Physics 350. Selected Topics: Biophysics (aka Physics of Biological Pattern Formation)

TR 1:10-2:25 pm in Stevenson 6105

Instructor: Shane Hutson, Stevenson 6835, 343-9980, shane.hutson@vanderbilt.edu

This course will cover the physical principles of developmental biology including: viscoelastic continuum mechanics; differential cell adhesion; gene regulatory networks as dynamical systems; self-organization; and activator-inhibitor systems. The course is intended for graduate students in biological physics, but should be accessible to any interested physics student. For students who have not had introductory biology, I will strongly recommend that they read relevant sections from an introductory biology text in addition to the course's primary readings.

The primary text for the course will be:

> G. Forgacs and S.A. Newman, *Biological Physics of the Developing Embryo* (Cambridge University Press, Cambridge, UK, 2005).

This text does a very nice job explaining the relevant physics of fluid and continuum mechanics, dynamical systems theory, self-organization and pattern formation. It also introduces the needed biological concepts (see the attached table of contents). In some instances, the text is light on the mathematical details of specific mathematical/physical models. In these cases, the text will be supplemented by articles from the primary literature (presented by students in the course). A few examples would include: Glazier's papers on the cellular Potts' model for describing cell-cell interactions (similar to the Ising model, but with multiple states); Meinhardt's papers on self-organization in activator-inhibitor systems; and Odell's papers on cellular mechanics.

My primary expectation is that each student will carefully read each assignment BEFORE class. Class time will be devoted to active discussions of what you've read. To make sure everyone is doing so, I will email everyone a discussion question on the reading a few days before each class – and expect an email response from everyone by 9:00 am on class days.

Each student will be expected to lead the discussion of an article from the primary literature approximately once every two weeks. Each student will also make one formal presentation of an article at the semester mid-point and complete a modeling project for the end of the semester. The modeling project will have the students work in teams to use one of several available platforms (CompuCell3D for Potts models, Vpython for cellular mechanics, Matlab or Mathematica for evaluating partial differential equations – dependent on student's existing expertise) to model some episode or aspect of developmental biology. Students will write up their findings and present them to the class.

Your grade for the course will be determined by: your participation in reading/discussions – both for days when you are and are not leading the discussion (1/3); your formal mid-semester presentation (1/3); and your modeling project (1/3).

The following two pages contain a preliminary sequence of topics and readings.

Day	Date	Led by	Reading Assignment
Tues	August 26, 2008		None - Preliminaries
Thur	August 28, 2008		No class
Tues	September 2, 2008		**F&N, Introduction (pp. 1-5)**
			F&N, Ch. 1 - The cell: fundamental unit of developmental systems. pp. 6-23
		MSH	M. Goulian and S. M. Simon (2000) "Tracking Single Proteins within Cells" Biophys. J. 79: 2188–2198.
Thur	September 4, 2008		W. Feneberg, M. Westphal and E. Sackmann (2001) "Dictyostelium cells' cytoplasm as an active viscoplastic body" Eur. Biophys. J. 30: 284-294.
			G. Lenormand et al (2004) "Linearity and time-scale invariance of the creep function in living cells" J. Royal Society - Interface 1: 91-97.
Tues	September 9, 2008		**F&N, Ch. 2 - Cleavage and blastula formation. pp. 24-50**
Thur	September 11, 2008		R. Shlomovitz and N. S. Gov (2008) "Physical Model of Contractile Ring Initiation in Dividing Cells" Biophys. J. 94: 1155–1168. D. Drasdo and G. Forgacs (2000) "Modeling the Interplay of Generic and Genetic Mechanisms in Cleavage, Blastulation, and Gastrulation" Dev. Dynamics 219:182–191.
			** NOTE J. Glazier physics colloquium at 4:00 pm "Multi-Cell Modeling of Biological Development using the CGH Model and CompuCell3D"
Tues	September 16, 2008		**F&N, Ch. 3 - Cell states: stability, oscillation, differentiation. pp. 51-76**
Thur	September 18, 2008		R. R. Klevecz, C. M. Li, I. Marcus and P. H. Frankel (2008) "Collective behavior in gene regulation: The cell is an oscillator, the cell cycle a developmental process" FEBS J. 275: 2372–2384.
			S. Huang, G. Eichler, Y. Bar-Yam and D. E. Ingber (2005) "Cell Fates as High-Dimensional Attractor States of a Complex Gene Regulatory Network" Phys. Rev. Lett. 94: 128701 (4 pp)
Tues	September 23, 2008		**F&N, Ch. 4 - Cell adhesion, compartmentalization, and lumen formation. pp. 77-98**
Thur	September 25, 2008		G. Forgacs, R. A. Foty,Y. Shafrir and M. S. Steinberg (1998) "Viscoelastic Properties of Living Embryonic Tissues: a Quantitative Study" Biophys. J. 74: 2227-2234.
			R. Foty and M. S. Steinberg (2005) "The differential adhesion hypothesis: a direct evaluation" Dev. Biol. 278: 255-263.
Tues	September 30, 2008		J. A. Glazier and F. Graner (1993) "Simulation of the differential adhesion driven rearrangement of biological cells" Phys. Rev. E 47: 2128-2154. J. C. M. Mombach, J. A. Glazier, R. C. Raphael and M. Zajac (1995) " Quantitative Comparison between Differential Adhesion Models and Cell Sorting in the Presence and Absence of Fluctuations" Phys. Rev. Lett. 75: 2244-2247. M. S. Hutson, G. W. Brodland, J. Yang and Denis Viens (2008) "Cell sorting in three-dimensions: topology, fluctuations and fluid-like instabilities" Submitted ~4 pp.
Thur	October 2, 2008		**F&N, Ch. 5 - Epithelial morphogenesis: gastrulation and neurulation. pp. 99-130**
Tues	October 7, 2008		gastrulation / neurulation
Thur	October 9, 2008		apical constriction / convergent-extension
Tues	October 14, 2008		**Formal student presentations**
Thur	October 16, 2008		**Formal student presentations**
Tues	October 21, 2008		Fall Break
Thur	October 23, 2008		**F&N, Ch. 6 - Mesenchymal morphogenesis. pp. 131-154**
Tues	October 28, 2008		extracellular matrix
Thur	October 30, 2008		dynamics of complex cell-matrix fluids

Tues	November 4, 2008	**F&N, Ch. 7 - Pattern formation: segmentation, axes, and symmetry. pp. 155-187**
Thur	November 6, 2008	Turing/Meinhardt patterns
Tues	November 11, 2008	lateral inhibition
Thur	November 13, 2008	case study in Drosophila
Tues	November 18, 2008	**F&N, Ch. 8 - Organogenesis. pp. 188-222**
Thur	November 20, 2008	branching morphogeneis, fractals
Tues	November 25, 2008	Thanksgiving
Thur	November 27, 2008	Thanksgiving
Tues	December 2, 2008	vertebrate limb development
Thur	December 4, 2008	**F&N, Ch. 10 - Evolution of developmental mechanisms. pp. 248-272**
Tues	December 9, 2008	evolution, physical interactions and developmental robustness
Fri	December 12, 2008	**Final Project Presentations (@ 9:00 am)**