PRINCETON UNIVERSITY
DEPARTMENT OF HISTORY

HISTORY 598, FALL 2004
COMPUTERS AND ORGANISMS

Professors Angela N.H. Creager and Michael S. Mahoney

Meeting Time: The seminar will meet Tuesday afternoons, 1:30-4:30, in Dickinson 211

Topics and Readings
(*Items added later for future offerings)

Week I (9/14) *Introduction: Questions and Themes*	Jeremy Campbell, *Grammatical Man* Evelyn Fox Keller, *Refiguring Life: Metaphors of Twentieth-Century Biology*
Week II (9/21) *The Discursive Rupture* Report: Philipp v. Hilgers	**Secondary** Lily E. Kay, "Cybernetics, Information, Life: The Emergence of Scriptural Representations of Heredity", *Configurations* 5(1997), 23-91 [PU online]; and "Who Wrote the Book of Life? Information and the Transformation of Molecular Biology," *Science in Context* **8** (1995): 609-34. Michael S. Mahoney, "Cybernetics and Information Technology," in *Companion to the History of Modern Science*, ed. R. C. Olby et al., Chap.34 [online] Karl L. Wildes and Nilo A. Lindgren, *A Century of Electrical Engineering and Computer Science at MIT, 1882-1982*, Parts III and IV (cf. treatment of some of the same developments in David Mindell, *Between Humans and Machines*) James Phinney Baxter, *Scientists Against Time* **Supplementary** John M.Ellis, *Against Deconstruction* (Princeton, 1989), Chaps. 2-3 Daniel Chandler, "Semiotics for Beginners"
Week III (9/28) *Machines and Nervous Systems* Report: Perrin Selcer	**Primary** [read for overall structure before digging in to the extent you can] Warren S. McCulloch and Walter Pitts, "A logical calculus of the ideas immanent in nervous activity", *Bulletin of Mathematical Biophysics* 5(1943), 115-33; repr. in Warren S. McCulloch, *Embodiments of Mind* (MIT, 1965), 19-39, and in Margaret A. Boden (ed.), *The Philosophy of Artificial Intelligence* (Oxford, 1990), 22-39. Alan M. Turing, "On Computable Numbers, with an Application to the Entscheidungsproblem", *Proceedings of the London Mathematical Society*, ser. 2, vol. 42(1936-7), 230-265; corrections, ibid., vol. 43(1937), 544-46; repr. in Martin Davis (ed.), *The Undecidable*, 116-164 [online version, requires IE]

Stephen C. Kleene, "Representation of Events in Nerve Nets and Finite Automata", in C.E. Shannon and J. McCarthy (eds.), *Automata Studies* (Princeton, 1956), 3-41

Secondary
Tara H. Abraham, "(Physio)logical circuits: The intellectual origins of the McCulloch-Pitts neural networks", *Journal of the History of the Behavioral Sciences* 38,1(2002), 3-25 [PU online]
Lily E. Kay, "From logical neurons to poetic embodiments of mind : Warren S. McCulloch's project in neuroscience", *Science in Context* 14,4(2001),591-614 [PU online]
Steven J. Heims, *The Cybernetics Group, 1946-1953: Constructing a Social Science for Postwar America* (Cambridge, MA: MIT Press, 1991, 1993), Chap. 3
Andrew Hodges, *Alan Turing: The Enigma* (NY: Simon & Schuster, 1983), pp. 78-159 (Hodges has composed a wonderful web page devoted to Turing's life and work; it includes a good account of Turing machines and a link to a Turing machine program for the Macintosh)
Martin Davis, "Mathematical Logic and the Origin of Modern Computers", in Esther R. Phillips (ed.), *Studies in the History of Mathematics* (Mathematical Assoc. of America, 1987), 137-165

