PORTLAND STATE UNIVERSITY
Systems Science Ph.D. Program
Professor Martin Zwick[&]
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Spring 2005
MW 4:00-5:50
Stephen Epler Hall, room 107
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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, and will be organized in a seminar format. 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. For PSU ALife research, see http://www.sysc.pdx.edu/res_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 PhD 2004; Professor Melanie Mitchell, Computer Science; Professor Wayne Wakeland, SySc; Professor Niles Lehman, Chemistry.

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

3/28 *Introduction* Taylor, Langton[a,b]

Main topics:

EVOLUTIONARY & ECOLOGICAL DYNAMICS; GAMES

3/30 *Guest presentation: Dr. J. Fletcher, PhD SySc 04* Fletcher[a,b{c,}d]{,Sober}

4/4 Lindgren,Lindgren, Hillis,Kaneko

AUTOMATA DYNAMICS & COMPLEXITY

4/6 *CHAOS & RECONSTRUCTABILITY* Zwick[a,{b}]

4/11 *Guest presentation: Prof. M. Mitchell, CS* *CAS & EDGE OF CHAOS* {Weisbuch,Wolfram,}Langton[c],Mitchell

4/13 *GENETIC NETWORKS* Kauffman[a,b],Wuensche,Liang{,Shmulevich}

AGENT-BASED SIMULATION.

4/18 *Guest presentation: Prof. W. Wakeland, SySc* Epstein&Axtell

4/20 Resnick, Bonabeau,Langton[a],Carlson

GENETIC ALGORITHMS

4/25 *GA BASICS; ORDERING GENOMES* Mitchell, Holland[a],Mitchell;Shervais

4/27 *GENETIC PROGRAMMING, GAS & NEURAL NETS* Koza[a,b],Ackley,Belew

Other topics:

5/2 *COMPLEX ADAPTIVE SYSTEMS; ALIFE & AI.*
Steels, Gell-Mann,Maes
Project/paper mini-proposals due; declarations to class

5/4 *COMPUTER LIFE (TIERRA, VIRUSES).*
Ray, Ray, Spafford, Kephart

5/9, 11 *NK MODELS; SELF-ORGANIZED CRITICALITY.*
Kauffman[b,c],Bak[a,b]

5/16 *ARTIFICIAL CHEMISTRY: AUTOCATALYTIC NETWORKS, METABOLISM, REPLICATION.*
Fontana, Kauffman[b],Bagley,Langton[a],Sipper

5/18 *REAL CHEMISTRY & WET ALIFE. Guest presentation: Prof. N. Lehman, Chemistry*
Schuster, Gibbs,Breaker,Szostak,Rasmussen

5/23 *GENERAL DISCUSSION; PHILOSOPHICAL ISSUES.* Dennett, Harnad, Bonabeau

5/30 HOLIDAY

5/25, 6/1,6 *PROJECT/PAPER PRESENTATIONS.*

6/1 **Projects/papers due.**

Xeroxed Articles

ALifeII = 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)

Distributed separately

Fletcher[a], J.A., and Zwick, M., N-Player Prisoner's Dilemma in Multiple Groups: A Model of Multilevel Selection, *Seventh International Conference on Artificial Life, Workshop on Group Selection*, Portland, 2000.

Fletcher[b], J.A., and Zwick, M., Hamilton's Rule Applied to Reciprocal Altruism, *IEEE Congress of Evolutionary Computation*, pp. 994-1000, vol. 1, Portland OR, June 2004.

Fletcher[c], J.A., and Zwick, M., Altruism, The Prisoner's Dilemma, and the Components of Selection, *Proceedings of the 2001 IEEE Systems, Man, and Cybernetics Conference*, 2001.

Fletcher[d], J.A., and Zwick, M., Strong altruism can evolve in randomly formed groups, *Journal of Theoretical Biology* 228 (2004) 303-313.

Sober, E., Altruism as a Biological Concept (Chapter 1), *Unto Others*, Harvard University Press, Cambridge MA, 1998.

