EN 01: Electricity inside of you
Fall 2022

Class meeting time: Mon/We 4:30-5:45
Instructor: Joel Grodstein. Office hours: as per the course web page, or by appointment.
Teaching assistants: Owen Ackerman, Neelofar Tamboli

Prerequisites: none

***Electricity and computing are medicine*:**

We humans are biological creatures – but we arguably run on electricity. In the not too distant future, it may be as common to attack disease by altering our bioelectrical system as it is today to take a medication.

Our nervous system contains almost 100 billion neurons, which conduct electrical impulses known as action potentials. These action potentials let us sense our surroundings, think about what we've observed, and control our muscles. In fact, they control almost every aspect of our body's functioning – from our blood pressure to our sensation of pain – with the result that we are becoming more and more able to control these functions bioelectrically.

Our heart is a bioelectrical oscillator. It is built from billions of error-prone small cells that, as a whole, function incredibly reliably over the course of an entire lifetime. When the oscillator does malfunction, we've learned to fix it in a hospital with pacemakers, or in the field with defibrillators.

Nearly every cell in our body creates its own bioelectrical voltage. Unlike neurons, these voltages change quite slowly. While we do not fully understand the purpose of all these voltages, there is a growing belief that they form an intricate signaling web that not only coordinates normal growth, but whose malfunction can be involved in abnormal growth such as cancer.

Not only does our body use electricity in many ways, but the combination of electronic instrumentation and computer processing is already ubiquitous in medicine, both measuring and altering our electric fields to improve our health.

What we will cover:

The heart of this course is the labs, which will be completely hands-on. They will cover

- Learning a bit of Python. Just a little, because this is not a programming course
- Building hardware to collect some of your body's bioelectrical signals (sEMG and ECG) and using them to power fun toys (which work on the same principles as some very sophisticated medical tools but are more fun to play with)

The equipment we will build and use in these labs is actually quite complex – preamps to amplify our small bodily electrical signals and a small, inexpensive computer that we will program to decode the signals. This combination is called *embedded computing*, and is a quickly-growing area not only of medicine but many other fields.

Our lectures will be split. Roughly half of them will give you the hardware and software background to better understand the labs. The other half will cover electrophysiology:

- Bioelectricity in your nervous system: brain, muscles, prosthetics, pain and electroceuticals
- Bioelectricity in your heart: cardiac electrophysiology
- Bioelectricity of shape: potential role of bioelectricity in creating body shape

Electrical medicine: the past, the future and the potential

- The past: electrical medicine (e.g., cardiac pacemakers, and drugs to control cardiac ion channels) has been around for some time.
- The near future: the intersection of biology, computing and engineering may be poised for transformative applications, in medicine and elsewhere. Scores of startups are focusing on electrical medicine, along with venture-capital firms specializing in the area.
- The possible: morphogenesis is one of the black mysteries of biology. We know very little about how an embryo grows into a full body, and how the body can repair itself. The course will cover, in some detail, one particular hypothesis that is being worked at the Tufts Allen Discovery Center. This hypothesis, which is supported by growing evidence, has by no means reached the status of fact.

Workload and groups:

You will work in groups of 2-3 people. Each group will work on the labs together (handing in just one report) and take the oral quizzes together as a group. Since this is a freshman-level course, you will re-form the groups with different group members three or four times during the semester. The goal of this is not only to minimize the downside of getting stuck with incompatible group member(s), but also to get out and meet new people!

The workload is as follows:

- There is a new lab roughly every week. Each lab has data and questions to turn in. You should all work on the lab together and just turn in one report.
- There is a final project (with presentations during the final-exam slot). There is no midterm or final exam. You can work in groups of 2-3 people for the final project, and pick the groups however you like.

Grading

The course grade will be computed roughly as follows:

- labs = 65% of the total grade
- final project = 25%
- participation = 10%

Late Assignments

Late assignments will be penalized by 10% per day. Any extensions due to extenuating circumstances (illness or family emergencies) must be arranged ahead of time with the instructor before the original due date.

Next steps

We covered bioelectricity only at a very superficial level. This is an EN01 course, so that's OK!

If you would like to learn more, there are lots of followup courses:

- Depending on your major, you may wind up taking General Physics 2 (PHY 2 or 12), which covers electricity in *much* more detail (but not bioelectricity).
- PHY 21 (Biological Physics) covers bioelectricity in more detail.

