7-1-2010

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

Informatics and Natural Computation: Bibliography

General and Overviews

A. Adamatzky. 2001. *Computing in Nonlinear Media and Automata Collectives*. IoP Publishing.

P. Bak. *How Nature Works: the Science of Self-organized Criticality*. OUP, 1997.

C. Calude and Gh. Paun. 200. *Computing with Cells and Atoms: An Introduction to Quantum, DNA and Membrane Computing*, Taylor and Francis, London.

H. von Foerster and G.W. Zopf (eds.). 1962. *Principles of Self-Organization*. Pergamon Press.

S. Forrest (ed.). 1990. *Emergent Computation*. MIT Press/ North-Holland. Special Issue of Physica D. Vol. 42.

H. Haken. 1977. *Synergetics*. Springer-Verlag.

J.H. Holland.1995. *Hidden Order: how adaptation builds complexity*. Addison-Wesley.

J.H. Holland. 1998. *Emergence: From Chaos to Order*. Oxford University Press.

S.A. Kauffman. 1993. *The Origins of Order: Self-Organization and Selection in Evolution*. Oxford University Press.

G.J. Klir. 1991. *Facets of Systems Science*. Plenum Press.

G. Nicolis and I. Prigogine. 1977. *Self-Organization in Nonequilibrium Systems: From Dissipative Structures to Order through Fluctuations*. Wiley-Interscience.

I. Prigogine. 1980. *From Being To Becoming*. Freeman.

J.H. Reif.1998. "Alternative Computational Models: A Comparison of Biomolecular and Quantum Computation." In *Proceedings of the 18th Conference on Foundations of Software Technology and* theoretical Computer Science (December 17 - 19, 1998). V. Arvind and R. Ramanujam, eds. Lecture Notes In Computer Science, Vol. 1530. Springer-Verlag, London, pp. 102-121.

R. Rosen. 1991. *Life Itself: A Comprehensive Inquiry into the Nature, Origin, and Fabrication of Life*. Columbia University Press.

T. Sienko, A. Adamatzky, N.G. Rambidi, and M. Conrad (eds.). 2003. *Molecular Computing*, MIT Press .

W. Weaver. 1948. "Science and Complexity," *American Scientist* 36, pp. 449-456.

Evolutionary Computing

D. E. Goldberg. 1989. *Genetic Algorithms in Search, Optimization, and Machine Learning*. Addison-Wesley.

J.H. Holland. 1975. *Adaptation in Natural and Artificial Systems.* University of Michigan Press.

T. Kohonen. 1988. *Self-Organization and Associative Memory*. Springer.

J.R. Koza. 1992. *Genetic Programming: on the Programming of Computers by Means of Natural Selection*. MIT Press.

J. R. Koza. 1994. *Genetic Programming II: Automatic Discovery of Reusable Programs*. MIT Press.

J. R. Koza, F. H. Bennett III, D.Andre, M. A. Keane. 1999. *Genetic Programming III: Darwinian Invention and Problem Solv*ing. Morgan Kaufmann.

L. F. Landweber and E. Winfree (eds). 2002. *Evolution as Computation*. Springer.

Neurocomputing

S. Haykin. 1998. *Neural Networks*, 2d edition. Prentice-Hall.

J. Hertz, A. Krogh, and R. G. Palmer. 1991. *Introduction to the Theory of Neural Computation*, Addison-Wesley.

C. Koch. 2004 *Biophysics of Computation: Information Processing in Single Neurons (Computational Neuroscience Series).* Oxford University Press, Inc.

I. Kostanic and F.M. Ham. 2000. *Principles of Neurocomputing for Science and Engineering*. McGraw-Hill.

Swarm Intelligence

E. Bonabeau, M. Dorigo, and G. Theraulaz. 1999. *Swarm Intelligence: From Natural to Artificial Systems* (Santa Fe Institute Studies in the Sciences of Complexity Proceedings). Oxford University Press.

R.C. Eberhart , Y. Shui, and J. Kennedy. 2001. *Swarm Intelligence.* Morgan-Kaufmann.

