Readings in the 'New Science': a selective annotated bilbiography

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Abstract: In this sampling of the literature-under the rubrics Undecidability, Uncertainty and Complexity; Macrostructures: Systems and the Human Scale (Entropy, Dynamical Systems, Computation); The Very Big and the Very Small: Physics, Astrophysics and Cosmology; Time; Culture and Epistemology-the emphasis is on the complexity brought to focus in studies of dynamical systems. The recent flowering of this work, characteristically scornful of traditional disciplinary boundaries, evidences, shift to relation over substance, synthesis over reduction, simulation over analysis.

During the last quarter of the nineteenth century the world of mathematics was rocked by a series of papers, beginning with the work of Georg Cantor on transfinite sets and that of Karl Weierstrass on the continuous but nondifferentiable function[1]. Henri Poincaré laid the foundations for what would later become bifurcation theory and proved that the three-body problem had no solution[2]. Though the tacit questioning continued with the proliferation of such

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[1] An appraisal of Cantor's work from a sociology of science perspective, in English, is to be found in: Dauben, Joseph Warren. GEORG CANTOR: HIS MATHEMATICS AND PHILOSOPHY OF THE INFINITE. *Princeton: Princeton Univ. Press, 1979.* Weierstrass, function, presented in an 1872 lecture and reported by du Bois-Reymond but unpublished until 1895, marked a watershed in mathematics. The original citations for Weierstrass are: Weierstrass, Karl. »Über continuirliche Functionen eines reellen Arguments, die für keinen Werth des letzteren einen bestimmten Differentialquotienten besitzen.« MATHEMATISCHE W£RKE. *vol II. Berlin: Mayer & Muller, 195 [reprint Hildesheim and New York: Olms and Johnson, 1967, 71-74].* du Bois-Reymond, Paul. »Versuch einer Classification der willkürlichen Functionen reeller Argumente nach ihren Änderungen in den kleinsten Intervallen.« JOURNAL FÜR DIE REINE UND ANGEWANDTE MATHEMATIK *(Creile), LXXIX, I, 1875, 21 -37.*

[2] Poincaré laid the groundwork for bifurcation theory in 1879; he proved the

»pathological« cases, for the most part neither mathematicians nor, later, physicists knew quite what to make of these ideas whose further development led in directions well beyond the still ample world framed by Newton and Descartes. Thus they were largely shelved and forgotten[3].

This revolution in mathematics,« as it was subsequently labeled predates, but by only a few years, the more widely recognized, and more immediately and spectacularly exploited, »revolution in physics«: the fundamental papers in relativity and quantum theory date from the first quarter of the twentieth century[4].

Although the chronology of our readings could well have begun with these twin events, we have chosen to inaugurate the present thematic bibliography with Gödel's 1931 paper, focusing on undecidability and the allied concepts of uncertainty and complexity. The two decades separating 1918 from 1939 were also the period in which both the theoretical and technological bases were laid for the computing machines-to undergo drastically accelerated development during WWII-that were to become a major tool of systems research and closely associated with work in information theory, cognitive science and artificial intelligence.

Warren Weaver's assertion in his 1948 paper, »Science and Complexity« (this bib.), that the new frontier of science would address problems of organized complexity« was prophetic. The bulk of the material starting from this notion is concerned with »Macrostructures: Systems and the Human Scale.« A salient feature of current developments is the coming together of mathematicians and physicists, as well as chemists, biologists, and other scientists from the »hard« disciplines, around the vindication and application of those late nineteenth-century developments in mathematics and the rebirth of geometry that were once written off as pathological. These anomalies and paradoxes are

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three body problem to be unsolvable in 1890, thus hastening the demise of classical physics by showing predictability to be untenable. See: Poincaré, Jules Henri., »Sur les propriétés des fonctions définies par les équations aux différences partielles.« OEUVRES DE HENRI POINCARÉ, *Tome I. Paris: Gauthier-Villars, 1951, XLIX-CXXIX.* Poincaré, Jules Henri. »Sur le problème des trois corps et les équations de la dynamique.« ACTA MATHEMATICA, *XIII, 1890, 1-270.*

[3] Benoit Mandelbrot, in his *Fractal Geometry of Nature* (this bib. III. B. 4.), offers a good discussion of, and explicitly ties his arguments to, the developments of this period.