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

Papers in packet: (approximately in order of use)

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, pp. 1-47, 1989. For *AGENT-BASED SIMULATION* session, read pp. 30-33.

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

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

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

Weisbuch, G., *Complex Systems Dynamics: An Introduction to Automata Networks* (*Vol. II, SFI Studies in the Sciences of Complexity*), Addison-Wesley, Redwood City CA, pp. 1-44, 1991.

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

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

Mitchell, M., Crutchfield, J.P., & Hraber, P.T., Dynamics, Computation, and the "Edge of Chaos": A Re-Examination, *Complexity*, pp. 497-513, 1994.

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

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

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

Kauffman[b], S.A., Whispers From Carnot: The Origins of Order and Principles of Adaptation in Complex Nonequilibrium Systems, *Complexity*, pp. 83-136, 1994. For *GENETIC NETWORKS* session, read pp. 100-117. For *ARTIFICIAL CHEMISTRY* session, read pp. 87-100.

Wuensche, A., Genomic Regulation Modeled as a Network with Basins of Attraction*, Pacific Symposium on Biocomputing*, 1998.

Liang, S., Fuhrman, S. , and Somogyi, R., REVEAL, A General Reverse Engineering Algorithm for Inference of Genetic Network Architectures, *Pacific Symposium on Biocomputing*, 1998.

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, pp. 1778-1792. 2002.

Bonabeau, E. & Theraulaz, G., Swarm Smarts, Scientific American, pp. 72-78, March 2000.

Carlson, S., Boids of a Feather Flock Together, Scientific American, Nov. 2000, pp. 112- 114.

Holland[a], J.H., Genetic Algorithms, *Scientific American*, 1992.

Mitchell, 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, pp. 491-502, 2003., June 1994.

Goldberg, D. E., Zen and the Art of Genetic Algorithms,

Koza, J. R., Genetic Evolution and Co-Evolution of Computer Programs, *ALife II*, 1991.

Koza, J.R., Evolving Inventions, *Scientific American*, Feb. 2003, pp. 52-59.

Ackley, D. and Littman, M., Interaction between Learning and Evolution. *ALife II*, 1991.

Belew, R.K., McInerney, J., and Schraudolph, N.N., Evolving Networks: Using the Genetic Algorithm with Connectionist Learning. *ALife II*, 1991.

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

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

Kephart, J.O., Sorkin, G.B., Chess, D.M., and White, S.R., Fighting Computer Viruses, *Scientific American*, Nov 1997, pp. 88-93

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, pp. 46-53

Bak[b], P., Self-Organized Criticality: A Holistic View of Nature, *Complexity*, pp. 477-495, 1994.

Bagley, R. and Farmer, J.D. Spontaneous Emergence of a Metabolism. *ALife II*, pp. 93-140, 1991.

Sipper, M. and Reggia, J.A., Go Forth and Replicate, *Scientific American*, Aug 2001, pp. 35-43.

Gibbs, W.W., Cybernetic Cells, *Scientific American*, Aug 2001, pp. 53-57.

Breaker, R.R. and Joyce, G.F., Inventing and Improving Ribozyme Function: Rational Design vs. Iterative Selection Methods. *Trends Biotechnol*., Vol. 12, No. 7, pp. 268-275, 1994

Szostak, J.W., Bartel, D.P., & Luisi, L., Synthesizing Life, *Nature*, Vol. 409, pp. 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, pp. 1-4, 1994.

Anderson, P.W., The Eightfold Way to the Theory of Complexity: A Prologue, , pp. 7-16, 1994.

Cowan,, pp. 709-717, 1994.

Arthur, W.B., On the Evolution of Complexity,

Frauenfelder, H., Proteins as Adaptive Complex Systems, Complexity, 179.

Schuster, P., How do RNA Molecules and Viruses Explore Their Worlds?, Complexity, 383., 1994.

Maes, P., Intelligent Software,

Godfrey-Smith, P., Spencer and Dewey on Life and Mind, *ALife IV*, 1995.