclusion and future developments

In the next run of the course in the fall of 2002, we plan to keep the general outline of the course with some modifications.

First, the NEURON tutorial will be a formal part of the course. More basic NEURON models will be discussed and provided for students. These simple illustrative models will help students understand the fundamental processes involved in neuronal functions.

Second, the syllabus of the course will be adjusted to fit better into the typical background of students from the Departments of Neuroscience and/or Physiology & Biophysics. Also, we will advertise the course in those departments to attract more students. We feel that a diverse population of students in the course will benefit everyone. We are confident that we can attract students from basic science departments, especially taking into account that the teaching assistant in the pilot run was from Physiology & Biophysics.

We also will add another textbook to the list of recommended reading: "From neuron to brain"[7], which will help students to learn and understand molecular basis of ion channel activity.

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