PEP 305 Physics of Biological Systems

Weekly Syllabus:

Week 1: Introduction: biology and physics What physics can and cannot do? What can physicists and biologists learn from each other?
Week 2: Order of magnitude estimates in living systems. What limits the size of animals and trees? How much carbon we can store in a forest?
Week 3: Allometric scaling. How does the energy consumption depend on the size of the mammal? Why all mammals have the same order of magnitude of heartbeats in their lifetime?
Week 4: Motion on a microscopic scale. How do E.Coli swim in water? And how do they *know* where to swim?
Week 5: Motion and stability on a macroscopic scale. Why are the proportion of our limbs as they are? What about the tree branch lengths?
Week 6: Physics of a cell Cell membrane properties, cell division, cell energy consumption – is physics of any use in in cell biology? What limits the cell size?
Week 7: Organism as a physical system Is there physics in the physical aspects of organism? How does the organism react to pathogens? What happens if you miss a dose of medication?
Week 8: Physical models of evolution. How does the sum of small changes become something qualitatively different? Are there any 'phase transitions' in evolutionary process? What is the effect of global catastrophic events?
Week 9A: Horizontal gene transfer. How did the diversity of life arise so quickly? How did the universal genetic code arise?
Week 9B: Simplicity and Complexity How do the simple laws of nature produce complexity in living systems?
Week 10: Physics of Ecosystems Does the interaction between species and environment give rise to qualitatively new phenomena? How stable is this equilibrium to the change of physical/biological parameters?
Week 11: Ethology and physics of animal behavior What part of our behavior is determined by physical world and physiological necessities?
Week 12: Sociophysics Can we use the lessons learned from animal societies to describe our own species? Or do we need a fundamentally different approach?
Week 13: Evolution of language. How do human languages evolve? What about the 'languages' of other species? Does the evolution of memes obey the same rules as the evolution of genes?
Week 14: Extremophiles and astrobiology. How extreme are the environments in which life can survive? Where to look for the extraterrestrial life? How to recognize that it *is* life?

Catalog Description:
Simple physics can be used to analyze the biological systems on the vastly different scales ranging from the cell organelles to the entire ecosystems. We will study the laws of physics in biological context and the limits of their applicability, i.e. the interplay of physical simplifications and biological complexities. We will also study the effect of geological and astronomical phenomena on biological systems. The course has a 'discovery' project component with statistical analysis of the biological data collected in image analysis, field studies, and computer simulations.

Course Objectives:
After finishing the course the student will be able to:

1. Apply the simple physical models to the biological systems
2. Identify the emergent phenomena arising in complex biological systems.
3. Give examples of the non-linear nature of the typical interacting system in biology.
4. Discuss the importance of computer simulations in biology.

List of Course Outcomes:

1. Make an order-of-magnitude estimate of the properties limiting the size of living organisms.
2. Calculate the energy expanded on the motion of bacteria in water in terms of number of ATP molecules.
3. Identify challenges faced by the mathematical and physical theories of evolution.
4. Describe physical requirement for the development of extra-terrestrial life.
5. Apply statistical methods to study the spatial distribution of organisms.

Textbook:
Selected papers.
Lecture notes.

Supplementary Texts:

Knut Schimdt-Nielsen *Scaling: why is animal size so important?*
Steven Vogel *Life in Moving Fluids*
R. Milo, R. Phillips *Cell Biology by the Numbers*
J.A.Tuszynskim J.M.Dixon *Biomedical Applications of Introductory Physics*
C.J.Pennycuick *Newton Rules Biology: A Physical Approach to Biological Problems*
Ehud Meron *Nonlinear Physics of Ecosystems*