PORTLAND STATE UNIVERSITY
Systems Science Ph.D. Program
Professor Martin Zwick[&]
503-725-4987

Spring 2008
TuTh 4:40-6:30
104 Harder House
zwick@pdx.edu

SySc 557 / 657 A R T I F I C I A L L I F E

"Artificial Life" (ALife) is a name given to theoretical, mathematical, and computationally "empirical" studies of phenomena commonly associated with "life," such as replication, metabolism, morphogenesis, learning, adaptation, and evolution. It focuses on the materiality-independent, i.e., abstract, bases of such phenomena. As such, it overlaps extensively with "theoretical biology" and, less extensively, with certain areas of physics and chemistry and the social sciences. It also raises important philosophical questions. It is part of a larger research program into "complex adaptive systems," one stream of contemporary systems theory.

In its intersection with computer science, ALife is the newest example of "the sciences of the artificial" (Herbert Simon). ALife is to life what AI is to intelligence. Christopher Langton writes that "Artificial Life ... complements the traditional biological sciences ... by attempting to synthesize life-like behaviors within computers and other artificial media." The purpose is twofold: to understand these phenomena better and to develop new computational technologies.

The course will sample the research literature in this field. Topics to be emphasized are: (1) discrete dynamics: cellular automata and random networks, (2) ecological & evolutionary dynamics, (3) genetic algorithm optimization and adaptation, (4) agent-based simulation. Other topics include: "complex adaptive systems," NK and self-organized criticality models, artificial and real chemistry (metabolism, reproduction), and philosophical issues. See the SySc ALife web page: http://www.pdx.edu/sysc/research_alife.html .

TEXTS

1. Christopher Langton, ed., *Artificial Life: An Overview*. MIT Press, Cambridge, 1997 (ISBN 0-262-62112-6 paperback)

2. Xeroxed articles reader (obtain at Smart Copy, 1915 SW 6th Ave, 227-6137)

PREREQUISITES: Graduate status or consent of instructor

COURSE WORK: Project or term paper; class participation.

[&]Guest presentations by Dr. Jeffrey Fletcher, SySc; Professor Melanie Mitchell, Computer Science; Professor Wayne Wakeland, SySc; Professor Niles Lehman, Chemistry.

COURSE OUTLINE: (the font indicates the source: Overview, Reader) {} = optional

4/1 *INTRODUCTION* {Taylor, Langton[a,b], Kim[a,b]}

Main topics:

AUTOMATA DYNAMICS & COMPLEXITY

4/3 *EDGE OF CHAOS; CHAOS & RECONSTRUCTABILITY* Langton[c], Zwick[a,{b}]

4/8 *COMPUTING IN CAs* *Guest presentation: Prof. M. Mitchell, CS* {Wolfram,} Mitchell[a]

4/10 *GENE NETWORKS* Kauffman[a,b], Shmulevich{Leemput}

EVOLUTIONARY & ECOLOGICAL DYNAMICS; GAMES

4/15 Lindgren, Lindgren, Hillis, Kaneko

4/17 *Guest presentation: Dr. J. Fletcher* Fletcher[a,b]

AGENT-BASED SIMULATION

4/22 *Guest presentation: Prof. W. Wakeland, SySc* Epstein&Axtell

4/24 Resnick, Bonabeau, Langton[a], Carlson {Loengarov}

GENETIC ALGORITHMS

4/29 *GA BASICS; ORDERING GENOMES* Mitchell, Holland[a], Mitchell[b]; Shervais {Knibbe}

5/1 *GENETIC PROGRAMMING, GAs & NEURAL NETS* Koza, Belew

Other topics:

5/6 ***COMPLEX ADAPTIVE SYSTEMS; ALIFE & AI***
Steels, Gell-Mann, Maes
*** **Project/paper mini-proposals due; declarations to class** ***

5/8 ***COMPUTER LIFE*** *(TIERRA, VIRUSES).*
Ray, Ray {Spafford}

5/13, 15 ***NK MODELS; SELF-ORGANIZED CRITICALITY***
Kauffman[b,c], Bak[a,b]

