Course Title: Engineering Analysis of Living Cells

Course number: ECE 700 T8

Rationale: Cell biology has developed into a stage where quantitative understanding is badly needed. The vast amount of data gathered with the advance of experimental technologies, in the search for a general understanding of the complex cell mechanism at the molecular level, have often made the traditional way of direct interpretation impossible. Therefore, recent years have seen significant efforts made to understand these data with more sophisticated mathematical models, using fundamental physical laws and engineering analytic techniques. This course is an introduction to some successful achievements of these approaches, and the exciting potentials along this line of research.

Description: This course introduces a quantitative understanding of cell biology at the molecular level. Guided with real experimental data, biological processes and systems are modeled using fundamental physical principles and engineering analytic techniques, including free-energy minimization, statistical mechanics, electrostatics, diffusive dynamics, random walk models, complex networks, feedback system analysis, Turing reaction-diffusion equations. Various complicated biological phenomena will be shown to be explicable with the same simple underlying principles.

Objective: At the end of the course, students should be able to:

1. Appreciate the power of physical modeling and engineering analysis in understanding biological data;

2. Realize numerous seemingly unrelated biological phenomena can be explained with the same fundamental physical principles;

3. Model biological processes with basic physical principles and engineering techniques, and if necessary, add finer details, to have a better match with experimental data.

Textbook: Phillips, Kondev, Theriot, and Garcia, *Physical Biology of the Cell*, 2nd Ed., 2013.

Main Topics:

1. Introduction to cell biology and the need of quantitative understanding

2. Simple numbers with quick estimation: the model organism *E. coli* as a basic unit of measure

3. Mechanical and chemical equilibrium in the living cell: the central role of energy and free-energy minimizers

4. The analytical engine of statistical mechanics, with applications to gene expression and osmotic pressure

5. Two-state systems: from ion channels to cooperative binding

6. The chemistry of water and the charge on DNA and proteins: electrostatics for salty solutions

7. A statistical view of biological dynamics: diffusion in the cell; active versus passive transport

8. Gene regulation networks: signals, dynamics and control

9. Biological patterns: order in space and time, Turing reaction-diffusion equations

Grading: Assignments 30%; Midterm exam 20%; Final exam 50%