Supplementary
Warren S. McCulloch, "What is a Number, that a Man May Know It, and a Man, that He May Know a Number?", in *Embodiments of Mind*
Michael A. Arbib, *Brains, Machines, and Mathematics* (NY: McGraw-Hill, 1964; 2nd ed., NY: Springer Verlag, 1987), Chaps. 1, 2, 6; cf. his more recent article "Warren McCulloch's Search for the Logic of the Nervous System", *Perspectives in Biology and Medicine* 43,2(2000), 193-216 [pdf]
Neil R. Smalheiser, "Walter Pitts", *Perspectives in Biology and Medicine* 43,2(2000), 217-226 [pdf]
Rolf Herken, *The Universal Turing Machine, a Half-Century Survey* (1988); arts. by Andrew Hodges, Stephen C. Kleene, Robin Gandy
Martin Davis, *The Universal Computer* (NY: Norton, 2000)
James A. Anderson and Edward Rosenfeld, *Talking Nets: An Oral History of Neural Networks* (MIT Press, 1998)

Week IV (10/5) *Automata* Report: Chris Jones	**Primary** John von Neumann, "First Draft of a Report on the Edvac" (1945), ed. Michael D. Godfrey (pdf) John von Neumann, "On a logical and general theory of automata", in *Cerebral Mechanisms in Behavior: The Hixon Symposium*, ed. L.A. Jeffries (New York: Wiley, 1951), 1-31; repr. in *Papers of John von Neumann on Computing and Computer Theory*, ed. William Aspray and Arthur Burks (MIT, 1987), 391-431 Claude E. Shannon, "Computers and Automata", *Proceedings Institute of Radio Engineers* 41(1953), 1234-41; repr. in *Methodos* 6(1954), 115-30; and in *Claude Elwood Shannon: Collected Papers* (IEEE Press, 1993), 703-10 Christopher G. Langton, "Self-Reproduction in Cellular Automata", *Cellular Automata*, ed. D. Farmer et al. (North-Holland), 145-156 Christian Burks and Doyne Farmer, "Towards Modeling DNA Sequences as Automata", *ibid.*, 157-67 **Secondary**

	Arthur W. Burks, "Computation, Behavior and Structure in Fixed and Growing Automata", in Marshall C. Yovits and Scott Cameron (eds.), *Self-Organizing Systems: Proceedings of an Interdisciplinary Conference, 5 and 6 May, 1959*, (New York, 1960), 282-311 Burks, "Von Neumann's Self-Reproducing Automata", in Burks (ed.), *Essays on Cellular Automata* (U. Illinois Pr., 1970), Chap. 1. Look over the rest of the collection for a sense of how the field of cellular automata was taking shape during the 1960s. **Supplementary** M.D. Godfrey and D.F. Hendry, "The Computer as von Neumann Planned It", *IEEE Annals of the History of Computing* 15,1(1993) (pdf) Ken Thompson, "Reflections on Trusting Trust", *Communications of the ACM* 27,8(1984), 761-63 [pdf] Robert McNaughton, "The Theory of Automata, A Survey", *Advances in Computing* 2(1961), 379-421
Week V (10/12) *Cybernetics* Report: Matt Hersch	**Primary** Arturo Rosenblueth, Norbert Wiener and Julian Bigelow, "Behavior, Purpose and Teleology," *Philosophy of Science* 10 (1943): 18-24 [JSTOR] Norbert Wiener, *Cybernetics, or Control and Communication in the Animal and the Machine* (Cambridge: MIT, 1948; 2nd ed., 1961) H. Kalmus, "A Cybernetical Aspect of Genetics," *Journal of Heredity* 41 (1950): 19-22 Jacques Monod and Francois Jacob, "General Conclusions: Teleonomic Mechanisms in Cellular Metabolism, Growth, and Differentiation," *Cold Spring Harbor Symposium on Quantitative Biology*, vol. 26 (1961): 389-401. **Secondary** Murray Eden, "Cybernetics", in Fritz Machlup and Una Mansfeld, *The Study of Information: Interdisciplinary Messages* (NY, 1983), 409-439; followed by commentaries by Peter Elias, Richard Mattessich, Manfred Kochen, Michael Arbib, and Eden in response, 441-471 Geof Bowker, "How to be Universal: Some Cybernetic Strategies, 1943-70," *Soc. Stud. Sci.* 23 (1993): 107-27 [JSTOR] Peter Galison, "The Ontology of the Enemy: Norbert Wiener and the Cybernetic Vision," *Critical Inquiry* **21** (1994): 228-265 David A. Mindell, *Between Human and Machine: Feedback, Control, and Computing Before Cybernetics* (Johns Hopkins, 2002), Chapters 11-12 Angela N.H. Creager and Jean-Paul Gaudillière, "Meanings in Search of Experiments and Vice-Versa: The Invention of Allosteric Regulation in Paris and Berkeley, 1959-1968," *HSPS* 27:1(1996): 1-89 (You only need to read 6-15, which focuses on what the authors called the "cell regulationists" and their agenda; 1-5 will give you an introduction to the whole paper if you want it.) Robert Trappl, ed. *Cybernetics: Theory and Application* (Washington: Hemisphere, 1983); students should look at the range of fields covered under "Applications" **Supplementary** Walter Cannon, *The Wisdom of the Body* (1932) Donna Haraway, "A Cyborg Manifesto: Science, Technology, and Socialist-Feminism in the Late Twentieth Century," in *Simian, Cyborgs, and Women* (New York: Routledge, 1991) Peter J. Taylor, "Technocratic Optimism, H. T. Odum, and the Partial Transformation of Ecological Metaphor after World War II," *J. Hist. Biol.* 21 (1988): 213-244