- EE 123 (Bioelectricity) is a full-semester course dedicated to bioelectricity.
- Tufts is creating an embedded-computing minor, to be jointly administered by the departments of Electrical and Computer Engineering, Biomedical Engineering and Mechanical Engineering.

Resources

This course covers a sampling from many areas: Python, bioelectricity, bioelectrical medicine and morphogenesis. You could make an entire career out of any of them. Here are some resources if you would like to dig deeper – none of them are required for the course

- There are numerous books on Python programming. Two that are available free online are
  - http://greenteapress.com/thinkpython2/thinkpython2.pdf
  - https://automatetheboringstuff.com
- You can learn more about MicroPython and the PyBoard at https://docs.micropython.org/en/latest/
- The best introduction to bioelectricity I've found is *"Biological Physics: Energy, Information, Life"* by Philip Nelson. It's the textbook for PHYS 25, and so the bookstore may have some copies left. Tisch has two copies. But be warned – high-school A.P. Physics may or may not give you the background to understand too much of this book.
- *Lippincott's Illustrated Reviews: Physiology, 2nd edition* is available online at Tisch. Its chapters on cardiac physiology (both the plumbing and the electrical sides) are quite readable.
- *Modeling Planarian Regeneration: A Primer for Reverse-engineering the worm*, Lobo and Levin 2012. A very readable overview of the computational problems that planaria seem to solve effortlessly as they regenerate themselves.
- *Gap junctional blockade stochastically induces different species-specific head anatomies in genetically wild-type Girardia dorotocephala flatworms*, Emmons-Bell 2015. Another paper describing the wild and wooly feats that planaria are capable of.
- *An Introduction to Systems Biology: Design Principles of Biological Circuits*, Uri Alon. An excellent introduction to the field of systems biology, with a bit of synthetic biology and morphogenesis thrown in. It doesn't really cover the material that we do – but it's such a nice book that I still recommend it!

Popular and entry-level literature on electroceuticals:

- *Why It's Time to Take Electrified Medicine Seriously*, Time Nov 2019
- https://spectrum.ieee.org/blog/the-human-os

Prerequisites

- This is an extremely interdisciplinary course, covering parts of biology, physics, medicine, electrical engineering, computer engineering and programming. It is expected that very few people will enter the course being competent in all of these areas. In fact, most freshmen will not really have much background in *any* of them! That's fine 😊

Collaboration policy

Learning is a creative process. Individuals must understand problems and discover paths to their solutions. During this time, discussions with friends and colleagues are encouraged—you will do much better in the course, and at Tufts, if you find people with whom you regularly discuss problems. But those discussions should take place in English, not in code. If you start

communicating in code, you're breaking the rules. When you reach the coding stage, therefore, group discussions are no longer appropriate. Each program, unless explicitly assigned as a pair problem, must be entirely your own work. Do not, under any circumstances, permit any other student to see any part of your program, and do not permit yourself to see any part of another student's program. In particular, you may not test or debug another student's code, nor may you have another student test or debug your code. (If you can't get code to work, consult a teaching assistant or the instructor.) Using another's code in any form or writing code for use by another violates the University's academic regulations. Do not, under any circumstances, post a public question to Piazza that contains any part of your code. Private questions directed to the instructors are OK. Suspected violations will be reported to the University's Judicial Officer for investigation and adjudication. Be careful! As described in the handbook on academic integrity, the penalties for violation can be severe. A single bad decision made in a moment of weakness could lead to a permanent blot on your academic record. The same standards apply to all homework assignments; work you submit under your name must be entirely your own work. Always acknowledge those with whom you discuss problems! Suspected violations will be reported to the University's Judicial Officer for investigation and adjudication. Again, be careful.

Additional resources

Tufts University values the diversity of our students, staff, and faculty, and recognizes the important contribution each student makes to our unique community. Tufts is committed to providing equal access and support to all qualified students through the provision of reasonable accommodations so that each student may fully participate in the Tufts experience. If you have a disability that requires reasonable accommodations, please contact the Student Accessibility Services office at Accessibility@tufts.edu or 617-627-4539 to make an appointment with an SAS representative to determine appropriate accommodations. Please be aware that accommodations cannot be enacted retroactively, making timeliness a critical aspect for their provision. Tufts and the teaching staff strive to create a learning environment that is welcoming to students of all backgrounds. If you feel unwelcome for any reason, please let us know so we can work to make things better. You can let us know by talking to anyone on the teaching staff. If you feel uncomfortable talking to members of the teaching staff, consider reaching out to your academic advisor, the department chair, or your dean.