

Additional Readings

The following is a list of additional readings rather than a bibliography. The range of topics discussed in this text does not allow for a comprehensive bibliography. Our focus is on the effort to develop concepts and methodologies that enable the study of complex systems in a unified manner. Nevertheless, this effort must be informed by many fields and their phenomenologies. The following list attempts to address this by providing accepted keywords for literature searches as provided by the Library of Congress.

In addition to the keywords, a few references are provided with comments. Many of these texts were obtained from literature searches, and have been checked as relevant to the concepts we have been discussing. These references serve several purposes. First, they provide the student with an opportunity to pursue the phenomenology or theory in greater depth. Second, in a more specific domain, they provide a point of entry into the literature through a bibliography. Third, some references have an approach that is particularly compatible with the material presented in this text, or to the field of complex systems generally.

This list, however, does not serve three conventional purposes. It does not serve to trace the historical origin of concepts presented, or to motivate them from phenomenological grounds, or to prove them using experimental observations. Any of these would be a worthwhile but equally challenging endeavor to the objective of demonstrating the unity of concepts, which is the motivating force behind this text.

As is fitting for concepts that are to be a general underpinning of our understanding of complex systems, points made in this book appear in many contexts in the literature. A stronger statement may be made—the generality of the concepts presented in this text must imply that there are many ways to arrive at them, and many conclusions that may be drawn from them that can be compared with a large body of experimental literature. The effort in this text to draw conclusions from a very small set of assumptions is only a beginning in the effort to understand how widely applicable such concepts can be. In the few cases where we have made a greater effort to make contact with specific phenomenology and thus where support is necessary for material presented in the text (e.g. the discussion of sleep in Chapter 3), we have provided a few more specific references.

Chapter 0

keywords: system theory; autopoiesis; biological systems; chaotic behavior in systems; cybernetics; linear systems; social systems; system analysis; systems engineering; complexity (philosophy)

[0.1] Herbert A. Simon, *The Sciences of the Artificial*, 3d ed. (MIT Press: Cambridge, 1996). See the last chapter for an alternate overview of this text.

There are a remarkable number of popular or semipopular books on various concepts in the study of complex systems. For a number of reasons these books have appeared instead of textbooks. They are of two types: books written by observers of the field, and books written by researchers presenting their ideas to a popular audience.

There are both positive and negative aspects of this approach, the ultimate benefit of which will be judged by others. Here we provide a few references to this literature:

- [0.2] James Gleick, *Chaos: Making a New Science* (Penguin: New York, 1987).
Concept and personality history, focusing on chaotic and nonlinear dynamics (Section 1.1), and fractals (Section 1.10) but relevant to the study of complex systems in general.
- [0.3] Douglas R. Hofstadter, *Gödel, Escher, Bach* (Vintage: New York, 1989).
Semipopular and creative romp emphasizing mathematical and philosophical aspects of logic (Section 1.9).
- [0.4] Roger Lewin, *Complexity: Life at the Edge of Chaos* (Macmillan: New York, 1992).
- [0.5] M. Mitchell Waldrop, *Complexity: The Emerging Science at the Edge of Order and Chaos* (Simon & Schuster: New York, 1992).
- [0.6] John L. Casti, *Complexification: Explaining a Paradoxical World through the Science of Surprise* (HarperCollins: New York, 1994).
- [0.7] Brian Goodwin, *How the Leopard Changed its Spots: The Evolution of Complexity* (Charles Scribner's Sons: New York, 1994).
- [0.8] Stuart A. Kauffman, *At Home in the Universe* (Oxford University Press: New York, 1995).
- [0.9] John H. Holland, *Hidden Order: How Adaptation Builds Complexity* (Helix Books, Addison-Wesley: Reading, Mass., 1995).
- [0.10] Peter Coveney and Roger Highfield, *Frontiers of Complexity: The Search for Order in a Chaotic World* (Fawcett Columbine: New York, 1995).
- [0.11] Per Bak, *How Nature Works: The Science of Self-Organized Criticality* (Copernicus, Springer-Verlag: New York, 1996).

More technical references include some with classic and others with modern approaches:

- [0.12] James Grier Miller, *Living Systems* (McGraw-Hill: New York, 1978).
- [0.13] George J. Klir, *Architecture of Systems Problem Solving* (Plenum: New York, 1985).
- [0.14] Gérard Weisbuch, *Complex Systems Dynamics* (Addison-Wesley, Reading, Mass., 1991).
- [0.15] Thomas J. Sargent, *Bounded Rationality in Macroeconomics* (Carendon, Oxford, 1993). Title is inadequate.
- [0.16] Mikhail V. Volkenstein, *Physical Approaches to Biological Evolution* (Springer-Verlag: Berlin, 1994). Touches on many classic contributions in complex systems.