CHEMISTRY

5/20 *REAL CHEMISTRY & WET ALIFE. Guest presentation: Prof. N. Lehman, Chemistry*
Breaker, Szostak, Rasmussen {Schuster}

5/22 *ARTIFICIAL CHEMISTRY: AUTOCATALYTIC NETWORKS, METABOLISM, REPLICATION*
Fontana, Kauffman[b], Bagley

5/27, 5/29 ***GENERAL DISCUSSION; PHILOSOPHICAL ISSUES***
{Taylor, Langton[a,b], Kim[a,b]} Dennett, Harnad, Bonabeau

6/3 *** **Projects/papers due *****

6/3, 5 *PROJECT/PAPER PRESENTATIONS* (No class during finals week.)

Abbreviations for sources for xeroxed articles

ALife II = Langton, C.G., Taylor, C., Farmer, J.D., & Rasmussen, S, eds., *Artificial Life* II *(Vol. X, SFI Studies in the Sciences of Complexity),* Addison-Wesley, Redwood City, CA, 1991.

Complexity = George Cowan, David Pines, David Meltzer, ed., *Complexity: Metaphors, Models, and Reality*, *Santa Fe Institute Studies in the Sciences of Complexity*. Addison-Wesley, New York, 1994. (ISBN 0-201-62606-3 Paperback)

D I S T R I B U T E D S E P A R A T E L Y

Langton[c], C. G., Life at the Edge of Chaos, *ALife II*, 41-91, 1991.

Zwick[a], M. and Shu, H., Set-Theoretic Reconstructability of Elementary Cellular Automata, *Advances in Systems Science and Applications*, 31-36, 1995.

Zwick[b], M., An Overview of Reconstructability Analysis, *Kybernetes, Vol. 33, No. 5/6, 877-905, 2004*, especially 11-13.

Selection from Epstein, J.M. & Axtell, R.L., *Growing Artificial Societies: Social Science from the Bottom Up*, MIT Press, 1996.

R E A D E R

INTRODUCTION

Langton[a], C. G., Artificial Life, *Artificial Life (Vol. VI, Santa Fe Institute Studies in the Sciences of Complexity)*, Langton, C., ed., Addison-Wesley, Redwood City CA, 1-47; skim 30-33, 1989.

Langton[b], C. G., Introduction, *ALife II*, 3-23, 1991.

Kim[a], Kyung-Joong and Cho, Sung-Bae, A Comprehensive Overview of the Applications of Artificial Life, *Artificial Life* 12: 153-182 (2006).

Kim[b], Kyung-Joong and Eils, Roland, Systems Biology and Artificial Life: Towards Predictive Modeling of Biological Systems, *Artificial Life* 14: 1-2 (2008).

AUTOMATA DYNAMICS & COMPLEXITY

Wolfram, S., Computer Software in Science and Mathematics, *Scientific American*, Sept. 1984, 188-203.

Mitchell[a], M., *A Guided Tour of Complexity*, Ch. 9. Cellular Automata, Life, and the Universe & Ch. 10 Computing Beyond the Edge of Chaos, draft manuscript, 2008

Kauffman[a], S.A, Antichaos and Adaptation, *Scientific American*, Aug. 1991, 78-84

Kauffman[b], S.A., Whispers From Carnot: The Origins of Order and Principles of Adaptation in Complex Nonequilibrium Systems, *Complexity*, 83-136, 1994. For *GENETIC NETWORKS* session, read 100-117.

Shmulevich, I., Dougherty, E.R., & Zhang, W., From Boolean to Probabilistic Boolean Networks as Models of Genetic Regulatory Networks, Proceedings of the IEEE, Vol. 90, No. 11, 1778-1792, 2002.

Leemput, Koenraad; Bulcke, Tim Van den; Dhollander, Thomas; De Moor, Bart; Marchal, Kathleen; Remortel, Piet van, Exploring the Operational Characteristics of Inference Algorithms for Transcriptional Networks by Means of Synthetic Data, *Artificial Life* 14: 49-63 (2008).

