FYS: Nature's Nanotechnology

Imagine a world occupied by machines whose size is 10,000 times smaller than the width of a human hair. Some of them produce fuel by harnessing solar energy, while others transport cargo on tracks only 10 atoms across, or assemble other machines following molecular blueprints. This is the bustling world inside a living cell, and we will explore this world using high school level math, physics and biology.

Instructors: Lishi Mohapatra, Abelson 332, lishi87@brandeis.edu

Office hours: Mondays 4 - 5:30 pm in Abelson 307 or by appointment.

Course Goals: We will study what goes on inside cells by thinking of a cell as a collection of nanometer sized machines, as opposed to a bag of chemicals. These machines are responsible for storing and reading information required to keep the cell working, for producing energy, for transporting molecules between distant parts of the cell, for keeping the cell walls charged up as batteries, and so on. We will learn how modern science has realized the dream of manipulating these molecular machines and making them do our own bidding. This will require forays into different areas of physics, chemistry and biology, and one of the key goals of the course will be to show how the study of biological nanotechnology brings these disparate sciences together, unified by a common cause, namely, understanding the molecular basis of life.

Required course work:
In-class activities will consist of students presenting a vignette from "Cell Biology by the Numbers" (online book; link is on Latte). We will also have "group challenges" where students divided into groups will work together on an assigned problem and then present the solution to the rest of the class. One of our goals would be to gain proficiency in using the computation software MATLAB, and applying it to puzzles in biology. There will be in-class computation exercises.

There will be homework assignments given out, approximately, one per week. The assignments will consist of reading material from books and articles, qualitative and quantitative problems. Qualitative problems will cover concepts from the reading, while quantitative problems will be order of magnitude estimates and simple physics problems that address biological phenomena. There will be a term paper due on the last day of classes in which each of you will describe the science behind one of Nature's nanotechnologies, accompanied by a calculation or estimate. A list of suggested topics will be handed out in October, but you will be free to choose your own topic as well.

Course Outline:

Unit 1: Introduction: The cell as a collection of nano-machines

Unit 2: Viruses as DNA delivery devices
- Biology: Bacteriophage life cycle
- Physics: Force and energy

Unit 3: Molecular motors as transport devices
- Biology: Kinesin, actin and the cytoskeleton
- Physics: Probability and Random walks

Unit 4: Molecular switches for turning gene expression on and off
- Biology: Gene expression and transcriptional regulation
- Physics: Entropy

Unit 5: Genetic circuits and synthetic biology
- Biology: Cellular decision making
- Physics: Dynamical systems

Unit 6: Molecular basis of thought
- Biology: Ion channels and pumps
- Physics: Electrical potential

Unit 7: Photosynthesis: making molecules from light

- Biology: Molecular basis of photosynthesis
- Physics: Quantum mechanics

Grading procedure: Homework – 50%; Term paper – 30%; Class participation – 20%

Success in this 4 credit hour course is based on the expectation that students will spend a minimum of 9 hours of study time per week in preparation for class (readings, homework, class presentation, term paper)

Required reading:

1. "The Machinery of Life" by David S. Goodsell, 2nd ed.
2. "Microcosm: E. Coli and the New Science of Life" by Carl Zimmer.
3. "Biology by the Numbers" by Ron Milo and Rob Phillips, http://book.bionumbers.org/

Suggested reading:

1. "What is life?" by E. Schrodinger.
2. "What is life?: Investigating the Nature of Life in the Age of Synthetic Biology", by E. Regis.
3. "Wetware: A computer in every living cell", by D. Bray.
4. "Physical Biology of the Cell", by R. Phillips, J. Kondev and J. Theriot.