A series of books under the collective title "The Santa Fe Institute Studies in the Sciences of Complexity" published by Addison-Wesley, collects various workshops and lectures sponsored by the Santa Fe Institute on subjects relevant to complex systems. This series illustrates the great diversity of concepts and applications of this

field. We do not include a full list of these books here. A few volumes in this series are mentioned below as appropriate.

Chapter 1

Section 1.1

keywords: chaotic behavior in systems

- [1.1.1] Predrag Cvitanovic, ed. *Universality in Chaos: A Reprint Selection*, 2d ed. (Adam Hilger: Bristol, 1989).
- [1.1.2] Robert L. Devaney, *A First Course in Chaotic Dynamical Systems: Theory and Experiment* (Addison-Wesley: Reading, Mass., 1992). Excellent undergraduate-level textbook on basic mathematics of iterative maps and chaos.
- [1.1.3] Robert L. Devaney, *Introduction to Chaotic Dynamical Systems*, 2d ed. (Addison-Wesley, Reading, Mass., 1989). More advanced mathematical treatment than [1.1.2].
- [1.1.4] Steven H. Strogatz, *Nonlinear Dynamics and Chaos. With Applications to Physics, Biology, Chemistry, and Engineering* (Addison-Wesley: Reading, Mass., 1994). Undergraduate textbook on nonlinear dynamics that arise from differential equations.
- [1.1.5] Edward Ott, *Chaos in Dynamical Systems* (Cambridge University Press: Cambridge, 1993).

Section 1.2

keywords: probabilities; combinatorial probabilities; correlation (statistics); distribution (probability theory); games of chance (mathematics); limit theorems (probability theory); random variables; stochastic processes; stochastic sequences; random walks (mathematics)

Probability and statistics is a traditional field of study in many fields with varying emphasis depending on whether it is used for analysis of data, for modeling of systems, or for more abstract formal concepts. A reference that is particularly relevant to our purposes is:

- [1.2.1] N. G. van Kampen, *Stochastic Processes in Physics and Chemistry* (North-Holland, Amsterdam, 1981). Outstanding graduate text on the concepts and applications of stochastic processes. Somewhat more formal than this text, while still providing a useful conceptual framework.

Section 1.3

keywords: thermodynamics; statistical physics; statistical mechanics; phase transformations (statistical physics); statistical thermodynamics

Thermodynamics/statistical physics is a traditional field of physics covered by undergraduate and graduate textbooks with various approaches and flavors. Examples include:

- [1.3.1] Kerson Huang, *Statistical Mechanics*, 2d ed. (Wiley: New York, 1987). Undergraduate text.

- [1.3.2] Edward A. Guggenheim, *Thermodynamics: An Advanced Treatment for Chemists and Physicists* (North-Holland: Amsterdam, 1967). Graduate text with elegant review of basics.
- [1.3.3] Lev Davidovich Landau and E. M. Lifshitz, *Statistical Physics (Course of Theoretical Physics, vol. 5)* 2d ed. (Pergamon: Oxford, 1969). Classic advanced text.

Section 1.4

keywords: chemical reaction, conditions and laws of; chemical kinetics

The two-state system analysis is based on classic transition-state theory covered in many physical chemistry books as a model for chemical reaction kinetics.

Section 1.5

keywords: cellular automata

- [1.5.1] Stephen Wolfram, ed. *Theory and Applications of Cellular Automata* (World Scientific, Singapore, 1983). Many of the original articles are collected in this book. Includes an extensive bibliography.
- [1.5.2] Doyne Farmer, Tommaso Toffoli and Stephen Wolfram, eds. *Cellular Automata* (North-Holland: Amsterdam, 1984). A conference proceedings volume.
- [1.5.3] Tommaso Toffoli and Norman Margolus, *Cellular Automata Machines: a New Environment for Modeling*. (MIT Press: Cambridge, Mass., 1987). Many useful concepts and methods discussed.

Section 1.6

keywords: phase transformations (statistical physics); ferromagnetism; Ising model

Most books on statistical physics (Section 1.3) include a discussion of the Ising model. See especially:

- [1.6.1] H. Eugene Stanley, *Introduction to Phase Transitions and Critical Phenomena* (Oxford University Press: New York, 1971).
- [1.6.2] Giorgio Parisi, *Statistical Field Theory* (Addison-Wesley, Reading, Mass., 1988). Advanced formal treatment.