Week VI (10/19) *Information Theory* Report: Corinna Schlombs	**Primary** Claude E. Shannon, "The Mathematical Theory of Communication", *Bell System Technical Journal* 27(1948), 379-423, 623-656 (pdf) Claude E. Shannon and Warren Weaver, *The Mathematical Theory of Communication* (Urbana, U. Illinois, 1949, rep. 1963) Henry Quastler (ed.), *Essays on the Use of Information Theory in Biology* (Urbana: University of Illinois Press, 1953) F. H. C. Crick, "On Protein Synthesis," *Symposium of the Society for Experimental Biology* 12 (1958): 138-63 J.B.S. Haldane, "Data Needed for a Blueprint of the First Organism," in Sideney W. Fox, ed. *The Origins of Prebiological Systems* (Academic Press, 1965) **Secondary** Mindell, Chapter 4 Sahotra Sarkar, "Biological Information: A Skeptical Look at Some Central Dogmas of Molecular Biology," *The Philosophy and History of Molecular Biology: New Perspectives* (Kluwer, 1996), pp. 187-231 Jean-Paul Gaudillière, "Regulation or Information: The Rhetoric and Practice of Molecular Biology in and out of the Pasteur Institute," unpublished manuscript. Evelyn Fox Keller, "The Body of a New Machine: Situating the Organism Between the Telegraph and the Computer," last essay in *Refiguring Life: Metaphors of Twentieth-Century Biology* (New York: Columbia University Press, 1995). Soraya de Chadarevian, "Sequences, Conformation, Information: Biochemists and Molecular Biologists in the 1960s," *J. Hist. Biol.* **29** (1996): 361-86 **Supplementary** Lila L. Gatlin, *Information Theory and the Living System* (Columbia U.P., 1972), Chaps. 1,6,7 Francois Jacob, *The Logic of Life: A History of Heredity* (Pantheon, English translation 1973, French 1970) John R. Pierce, *An Introduction to Information Theory: Symbols, Signals and Noise* (NY: Harper, 1961; 2nd. rev. ed., NY: Dover, 1980) William Aspray, "The Scientific Conceptualization of Information: A Survey," *Annals of the History of Computing* **7:2** (1985): 117-140 Jérôme Segal, *Le zéro et le un : histoire de la notion scientifique d'information au 20e siècle (*Paris: Syllepse, 2003*)*
Week VII (11/2) *Entropy and Organization* Report: Sultana Banalescu	**Primary** Erwin Schrödinger, *What is Life?* (Cambridge University Press, 1944) [online Word version] Max Delbrück, " What Is Life? And What is Truth?", *Quarterly Review of Biology* 20(1945): 370-372 (A review of *What Is Life?*) [JSTOR] L. Brillouin, "Life, Thermodynamics, and Cybernetics," in Harvey S. Leff and Andrew Rex, *Maxwell's Demon: Entropy, Information, Computing* (Princeton: Princeton University Press, 1990). **Secondary** Edward J. Yoxen, "Where Does Schrödinger's *What Is Life?* Belong in the History of Molecular Biology?," *Hist. Sci.* 17(1979): 17-52. Robert C. Olby, "Schrödinger's Problem: What is Life?," *Jour. Hist. Biol.* **4** (1971): 119-148 Evelyn Fox Keller, "Molecules, Messages, and Memory: Life and the Second Law", in

