

Bioengineering Activities in EECS: Electrical Engineering

Outline of this session:

- description of biology related coursework taken by electrical engineering students
- overview of the biological engineering research in the electrical engineering department

Introduction

Assistant Professor of Electrical Engineering and Computer Science (EECS) Joel Voldman is interested in the integration of biology and engineering in the development of small scale devices such as biological micro-electromechanical systems (MEMS). His research focuses on improving information storage and transfer at the cellular level.

Faculty in Electrical Engineering (EE) with Interest in Bioengineering

The EECS department (Course 6) at MIT is biology friendly. Approximately 25% of the department is involved in some type of biology related research that makes use of applied electrical engineering. The following slides outline the research areas of these faculty members.

Bio-Electrical Engineering on Course 6

Course 6 students interested in biology take the same four core courses as traditional EECS students. They are listed below:

- 6.001 Structure and Interpretation of Computer Programs
- 6.002 Circuits and Electronics
- 6.003 Signals and Systems
- 6.004 Computation Structures
- 18.03 Differential Equations

In addition, they may choose a biology-oriented concentration and choose to take additional classes such as:

- 6.021J Quantitative Physiology: Cells and Tissues
- 6.022J Quantitative Physiology: Organ Transport Systems
- 6.023J Fields, Forces, and Flows in Biological Systems
- 6.121J Bioelectronics Project Laboratory

Freeman: Hearing Research

Associate Professor of EECS Dennis M. Freeman is interested in the study of how the motion of hair cells is translated into hearing in the tectoral membrane. In this slide, the leftmost picture is a cartoon of moving hair cells. The right images are projections of the movement of hairs at different heights above the surface of the membrane.

Freeman also studies the mechanical properties of hair cells by tracking the movement of magnetic beads on the surface of the membrane when exposed to electromagnets on either side. In this slide, a probe pulls on the membrane to determine the stiffness of the

cell.

Oppenheim: Signal Processing

Professor of EECS Alan V. Oppenheim is primarily interested in the applications of signal processing to biological systems. In this slide, each dot represents a different protein present in yeast and the lines indicate protein-protein interactions. Oppenheim is interested in the modeling of how these protein functions are encoded at the network level. This graph plots the global properties of damage-recovery proteins. On the x-axis, the protein degree (z) indicates the number of connections present. On the y-axis, $p(z)$ indicates the percentage of the protein that has connections (i.e. the degree of importance of the protein). It is the essential proteins that have the most connections.

White: Computational and Systems Biology

Professor of EECS Jacob White is the associate director of the Research Laboratory of Electronics (RLE). He is interested in the use of computational methods to solve real-life problems in areas such as electrical-biological engineering and optimal drug delivery. His research on integrated circuit design led to the development of “fast solver” algorithms for 3-D electromagnetic, electromechanical, and fluid flow analysis. These algorithms can be developed into simple models.

Fujimoto: Laser Technology and its Application to Biomedical Optical Imaging

Professor of EECS James G. Fujimoto, principal investigator in the Optics and Quantum Electronics Group of the Research Laboratory of Electronics, is interested in laser optics and in the development of low cost and high resolution laser technology. He uses strobe photography, like the one shown on the right, and femtosecond optics to measure the rate of high speed processes. This slide shows a lab equipped with femtosecond pulse generation devices with a time scale of 10^{-15} , devices that can supposedly “freeze time.”

Optical coherence tomography (OCT) is an imaging technique used to obtain high-resolution cross-sectional images of the retina. Unlike sonar and ultrasound techniques, which make use of sound waves, OCT employs light through the use of high resolution lasers. This slide shows a cross section of the retina tissue. A portion of the incoming light wave on the left is transmitted through the tissue and the rest is reflected back into the environment. The diagram on the left shows the degree of penetration of the incoming light wave.

This slide shows two different views of the eye. Current OCT techniques combined with ultra-high resolution (UHR) allows for finer images and allows for earlier detection and treatment of diseases.

Voldman: Microtechnology to Measure and Manipulate Cells

Assistant Professor of EECS Joel Voldman uses electric fields and microfluidics to study how cells behave in defined environments. The dielectrophoretic (DEP) trap shown in this slide makes use of positive and negative charges to generate electric dipoles and move particles around in a given cell. This DEP trap, designed at MIT, consists of four gold posts with alternating positive and negative ends. The opposing charges push particles in certain directions. Different electroconfigurations create different traps. The

screening cytometer manipulates, traps, images and sorts cells (i.e. based on mutagenicity).

The Voldman lab is also interested in the fabrication of microscale devices which can create different conditions to grow and study cells. Its design makes use of a combination of physics and chemical engineering modeling and transport. In the picture on the right, the attached tubes allow for the inflow of material. The device can be easily modeled through the use of fluid-flow resistors.

Wyatt: Vision Research

Professor of EECS John L. Wyatt is interested in the use of electric fields and semiconductor devices to function as optical/electrical transducers. The retina of the eye takes in an incoming light wave and turns it into an electrical signal. Wyatt's research focuses on the correction of certain damaged parts of the retina. In this slide, the chip on the right is inserted into the eye with the tools shown. This is an image of how surgery would be done. The chip stimulates different electrodes in the retina and supposedly induces sight. As of now, this research is still at its beginning stages. Patients are able to make out certain images, but are not endowed with full sight.

Grodzinsky: Cartilage Tissue Engineering

Professor of electrical, mechanical, and bioengineering Alan Grodzinsky is interested in the mechanics associated with tissue function and in the design of suitable replacement bone cartilage. A set of proteins in the cartilage give it its stiffness and at the same time prevent adjacent bones from rubbing against each other. Electric fields in the body create the interactions between proteins in cartilage.

Collagen is a structural protein that prevents tension and shear in the body. It strengthens tendons, supports the skin, and connects tissue to the skeleton. This slide shows different scaled images of collagen, which is composed of three chains wound together in a triple helix.

Aggrecan is a proteoglycan that makes up 10% of the dry weight of cartilage, at least 75% more of which is water. An aggrecan monomer consists of a protein backbone with negatively charged side chains that repel each other. Over 100 individual monomer aggrecans at a time bind to hyaluronic acid (HA) to form aggregates. These aggregates also have side chains. Mechanical wear and tear contributes to the loss of the negatively charged glycosaminoglycan (GAG) chains and causes the degeneration of aggrecan. Atomic force microscopy is used to detect the aggrecan on a plate of mica stone. In this slide, the red stain is for GAG. Its gradual loss leads to osteoarthritis.

Mechanotransduction is the process by which cells convert outside stimuli into biochemical signals. This diagram indicates how different forces affect how the cell behaves. In this slide, a load cell is placed in an incubator. The load cell applies a known load and pressure to the cartilage cells and subsequent cell behavior is observed. In experiments, it is found that a dynamic compression, one that is changing with respect to time, stimulates the most synthesis of replacement cartilage.

Negatively charged GAG molecules are placed on the tip of the molecular force probe. These like charged molecules repel each other. As the distance decreases, the force of repulsion increases. The addition of positively charged Na allows two molecules to get closer together before they begin to repel.