Section 1.7

keywords: simulation methods; mathematical models; computer simulation; Monte Carlo method

- [1.7.1] M. P. Allen and D. J. Tildesley, *Computer Simulations of Liquids* (Oxford Science Publications: Oxford, 1987). Readable, practical guide to modern simulation strategies.
- [1.7.2] Malvin H. Kalos and Paula A. Whitlock, *Monte Carlo Methods, vol. 1: Basics* (Wiley & Sons: New York, 1986).

Section 1.8

keywords: information theory; statistical communication theory

- [1.8.1] C. E. Shannon, "A Mathematical Theory of Communication," in *Bell Systems Technical Journal*, July and October 1948; reprinted in C. E. Shannon and W. Weaver, *The Mathematical Theory of Communication* (University of Illinois Press: Urbana, 1963). The original manuscript on this subject is still the best discussion. Note the change in the first word of the title from original to reprint.

Section 1.9

keywords: logic, symbolic and mathematical; machine theory; computer science; Turing machines

- [1.9.1] Ira Pohl and Alan Shaw, *The Nature of Computation: An Introduction to Computer Science* (Computer Science Press, Potomac, Md., 1981). Pleasant introduction to concepts and language of computer science.
- [1.9.2] John N. Crossley, *What is Mathematical Logic?* (Oxford University Press: Oxford, 1972). Dense overview.
- [1.9.3] Elliott Mendelson, *Introduction to Mathematical Logic*, 2d ed. (Van Nostrand: New York, 1979).
- [1.9.4] Herbert B. Enderton, *A Mathematical Introduction to Logic* (Academic Press: New York, 1972).
- [1.9.5] H. (Hartley) Rogers, *Theory of Recursive Functions and Effective Computability* (McGraw-Hill: New York, 1967; MIT Press: Cambridge, 1987). Formal discussion of the theory of universal computation.

Section 1.10

keywords: fractals; renormalization group; scaling laws (statistical physics); multigrid methods numerical analysis

The subject of fractals has strong overlaps with the topic of chaos (Section 1.1) due to the connection between multiscale phenomena and chaotic dynamics discussed in Chapter 9. Thus, see also the references in Section 1.1.

- [1.10.1] Benoit B. Mandelbrot, *The Fractal Geometry of Nature* (W. H. Freeman: New York, 1983). The original source.
- [1.10.2] R. J. Creswick, H. A. Farach and C. P. Poole, Jr., *Introduction to Renormalization Group Methods in Physics* (Wiley: New York, 1992). A relatively accessible discussion of renormalization methods.
- [1.10.3] Albert-Laszlo Barabasi, H. Eugene Stanley, *Fractal Concepts in Surface Growth* (Cambridge University Press, New York, 1995).
- [1.10.4] F. Family and T. Vicsek eds. *Dynamics of Fractal Surfaces* (World Scientific: Singapore, 1991). A collection of articles on the application of scaling ideas to surfaces. The principal relevance to us is the scaling treatment of spatial

and temporal properties of these systems. References on the application of scaling to polymers are given in Chapter 5.

- [1.10.5] James H. Bramble, *Multigrid Methods* (Longman: Harlow, Essex, 1993; Wiley: New York, 1993).
- [1.10.6] William L. Briggs, *A Multigrid Tutorial* (SIAM: Philadelphia, 1987).

Chapter 2

keywords: neurophysiology; brain—localization of functions; neural networks (neurobiology); cognitive neuroscience; artificial intelligence; neural networks (computer science); pattern-recognition systems

Discussions of neural function from a biological perspective:

- [2.1] Michael S. Gazzaniga, Richard Ivry and George R. Mangun, *Fundamentals of Cognitive Neuroscience* (W.W. Norton: New York, 1997).
- [2.2] Eric R. Kandel, James H. Schwartz, Thomas M. Jessell eds. *Principles of Neural Science*, 3d ed. (Elsevier: New York, 1991).
- [2.3] Gordon M. Shepherd, *Neurobiology* (Oxford University Press: New York, 1983).
- [2.4] *Scientific American* (September 1992). Issue devoted to the biological approach to brain function, specifically cellular function and brain imaging.