	Refiguring Life Robert Rosen, "The Schrödinger Question, *What Is Life?* Fifty-Five Years Later", in *Essays on Life Itself*, 5-32 **Supplementary** Gatlin, Chap. 2
Week VIII (11/9) ***Origins of the Genetic Code*** Report: Doogab Yi	**Primary** Richard W. Hamming, "Error Detecting and Error Correcting Codes", *Bell System Technical Journal* 29(1950), 147-60; repr. in *Key Papers in the Development of Coding Theory*, ed. E.R. Berlekamp George Gamow, "Possible Relation between Deoxyribonucleic Acid and Protein Structure"*Nature* 173(1954), 318 George Gamow, Alexander Rich, Martynas Ycas, "The Problem of Information Transfer from Nucleic Acids to Proteins", *Advances in Biological and Medical Physics* 4(1956), 41-51 F.H.C. Crick, J.S. Griffith, L.E. Orgel, "Codes Without Commas", *Proc. Nat. Acad. Sci.* 43,5(1957), 416-421 [JSTOR] Sydney Brenner, "On the Impossibility of all Overlapping Triplet Codes in Information Transfer from Nucleic Acid to Proteins" *Proceedings of the National Academy of Sciences* 43,8(1957), 687-694 [JSTOR] Robert Rosen, "The DNA-Protein Coding Problem", *Bull. Math. Biophysics* 21(1959), 71-95 Heinz Fraenkel-Conrat, "The Genetic Code of a Virus", *Scientific American* 211(1964) **Secondary** David Kahn, *The Code-Breakers*, Chaps. 1, 12, 14, 27 Lily Kay, *Who Wrote the Book of Life? A History of the Genetic Code* **Supplementary** Claude E. Shannon, "Communication Theory of Secrecy Systems" (1945), *Collected Papers*, 84-143 Thomas M. Thompson, *From Error-Correcting Codes Through Sphere-Packings to Simple Groups*, Chap. 1 Francis Y.C. Fung, "A Survey of the Theory of Error-Correcting Codes", *Tangents Online*, I,1 (Spring 1994) Carl E. Woese, *The Genetic Code: The Molecular Basis for Genetic Expression* (1967) Errol C. Friedberg, *Correcting the Blueprint of Life: An Historical Account of the Discovery of DNA Repair Mechanisms* (Cold Spring Harbor Laboratory Press, 1997) Charles Petzold, *Code: The Hidden Language of Computer Hardware and Software* (Microsoft Press, 1999)
Week IX (11/16) ***Bioinformatics*** Report: Joe November	**Primary** Robert S. Ledley, "Digital Electronic Computers in Biomedical Science", *Science* 130(no. 3384), 1225-1234; cf his *The Use of Computers in Biology and Medicine* (NY, 1965) Douglas Brutlag, "Conclusions and Recommendations" (of report to the NIH on biomedical modeling) [pdf] Robert K. Lindsay, "DENDRAL: a case study of the first expert system for scientific hypothesis formation", *Artificial Intelligence* 61(1993), 209-61 Peter Friedland and Laurence H. Kedes, "Discovering the Secrets of DNA"