[4] The question »who was'right'?« is still hotly contested. Although both include Newtonian mechanics and share with classical science deterministic and time-reversible (at the level of the wave function for quantum mechanics) basic laws, they so far remain incompatible-hence the search for a unified theory. See: Kitchener, Richard F. *The World View of Contemporary Physics* (this bib.). Sachs, Mendel. *Einstein Versus Bohr: The Continuing Controversies in Physics.* La Salle: Open Court, 1988.

recognized today as revealingly characteristic of the very nonlinear material world in which the symbiosis of order and disorder engenders determined but unpredictable change. Computer simulation has become the heuristic of choice in this arena of complex systems and the emphasis has shifted away from analysis through reduction to holistic synthesis. Although brief, it is hoped that the section entitled »The Very Big and the Very Small: Physics, Astrophysics and Cosmology,« will give some of the flavor of the very real developments in this enormous and not-to-be-slighted domain.

»Time« is a central concern in what we have loosely designated »new scien-ce^ Here, moreover, the blur between the philosophical and the scientific is particularly acute and indicative of an important aspect of contemporary developments. We may see in it a »softening« that is apparent as well in the area of »Culture and Epistemology« where again it has only been possible to offer a small sampling of the literature.

Taken as a whole this bibliography has been compiled primarily with the working historical scientist in mind, to provide pointers to the literature and explore the developing contours of the research and, of necessity, to suggest an interpretative framework. Although it may interest some specialists, it would probably satisfy none. The entries range from »very hard,« highly technical material to »very soft« popularizations. In general, an attempt was made to include as many different authors as possible; unfortunately, despite our best efforts, the end product must *perforce* reflect the gender bias so prevalent in the natural sciences. Finally, the author takes full responsibility for the choices-inescapably personal-that have been made and apologizes for the errors and lacunae which may persist.

Outline

I. Undecidability, Uncertainty, and Complexity

II. Macrostructures: Systems and the Human Scale

- A. Entopy
- B. Dynamical Systems
  1. Game theory
  2. Cellular automata
  3. Catastrophe theory
  4. Chaos
     - a. Historical accounts
     - b. Order-in-chaos, strange attractors, universality
     - c. Order-out-of-chaos
  5. Fractal geometry
  6. Anticipatory systems

7. Living systems
   a. Evolution
   b. Self-organization, morphogenesis, and pattern formation

C. Computation
   1. Information theory
   2. Cognitive science and artificial intelligence

III. The Very Big and the Very Small: Physics, Astrophysics, and Cosmology

IV. Time

V. Culture and Epistemology

I. UNDECIDABILITY, UNCERTAINTY AND COMPLEXITY

AIDA, S., P. M. ALLEN, H. ATLAN, K. E. BOULDING, G. P. CHAPMAN, O. COSTA DE BEAUREGARD, A. DANZINJ. -P. DUPUY, O. GIARINI, T. HAGERSTRAND, C. S. HOLLING, M. J. L. KIRBY, G.J. KLIR, H. LABORITJ. -L. LE MOIGNE, N. LUHMANN, P. MALASKA, R. MARGALEF, E. MORIN, E. W. PLOWMAN, K. H. PRIBRAM, I. PRIGOGINE, SOEDJATMOKO, J. VOGE & M. ZELENY. *The Science and Praxis of Complexity: Contributions to the Symposium Held at Montpellier, France, 9-11 May, 1984.* Tokyo: United Nations University, 1985.

ATLAN, HENRI, GIANLUCA BOCCHI, MAURO CERUTI, DONATA FABBRI MONTESANO, HEINZ VON FOERSTER, LUCIANO GALLINO, ERNST VON GLASERSFELD, BRIAN GOODWIN, STEPHEN J. GOULD, HERMANN HAKEN, DOUGLAS HOFSTADTER, ERVIN LASZLO, JEAN-LOUIS LE MOIGNE, JAMES LOVELOCK, EDGAR MORIN, ALBERTO MUNARI, GIANFRANCO PASQUINO, KARL PRIBRAM, ILYA PRIGOGINE, ISABELLE STENGERS, FRANCISCO VARELA, MILAN ZELENY. *La sfida délia complessità. A* cura di Gianluca Bocchi e Mauro Ceruti. Milano: Feltrinelli, 1985.

There is considerable overlap among the contributors to these two collections, and likewise for the material, which views complexity not just as crisis but from the standpoint of a »new science« confronting uncertainty and developing new concepts and new models to further science's dialogue with nature. Both volumes give ample coverage to social systems alongside natural and artificial systems. In Atlan, et al., however, Isabelle Stengers argues that in fact there can be no paradigm of the complex since this is a notion about science-a discovery of problems rather than solutions-and not a concept of science.