Almost any book on neural networks, of which there are a number, will offer a basic introduction to various types of neural networks including the attractor network and the feedforward network, variations on these networks and other simple models. Unfortunately, the field is polarized, with distinct camps taking different approaches and claiming priority on ideas, realism or other issues. The complexity of biological neural systems enables various approaches to coexist without much more than acknowledging each other. A collection of articles that are central to the development of various threads in the field of neural networks is contained in:

- [2.5] J. A. Anderson and E. Rosenfeld eds. *Neurocomputing* (MIT Press, Cambridge, Mass., 1988).

While it is important to respect the value of all approaches, the treatment emphasized in this chapter originates from J. J. Hopfield. This approach emphasizes simplicity of the microscopic components so that collective behavior can be more easily (but still not trivially!) understood. Books expanding on this:

- [2.6] Daniel J. Amit, *Modeling Brain Function: The World of Attractor Neural Networks* (Cambridge University Press, Cambridge, 1989). A systematic description of the analysis of attractor networks using techniques developed in statistical mechanics. The early chapters motivate the use of the attractor network from a biological perspective and introduce the models.
- [2.7] Marc Mezard, Giorgio Parisi, and Miguel Angel Virasoro, *Spin Glass Theory and Beyond* (World Scientific: Singapore, 1987).

Specific references:

- [2.8] P. Baldi and S. Venkatesh, "Number of Stable Points for Spin-Glasses and Neural Networks of Higher Orders," *Phys. Rev. Lett.*, 58, 913 (1987). The maximum number of stored independent bits cannot be greater than $2N^2$, or $2N$ uncorrelated patterns—note that the synaptic matrix is not required to be symmetric.

Chapter 3

Section 3.1

keywords: sleep; sleep—physiological aspects

Discussions of sleep phenomenology and models of its function are contained in:

- [3.1] James A. Horne, *Why We Sleep: The Functions of Sleep in Humans and Other Mammals* (Oxford University Press, Oxford, 1988). Excellent review focusing on sleep-deprivation studies. Counters notion that sleep serves physiological restorative function.
- [3.2] Andrew Mayes, ed. *Sleep Mechanisms and Functions in Humans and Animals: An Evolutionary Perspective* (Van Nostrand Reinhold (UK): Wokingham, 1983). See particularly Chapter 1 by W. B. Webb for the evolutionary perspective on sleep criticized in this chapter.
- [3.3] William Fishbein, ed. *Sleep, Dreams and Memory: Advances in Sleep Research* vol. 6, (Spectrum Publications Medical and Scientific: New York, 1981). This and the next reference suggest that sleep serves a role in memory.
- [3.4] David B. Cohen, *Sleep and Dreaming: Origins, Nature and Functions* (Pergamon: Oxford, 1979).
- [3.5] J. Allan Hobson, *The Dreaming Brain* (Basic Books: New York, 1988). Dissociation of neural function from sensory information is discussed on pp. 209–210.
- [3.6] Ernest L. Hartmann, *The Functions of Sleep* (Yale University Press: New Haven, 1973). Mention of the similarity of aspects of dreams to cognition of postlobotomy patients, pp. 136–138.

Specific references:

- [3.7] F. Crick and G. Mitchison, "The Function of Dream Sleep," *Nature* 304, 111 (1983).
- [3.8] J. J. Hopfield, D. I. Feinstein and R. G. Palmer, "'Unlearning' Has a Stabilizing Effect in Collective Memories" *Nature* 304, 158 (1983).
- [3.9] T. Geszti and F. J. Pázmándi, "Learning within Bounds and Dream Sleep," *J. Phys. A* 20, L1299 (1987); "Modeling Dream and Sleep," *Physica Scripta* T25, 152 (1989).
- [3.10] L. M. Mukhametov, "Sleep in Marine Mammals," in A. A. Borbély and J. L. Valatx, eds. *Sleep Mechanisms* (Springer-Verlag, 1984) pp. 227–238. Studies

of dolphins sleeping half brain at a time. Among other arguments, refutes the evolutionary perspective of ref. [3.2].

- [3.11] M. A. Wilson and B. L. McNaughton, "Reactivation of Hippocampal Ensemble Memories During Sleep," *Science* 265, 676 (1994).

Section 3.2

keywords: knowledge, theory of; intellect; perception; human information processing; artificial intelligence; philosophy of mind; cognitive science; memory; psychology of learning

- [3.12] Marvin Minsky, *Society of Mind* (Simon and Schuster, New York, 1985).