	Comm.ACM 28,11(1985), 1164-86 ([pdf](#)) (MOLGEN) R. J. Spinrad, "Automation in the Laboratory", *Science*, 158: 55-60 (Oct 6, 1967) [[online](#)] Lindsay, Robert K., Bruce G. Buchanan, and Edward A. Feigenbaum. DENDRAL: A Case Study of the First Expert System for Scientific Hypothesis Formation. *Artificial Intelligence* 61 (1993): 209-261. [[pdf](#)] {NOT PERMANENT} James Shreeve, T*he Genome War: How Craig Venter Tried to Capture the Code of Life and Save the World*, 2004. Joe November, "LINC: Biology's Revolutionary Little Computer" *Endeavour* 28,3 (September 2004): 125-131 [[pdf](#)] **Secondary** Timothy Lenoir, " [Shaping Biomedicine as an Information Science](#)" Evelyn Fox Keller, "Models of and Models For: Theory and Practice in Contemporary Biology" [[pdf](#)] Eric S. Lander, Robert Langridge, Damian M Saccocio, "[Computing in Molecular Biology: Mapping and Interpreting Biological Information](#), *Computer* 24,11(1991), 6-13; [another version](#) in *Communications of the ACM* 34,11(1991), 32-39 Joshua Lederberg, "How DENDRAL Was Conceived and Born", *A History of Medical Informatics* (NY: ACM Press, 1987), 14-44; appendix (37-44) is memo of 4/5/65 by E.A. Feigenbaum and R.W. Watson, "An Initial Research Statement for a Machine Induction Research Project" ([pdf version](#)) Temple F. Smith, "[The History of Genetic Sequence Database](#)s", *Genomics* 6(1990): 701-707 **Supplementary** [History of Bioinformatics](#) is the subject of an extensive online collection of primary and secondary sources compiled as a collaboration between historians of science and the scientists involved. As an introduction to the subject and to the resources, see Lenoir, above. Use the site to get a sense of the nature and structure of the major early projects, DENDRAL, MYCIN, AND MOLGEN (current version [online](#))
Week X (11/23) *Evolution and Communication* Report: Dan Bouk	**Primary** Eigen, Manfred et al., "The Origin of genetic information" *Scientific American* (1981) Herbert Simon, "The Architecture of Complexity", in *The Sciences of the Artificial* 1962 Rupert Riedl, *Order in Living Organisms,* 1975 (1978), Chapters 1 2 and 8 C.H. Waddington, "The basic ideas of biology", in *Towards a Theoretical Biology* 1967 C.H. Waddington, "Form and Information", in *Towards a Theoretical Biology* 1968 H.H. Pattee, "The physical basis of coding and reliability in biological evolution", in *Towards a Theoretical Biology* Michael A. Arbib, , "Self-reproducing Automata - Some implications for Theoretical Biology", *in Towards a Theoretical Biology* **Secondary** Walter Fontana, et al., "Beyond Digital Naturalism", *Artificial Life* 1(1994), 211-227 [[ps](#)] Walter Fontana and Leo Buss, "What would be conserved if 'the tape were played twice?", *Proc. NAS* 91,2(1994), 757-761. [[JSTOR](#)] **Supplementary** Alan M. Turing, "The Chemical Basis of Morphogenesis" *[Philosophical Transactions](#)*

