# Simulation of Biological Systems

**Overview:** This course is about the simulation of biological systems with computer programs. Please note that the course is not about computational biology, biochemistry or biomedical engineering. Course will draw from biology, artificial life, robotics, computer graphics and other research areas.

**Course work:** The work for this course is twofold. First, students are expected to read individual research papers on specific topics. Second, each student will carry out a number of computer programming projects. There will be four projects in the course, and at least the first three of them will be done using a programming system called “Processing”. The first project is a one-week project that is for introducing you to the Processing system. The next two are more involved projects that will take several weeks. The first three projects are to be done individually. The final project is on a topic of your choice (negotiated with the instructor), and may be done individually or in groups of two students. The rough duration of the projects and their contribution to final grades are as follows:

Warm-Up project: One Week (5% of class grade)

Medium project 1: Three Weeks (20%)

Medium project 2: Three Weeks (20%)

Large project: Eight Weeks (40% to 55%)

If most students seem to be keeping up with the reading for the course, there will be no homework or exams for the course. If, however, the instructor finds that too few people are doing the readings, then short quizes or homeworks may be given, with a total contribution of up to 15% of the final grade.

Optional Textbook:

The Origins of Life: From the Birth of Life to the Origin of Language

John Maynard Smith and Eors Szathmary

**Projects**

Warm-up Project: Life Cellular Automata

You will write a cellular automata simulator for the game of Life, originally create by John Horton Conway. Life is simulated on a square grid of cells. Each cell is either live (white) or dead (black). The rules for life are simple. At each simulation step, a cell changes its live/dead state according to its last state and the number of live cells adjacent to it. Each cell is said to have eight neighbors, that is, diagonal neighbors count. The rules are simple: a live cell continues to live if it has two or three live neighbors. A dead cell is turned into a live cell if it has exactly three live neighbors. All other cells will be dead.

Medium Project 1: Flocking

The goal of this assignment is to learn about simulation based on particle systems. In particular, you will implement flocking, herding and schooling behaviour. Your virtual creatures will group together similar to the way in which fish swim together in schools. A major part of this assignment is learning how to tune simulation parameters to get reasonable behaviors. This assignment is based on the simulated flocking work of Craig Reynolds.

Medium Project 2: Reaction-Diffusion

This assignment will give you experience in solving partial differential equations (PDE's) using finite differencing techniques.  In particular, you will simulate a reaction-diffusion system known as Gray-Scott.  This system creates patterns of spots, stripes or spiral waves, depending on the parameter settings.  One aspect of this assignment is learning about how to implement two different kinds of diffusion operators.  In the process, you will see how different solvers can let you take different timesteps.  Another aspect of this project is creating an image that gives a map of the parameter space of the simulation system.

Large Project: Decided by each student, with input from instructor.

**Course Topics**

Simulation Techniques

cellular automata

mass-spring systems

systems of ordinary differential equations (ODE’s)

partial differential equations (PDE's)

reaction-diffusion

well-stirred reactor

genetic algorithms

Self-Organization

self-replication (von Neumann, Christopher Langton, others)

complexity at edge of chaos

Molecules

artificial chemistry

RNA self-splicing

DNA codon optimality

metabolism

Membranes and Cells

membrane formation

cell models

cell cytoskeletons

immune systems

Development

multicellular animal development

slime mold aggregation

pattern formation

gene cascades/networks

cell simulation of development (Fleischer and Barr)

plant development

Evolution

evolution

speciation

Dawkins on major events in evolution

genetic algorithms

blind watchmaker

co-evolution (Karl Sims, Craig Reynolds)

sexual selection

Locomotion

modes of locomotion

Braitenberg vehicles

evolution of walking, hopping and swimming

Multi-Organism Interaction

communication

prisoner's dilemma, tit-for-tat

predator/prey

flocks, schools, swarms

ant foraging

parasites

digital creatures (Thomas Ray)