A. Engelbrecht. 2006. *Fundamentals of Computational Swarm Intelligence*. Wiley & Sons.

M. Resnick. 1997. *Turtles, Termites, and Traffic Jams: Explorations in Massively Parallel Microworlds*. MIT Press.

Jean-Baptiste Waldner. 2008. *Nanocomputers and Swarm Intelligence*, Wiley-ISTE.

Immunocomputing

L. N. de Castro and J. Timmis. 2002 *Artificial Immune Systems: a New Computational Intelligence Approach*. Springer-Verlag.

D. Dasgupta (ed.). 1999. *Artificial Immune Systems and Their Applications*. Springer-Verlag.

J. D. Farmer, N. H. Packard, A. S. Perelson. 1986. "The Immune System, Adaptation, and Machine Learning," *Physica D*22, pp. 187-204.

Fractal Geometry of Nature

B.B. Mandelbrot. 1977. *The Fractal Geometry of Nature*. Freeman.

Heinz-Otto Peitgen and P.H. Richter. *The Beauty of Fractals: Images of Complex Dynamical Systems*. Springer-Verlag.

P. Prusinkiewicz and A. Lindenmayer. 1990. *The Algorithmic Beauty of Plants*. Springer.

Artificial Life

C. Emmeche. 1995. *The Garden in the Machine: the Emerging Science of Artificial Life*. Princeton University Press.

C. Langton (ed.). 1989. *Artificial Life*. Addison-Wesley.

C. Langton (ed.). 1992. *Artificial Life II*. Addison-Wesley.

DNA Computing

L. Adleman. 1994. "Molecular Computation of Solutions to Combinatorial Problems," *Science* 226, pp. 1021-1024.

M.H. Garzon and R.J. Deaton. 1999. "Biomolecular Computing and Programming,' *IEEE Transactions on Evolutionary Computation* 3, pp. 236-250.

T. Head. 1987. "Formal Language Theory and DNA: an Analysis of the Generative Capacity of Specific Recombinant Behaviors," *Bull. Math. Biology* 49, pp. 737-759.

S. Ji. 1997. "The Cell as a DNA-based Molecular Computer," *BioSystems* 44, pp. 17-39.

Cellular Automata

J. Rennard. 2002. "Implementation of Logical Functions in the Game of Life. In *Collision-Based Computing*, A. Adamatzky, ed. Springer-Verlag, London, pp. 491-512.

M. Sipper. 1997 *Evolution of Parallel Cellular Machines: The Cellular Programming Approach*. Springer-Verlag.

M. Sipper. 1999. "The Emergence of Cellular Computing," *IEEE Computer*, vol. 32, no. 7. pp. 18-26.

T. Toffoli and N. Margolus. 1987. *Cellular Automata Machines*. MIT Press

J. von Neumann. *The Theory of Self-Reproducing Automata.* Arthur Burks (Ed.) University of Illinois Press.
S. Wolfram (ed.). 1986. *Theory and Applications of Cellular Automata*. World Scientific Press.

Quantum Computing

P. Arrighi and C. Patricot. 2004. "Quantum Computation Explained to My Mother," *Current Trends in Theoretical Computer Science*, G. Paun, G. Rozenberg, and A. Salomaa (eds.), World Scientific.

G.P Berman, G.D. Doolen, R. Mainieri, and V.I Tsifrinovich. 1998. *Introduction to Quantum Computers*, World Scientific.

D. Deutsch. 1985. "Quantum Theory, the Church-Turing principle, and the Universal Quantum Computer," *Proc. Royal Society* (London) A400, pp. 95-117.

D.C. Marinescu and G. M. Marinescu. 2005. *Approaching Quantum Computing*, Prentice-Hall.

N. D. Mermin. 2003. "From Cbits to Qbits: Teaching Computer Scientists Quantum Mechanics," *Am. J. Phys*. 71, 23.

M.A. Nielsen and I.L. Chuang, 2000. *Quantum Computation and Quantum Information*, Cambridge University Press.

E. Rieffel. 2000. "An Introduction to Quantum Computing for Non-physicists," *ACM Comput. Surv.* 32, 3 (Sep. 2000), pp. 300-335.

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**