Specific references:

- [3.13] L. Standing, "Learning 10,000 pictures," *Quarterly Journal of Experimental Psychology* 25, 207 (1973). Testing recognition.
- [3.14] R. D. Hawkins, T. W. Abrams, T. J. Carew, and E. R. Kandel, "A Cellular Mechanism of Classical Conditioning in Aplysia: Activity-Dependent Amplification of Presynaptic Facilitation" *Science* 219, 400 (1983); E. R. Kandel and R. D. Hawkins, *Scientific American* (September 1992) pp. 78–86, Experimental studies of the biology of neurons showing synapses that couple three neurons; e.g. implementing the logical AND operation.

Chapter 4

keywords: proteins; proteins–conformation; protein folding

Note: the problem of identifying time scale can also be seen in other fields. In computer science see keyword: computational complexity.

- [4.1] Jack Kyte, *Structure in Protein Chemistry* (Garland: New York, 1995).
- [4.2] Carl Branden and John Tooze, *Introduction to Protein Structure* (Garland: New York, 1991).
- [4.3] Alan Ferscht, *Enzyme Structure and Mechanism*, 2d ed. (Freeman: New York, 1985).
- [4.4] Thomas E. Creighton, *Proteins: Structures and Molecular Principles* (Freeman: New York, 1983).

Chapter 5

keywords: macromolecules; polymers; polymer solutions; biopolymers

Books on the scaling properties of polymers:

- [5.1] Pierre-Gilles de Gennes, *Scaling Concepts in Polymer Physics* (Cornell University Press, Ithaca, N.Y., 1979).
- [5.2] Masao Doi and Sam F. Edwards, *The Theory of Polymer Dynamics* (Oxford University Press, Oxford, 1986).

A discussion of parallel-processing simulations is found in:

- [5.3] B. M. Boghosian, *Computers in Physics* 4, 14 (1990).

Specific references:

- [5.4] P. G. de Gennes, "Kinetics of Collapse for a Flexible Coil," *Journal de Physique Lettres* 46 L639 (1985).
- [5.5] B. Ostrovsky, M. A. Smith and Y. Bar-Yam, "Applications of parallel computing to biological problems," *Annual Review of Biophysics and Biomolecular Structure* 24, 239 (1995).
- [5.6] Y. Bar-Yam, "Polymer Simulation Using Cellular Automata: 2-d Melts, Gel-Electrophoresis and Polymer Collapse," in G. Bhanot, S. Chen, and P. Seiden eds. *Some New Directions in Science on Computers* (World-Scientific: Singapore, 1996).

Chapter 6

keywords: evolution; evolution (biology); heredity; adaptation(biology); variation (biology); natural selection; genetics; population genetics; cytoplasmic inheritance; egoism; genetic algorithms

- [6.1] Charles Darwin, *On the Origin of Species (By Means of Natural Selection)* (a facsimile of the first edition, 1859) (Harvard University Press: Cambridge, Mass., 1964). The original discussion is still enlightening, and shows the strong phenomenological basis for the conceptual developments.
- [6.2] Douglas J. Futuyma, *Evolutionary Biology*, 2d ed. (Sinauer Assoc., Sunderland, Mass., 1986). Outstanding discussion of phenomena in biological evolution and their relation to conceptual issues in the theoretical understanding of evolution.
- [6.3] Robert N. Brandon and Richard M. Burian, eds. *Genes, Organisms, Populations: Controversies Over the Units of Selection* (MIT Press, Cambridge, Mass., 1984).
- [6.4] Richard Dawkins, *The Selfish Gene*, 2d ed. (Oxford University Press: Oxford, 1989). Presents the extreme reductionist view criticized in this chapter.
- [6.5] Stephen Jay Gould, *Wonderful Life: The Burgess Shale and the Nature of History* (Norton, New York, 1989). Punctuated equilibria. See also ref. [0.11]
- [6.6] Stuart A. Kauffman, *The Origins of Order: Self Organization and Selection in Evolution* (Oxford University Press: New York, 1993). A complex systems perspective.
- [6.7] Karl Sigmund, *Games of Life: Explorations in Ecology, Evolution, and Behavior* (Oxford University Press: Oxford, 1993). Many fine points on mathematical treatment of evolution.
- [6.8] William Day, *Genesis on Planet Earth: The Search for Life's Beginning*, 2d ed. (Yale University Press: New Haven, Conn., 1984). Molecular to cellular evolution.