	B,237(1952), 37-72 Karl Sigmund, *Games of Life* J.B.S. Haldane, "The Mechanical Chess-Player," *Brit. J. Phil. Sci.* **3** (1952): 190 Alex Rich, "On the Problems of Evolution and Biochemical Information Transfer," *Horizons in Biochemistry* (1962)
Week XI (11/30) *Automata, Languages, Development* Report: Alicia Imperiale	**Primary** Noam Chomsky, "Three models of language", *IRE Transactions in Information Theory* 2,3(1956), 113-24, and "On certain formal properties of grammars", *Information and Control* 2,2(1959), 137-167 Noam Chomsky and George A. Miller, "Introduction to the Formal Analysis of Natural Languages", in *Handbook of Mathematical Psychology* [1963-5], ed. R.D. Luce, R.R. Bush, E. Galanter, Vol. 2, Chap. 11 Aristide Lindenmayer, "Mathematical models for cellular interactions in development", *J. Theor. Biol.* 18(1968), 280-99, 300-15 Cf. his L-systems (also An L-system Tutorial, another tutorial, L-system java applet) **Secondary** David B. Searls, "The language of genes", *Nature* 420(2002), 211-217 [html, pdf (PU only)] Noam Chomsky, *The Logical Structure of Linguistic Theory*, 1-53 ("Introduction 1973") Robert Friedin, "Conceptual Shifts in the Science of Grammar: 1951-1992", in Carlos P. Otero (ed.), *Noam Chomsky: Critical Assessments* Sheila A. Greibach, "Formal languages: Origins and directions", *Annals of the History of Computing* 3,1(1981), 14-41 **Supplementary** Gary William Flake, *The Computational Beauty of Nature* Przemyslaw Prusinkiewicz and Aristid Lindenmayer, *The Algorithmic Beauty of Plants* (Springer Verlag, 1990), esp. Chap.1 Przemyslaw Prusinkiewicz, Mark Hall, and Radomir Mech, *Visual Models of Morphogenesis: A Guided Tour* (online text with illustrations)
Week XII (12/7) *Synthetic Biology* Report: Lydia Kallipoliti	**Primary** Christopher Langton, "Artificial Life", in Margaret A. Boden (ed.) *The Philosophy of Artificial Life*, Chap. 1 Thomas S. Ray, "An Approach to the Synthesis of Life", *ibid.*, Chap. 3; see the Tierra home page and get a copy of the software John Maynard Smith, "Evolution -- Natural and Artificial" *ibid.*, Chap. 5 Elliott Sober, "Learning from Functionalism -- Prospects for Strong Artificial Life", *ibid.*, Chap. 14 John L. Casti, "Newton, Aristotle and the Modeling of Living Systems", in John Casti and Anders Karlqvist (eds.), *Newton to Aristotle: Toward a Theory of Models for Living Systems*, 47-89 Carlo C. Maley, "Models in Evolutionary Ecology and the Validation Problem", *Artificial Life VI* *Mark A. Bedau, "Can Unrealistic Computer Models Illuminate Theoretical Biology?" , *Proc. 1999 Genetic and Evolutionary Computation Conference Workshop Program, Orlando, FL, July 13, 1999*, ed. Annie S. Wu, 20-23 [pdf] *Mark A. Bedau, *et al.*, "Open Problems in Artificial Life", *Artificial Life* 6,4(2000), 363-376 [preprint pdf]

Secondary
Claus Emmeche, *The Garden in the Machine: The Emerging Science of Artificial Life*
Stefan Helmreich, *Silicon Second Nature: Culturing Artificial Life in a Digital World*

Supplementary
John H. Holland, *Hidden Order: How Adaptation Builds Complexity*
Richard Doyle, *On Beyond Living: Rhetorical Transformations of the Life Sciences*,
Chap. 7, "Emergent Power: Vitality and Theology in Artificial Life"
John L. Casti, *Alternate Realities: Mathematical Models of Nature and Man*, Chap. 2

Genetic Algorithms
John H. Holland, "Outline for a Logical Theory of Adaptive Systems", *J. ACM*
9,3(1962), 297-314 [pdf (PU only)] and *Adaptation in Natural and Artificial Systems:
An Introductory Intelligence* (Ann Arbor, 1975)
Stephanie Forrest, "Genetic Algorithms: Principles of Natural Selection Applied to
Computation", *Science* 261, no. 5123 (Aug. 13, 1993), 872-878
Melanie Mitchell, *An Introduction to Genetic Algorithms* (MIT, 1998) [online PU only]