EVOLUTIONARY & ECOLOGICAL DYNAMICS; GAMES

Lindgren, K., Evolutionary Phenomena in Simple Dynamics, *ALife II*, 295-312, 1991.

Hillis, W. D., Co-Evolving Parasites Improve Simulated Evolution as an Optimization Procedure. *ALife II*, 313-324, 1991.

Fletcher[a], J.A., and Zwick, M. (2006), Unifying the Theories of Inclusive Fitness and Reciprocal Altruism. *The American Naturalist*, 168:252-262.

Fletcher[b], J.A., and Zwick, M. (2007), The Evolution of Altruism: Game Theory in Multilevel Selection and Inclusive Fitness, *Journal of Theoretical Biology*, 245:26-36.

AGENT-BASED SIMULATION

Bonabeau, E. & Theraulaz, G., Swarm Smarts, *Scientific American*, 72-78, March 2000.
Langton[a]: read 30-33; reference is above in *INTRODUCTION*
Carlson, S., Boids of a Feather Flock Together, *Scientific American*, Nov. 2000, 112- 114.
Loengarov, Andreas and Tereshko, Valery, Phase Transitions and Bi-stability in Honeybee Foraging Dynamics, *Artificial Life* 14: 111-120 (2008).

GENETIC ALGORITHMS

Holland[a], J.H., Genetic Algorithms, *Scientific American*, 1992.
Mitchell[b], M., *An Introduction to Genetic Algorithms*, MIT Press, Cambridge, 1999, Ch. 1, 5.
Shervais, S. and Zwick, M., Ordering Genetic Algorithm Genomes with Reconstructability Analysis, *Int. J. General Systems*, Vol. 32, No. 5, 491-502, 2003.
Knibbe, Carole; Fayard, Jean-Michel; Beslon, Guillaume, The Topology of the Protein Network Influences the Dynamics of Gene Order: From Systems Biology to a Systemic Understanding of Evolution, *Artificial Life* 14: 149-156 (2008).
Koza, J.R., Genetic Evolution and Co-Evolution of Computer Programs, *ALife II*, 1991.
Belew, R.K., McInerney, J., and Schraudolph, N.N., Evolving Networks: Using the Genetic Algorithm with Connectionist Learning. *ALife II*, 1991.

COMPLEX ADAPTIVE SYSTEMS; ALIFE & AI

Gell-Mann, M., Complex Adaptive Systems, *Complexity*, 17-29, 1994.

COMPUTER LIFE

Ray, T.S., An Approach to the Synthesis of Life, *ALife II*, 371-408, 1991.

NK MODELS; SELF-ORGANIZED CRITICALITY

Kauffman[b]: see reference above in *AUTOMATA*
Kauffman[c], S. and Johnsen, S., Coevolution to the Edge of Chaos: Coupled Fitness Landscapes, Poised States, and Co-Evolutionary Avalanches. *ALife II*, 1991.
Bak[a], P., and Chen, K., Self-Organized Criticality, *Scientific American*, Jan. 1991, 46-53
Bak[b], P., Self-Organized Criticality: A Holistic View of Nature, *Complexity*, 477-495, 1994.

CHEMISTRY

Breaker, R.R. and Joyce, G.F., Inventing and Improving Ribozyme Function: Rational Design vs. Iterative Selection Methods. *Trends Biotechnol*., Vol. 12, No. 7, 268-275, 1994
Szostak, J.W., Bartel, D.P., & Luisi, L., Synthesizing Life, *Nature*, Vol. 409, 387-390, 2001.
Rasmussen, S., Chen, L., Deamer, D., Krakauer, D.C., Packard, N.H., Stadler, P.F., Bedau, M.A., Transitions from Nonliving to Living Matter, *Science*, Vol. 303, 13 Feb 2004, pp. 963-965.
Kauffman[b]: read 87-100; reference is above in *AUTOMATA*
Bagley, R. and Farmer, J.D. Spontaneous Emergence of a Metabolism. *ALife II*, 93-140, 1991.