Artificial life references include:

- [6.9] Christopher G. Langton, ed. *Artificial Life: The Proceedings of an Interdisciplinary Workshop on the Synthesis and Simulation of Living Systems* (Addison-Wesley, Reading, Mass., 1989). See also the sequels in the same series, *Artificial Life II–IV*. See the video for *Artificial Life II*.
- [6.10] Christopher G. Langton, ed. *Artificial Life: An Overview* (MIT Press, Cambridge, 1995).

For genetic algorithms, see:

- [6.11] John H. Holland, *Adaptation in Natural and Artificial Systems*, 2d ed. (MIT Press: Cambridge, Mass., 1992).
- [6.12] Melanie Mitchell, *An Introduction to Genetic Algorithms* (Bradford, MIT Press: Cambridge, Mass., 1996).

For discussions of the philosophy of egoism—self-interest vs. altruism, see:

- [6.13] David P. Gauthier, ed. *Morality and Rational Self-interest* (Prentice-Hall: Englewood Cliffs, N.J., 1970).
- [6.14] Robert M. Axelrod, *The Evolution of Cooperation* (Basic Books: New York, 1984). Shows the marginal stability of the most primitive form of cooperation (tit for tat); i.e. upon introduction of spatial correlations (correlations in selective forces).
- [6.15] David P. Gauthier, *Morals by Agreement* (Clarendon: Oxford, 1986).

Chapter 7

keywords: developmental biology; embryology; pattern formation (biology); chemical reactions

- [7.1] Lee A. Segel, *Modeling Dynamic Phenomena in Molecular and Cellular Biology* (Cambridge University Press: Cambridge, 1984).
- [7.2] James D. Murray, *Mathematical Biology* (Springer-Verlag, New York, 1989).
- [7.3] Hans Meinhardt, *The Algorithmic Beauty of Sea Shell Patterns* (Springer-Verlag: New York, 1994).
- [7.4] H. F. Nijhout, "Pattern Formation in Biological Systems," in Lynn Nadel and Daniel L. Stein, eds. *1991 Lectures in Complex Systems* (Addison-Wesley: Reading, Mass., 1992). A brief presentation.
- [7.5] Przemyslaw Prusinkiewicz and Aristid Lindenmayer with James S. Hanan, *The Algorithmic Beauty of Plants* (Springer-Verlag: New York, 1990). L-systems.

Chapter 8

keywords: Kolmogorov complexity

- [8.1] <http://www.fmb.mmu.ac.uk/~bruce/combib/>. An extensive bibliography on complexity.

- [8.2] Gregory J. Chaitin, *Algorithmic Information Theory* (Cambridge University Press: Cambridge 1987).
- [8.3] W. H. Zurek, ed. *Complexity, Entropy and the Physics of Information* (Addison-Wesley: Reading, Mass., 1990).
- [8.4] Ming Li and Paul Vitanyi, *An Introduction to Kolmogorov Complexity and Its Applications* (Springer-Verlag: New York, 1993).

Specific references:

- [8.5] J. E. Lovelock, *Gaia, A New Look at Life on Earth* (Oxford University Press: Oxford, 1979).
- [8.6] E. R. Cohen and B. N. Taylor, "The 1986 Adjustment of the Fundamental Physical Constants," *Rev. Mod. Phys.* 59, 1121 (1987). Value of the electron magnetic moment.
- [8.7] Neville H. Fletcher, *The Chemical Physics of Ice* (Cambridge Univ. Press: London, 1970). Excellent review of basic knowledge of the low temperature properties of ice.
- [8.8] Charles H. Bennett, "The Thermodynamics of Computation—A review," *International Journal of Theoretical Physics* 21, 905 (1982).

Chapter 9

keywords: civilization—history, civilization—philosophy; social history; social change; technology and civilization; organization; management; management science; economic history; international economic relations; man—origin

For modeling using system dynamics, a method that was not discussed in this text, see:

- [9.1] George P. Richardson and Alexander L. Pugh III, *Introduction to System Dynamics Modeling with DYNAMO* (MIT Press: Cambridge, Mass., 1981).

Books on the structure of corporations and the recent changes in civilization include:

- [9.2] Henry Mintzberg, *The Structuring of Organizations: A Synthesis of the Research* (Prentice-Hall, Englewood Cliffs, 1979). Remarkable phenomenologically-driven discussion.
- [9.3] David Mitchell, *Control Without Bureaucracy* (McGraw-Hill, London, 1979). Experience-driven discussion.
- [9.4] Gregory Stock, *Metaman: The Merging of Humans and Machines into a Global Superorganism* (Simon & Schuster: New York, 1993). Includes an extensive set of references.

