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Informatics and Natural Computation: Final Report

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ThinkFinity Grant

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7/15/2010

Introduction

The purpose of this grant is to develop an interdisciplinary course in Informatics and Natural Computation that would service undergraduate computer, natural, and physical science majors. Informatics is the science of information, the practice of information processing, and the engineering of information systems. Informatics studies the structure, algorithms, behavior, and interactions of *natural* and artificial systems that store, process, access and communicate information. *Natural* computing refers to a collection of disciplines that unite nature with computing in three distinct ways:

1. Nature serves as a source of inspiration for the development of computational tools or systems that are used for solving complex problems.
2. Computers are used as a means of synthesizing the structural patterns and behaviors of natural phenomena.
3. Natural materials such as those molecules found in nature (e.g. DNA) or those designed by humans (e.g. nanotechnology) are employed as the computers.

The logical intersection point between natural computing and the sciences is in the field of bioinformatics, a growing interdisciplinary scientific area aimed at analyzing, interpreting, and managing information from biological data, sequences, and structures. By employing natural computing methods, it is possible to solve bioinformatics problems in classification, clustering, feature selection, data visualization, and data mining.

Project Specifications

There are three parts to this project:

1. Develop an upper-level undergraduate interdisciplinary course in Informatics and Natural Computation.
2. Develop a set of experiences in the planning, executing, writing up, and critical evaluation of research in informatics and natural computation.
3. Develop a research agenda that may be integrated into the course. Specifically, design a set of evolving research projects that students may work on as part of the course and may be extended beyond the course.

Timeline and Progress to Date

The project has been placed on the following schedule:

Summer 2009	Select topics for course and assemble an initial bibliography
Fall 2009	Develop initial set of lectures
Spring and Summer 2010	Refine lectures, create exercises and experiments, and assemble an initial research perspective.
Spring 2011	Offer course.

The schedule was met for summer 2009 and the lectures and their PowerPoint presentations are currently (Summer 2010) being created. A textbook has been selected for the course by Leandro Nunes de Castro entitled *Fundamentals of Natural Computing* (2006), published by Chapman & Hall/CRC.

A topics list, bibliography, and initial lecture schedule are attached.

Richard Schlesinger was contacted as per the grant review committee's request. In a meeting with him he expressed his enthusiasm for the course and suggested I talk with Dan Strahs of the Biology department. This will be done either late summer 2010 or during the fall 2010 semester.

My current schedule has spring 2011 as the time period for the first course offering. The reason this is so is that I have been scheduled to teach a course entitled Visual Computing for fall 2010.This course is new as well, and will be offered in fall 2010 for the first time.

Informatics and Natural Computation: Topic List

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7/15/2010

INTRODUCTION

Philosophy of Natural Computing
General Concepts

COMPUTING INSPIRED BY NATURE

Evolutionary Computing

Scope of Evolutionary Computing
Problem Solving as a Search Task
Hill Climbing and Simulated Annealing
Evolutionary Biology
Evolutionary Computing
From Evolutionary Biology to Computing

Neurocomputing

Scope of Neurocomputing
The Nervous System
Artificial Neural Networks (ANN)
Typical ANNS and Learning Algorithms
From Natural to Artificial Neural Networks

Swarm Intelligence

Ant Colonies
Swarm Robotics
Social Adaptation of Knowledge

Immunocomputing

Scope of Artificial Immune Systems
The Immune System
Artificial Immune Systems
Artificial Immune Networks
From Natural to Artificial Immune Systems

COMPUTER SIMULATION AND EMULATION OF NATURAL PHENOMENA

Fractal Geometry of Nature

Cellular Automata
L-Systems
Iterated Function Systems
Fractional Brownian motion
Particle Systems
Evolving the Geometry of Nature

From Natural to Fractal Geometry

Artificial Life
Scope of Artificial Life
Concepts and Features of Artificial Life Systems
Examples of Artificial Life Projects
From Artificial Life to Life-As-We-Know-It

COMPUTING WITH NATURAL MATERIALS

DNA Computing
Scope of DNA Computing
Basic Concepts from Molecular Biology
Formal Models: A Brief Description
Universal DNA Computers
From Classical to DNA Computing

Quantum Computing
Scope of Quantum Computing
Basic Concepts from Quantum Theory
Principles from Quantum Mechanics
Quantum Information
Universal Quantum Computers
Quantum Algorithms
Physical Realizations of Quantum Computers
From Classical to Quantum Computing

THE FUTURE

New Prospects
The Growth of Natural Computing
Some Lessons from Natural Computing
Artificial Intelligence and Natural Computing

Informatics and Natural Computation: ***Bibliography***

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Lecture Schedule (Tentative)

Week	Topic
1	**Nature to Natural Computing** - Overview
2	**Computing Concepts** – Part 1 (Theory of Information)
3	Computing Concepts – Part 2 (Theory of Computation)
4	**Evolutionary Computing** Problem-solving techniques based on principles of biological evolution, such as natural selection and genetic inheritance.
5	**Neurocomputing** Using parallel, distributed, adaptive information processing systems that mimic the brains neurons to solve computational problems.
6	**Swarm Intelligence** The design and use of algorithms or distributed problem-solving devices inspired by the collective behavior of social insects and other animal societies
7	**Midterm Exam**
8	**Immunocomputing** Principles of information processing that immune networks utilize in order to solve specific complex problems while protected from viruses, noise, errors and intrusions
9	**Fractal Geometry of Nature** The geometry of the irregular shapes found in nature, and, in general, fractals are characterized by infinite details, infinite length, *self-similarity*, *fractal dimensions*, and the absence of smoothness or derivative
10	**Artificial Life** Systems related to life, its processes, and its evolution expressed as simulations using computer models, robotics, and biochemistry
11	**Molecular Computing** (DNA) The use of (bio)molecules and biomolecular operations to solve problems and to perform computation
12	**Molecular Computing** (Molecular Recognition) The specific interaction between two or more molecules through noncovalent bonding such as hydrogen bonding, metal coordination, hydrophobic forces, van der Waals forces, pi-pi interactions, electrostatic and/or electromagnetic effects.
13	**Quantum Computing** – Part 1 Computation that makes direct use of quantum mechanical phenomena, such as superposition and entanglement, to perform operations on data.
14	**Quantum Computing** – Part 2
15	**Final Exam**