CASTI JOHN L. & ANDERS KARLQVIST, eds. *Complexity, Language, and Life: Mathematical Approaches.* Berlin: Springer, 1986.

This group of papers falls into three groups: »conceptual and formal structures for characterizing system complexity; evolutionary processes in biology and ecology; the emergence of complexity through evolution in natural languages« (v). Casti characterizes complexity as arising from the *interaction* between the system and its observer« (xi). Robert Rosen stresses *informational interaction»(xi)* based on the idea of an activation-inhibition pattern. Howard H. Patee argues that the »generalized functions of language and measurement form a semantically closed loop, which is a *necessary* condition for evolution« (xii).

EKELAND, IVAR. *Au hasard: La chance, la science et le monde.* Paris: Le Seuil, 1990.

Is chance a fundamental attribute of the physical world? Putting the flint of Norse sagas to the steel of contemporary science and mathematics, Ekeland strikes sparks illuminating the problem. His stylish presentation of complexity (excepting spotty citations and the lack of a bibliography) is down-to-earth in its readability and intellectually stimulating in its breadth. He bequeaths us a world where one determinism displaces another, the choice of »which mathematics?« is quite arbitrary, and qualitative depiction is to be privileged over quantitative description. The aspiration of the scientist becomes the reality of beauty and creativity.

GÖDEL, KURT. »Über formal unentscheidbare Sätze der Principia Mathematica und verwandter Systeme I.« *Monatshefte für Mathematik und Physik,* XXVIII, 1931, 173-98. [English: Gödel, Kurt. *On Formally Undecidable Propositions Of Principia Mathematica And Related Systems.* B. Meitzer, trans., with Introduction by R. B. Braithwaite. Edinburgh: Oliver & Boyd, 1962.]

NAGEL, ERNEST &JAMES R. NEWMAN. *GödeVs Proof.* New York: New York Univ. Press, 1958.

DAVIS, MARTIN, ed. *The Undecidable: Basic Papers On Undecidable Propositions, Unsolvable Problems And Computable Functions.* Hewlett: Raven Press, 1965.

CHAITIN, GREGORY J. »Göders Theorem and Information.« *International Journal of Theoretical Physics,* XXI, 12, December 1982, 941-54.

Godel's brilliant paper challenged fundamental assumptions of mathematics and logic, demonstrating that such systems can not be fully axiomatized and indicating the barriers to establishing internal logical consistency for a large class of deductive systems. Nagel and Newman's short introduction is an excellent guide to the complexities of Godel's reasoning and conclusions. Davis presents fundamental papers of Gödel, including the above, Alonzo Church, Alan M. Turing, J. B. Rosser, Stephen C. Kleene, and Emil Post treating recursive functions »computable by finite algorithms« (1), and problems of computing machines, mathematical logic and algebra »shown to be unsolvable in the sense that there is no finite algorithm for dealing with them« (1). Chaitin demonstrates Gôdel's theorem using arguments from thermodynamics, statistical mechanics and information theory and concludes that the phenomenon is »natural and widespread« (941) and asserts that »perhaps number theory should be pursued more openly in the spirit of experimental science« (942). He also offers some »pointers to the literature« (953).

GUILBAUD, G.-Th. *Leçons d'à-peu-près.* Paris: Christian Bourgois, 1985. CENTRE D'ANALYSE ET DE MATHÉMATIQUE SOCIALES, ed. *L'à-peu-près: Aspects anciens et modernes de l'approximation.* Paris: École des Hautes Études en Sciences Sociales, 1988.

Guilbaud contends that mathematics has never excluded approximation, despite its being opposed in the popular mind to exactitude. His Study served as a point of departure for the Urbino conference, the proceedings of which are collected in the CAMS volume. The common concerns are the history and development of the mathematics of approximation.

KLIR, GEORGE J. »Is There More to Uncertainty Than Some Probability Theorists Might Have Us believe?« *International Journal of General Systems,* XV, 4, Nov. 1989, 347-78.

This paper attacks the adequacy of probability as the only description of uncertainty. According to Klir, probability can only deal with that class of uncertainty conceptualized in terms of conflict and not as »imprecision in the form of nonspecificity or vagueness« (375). His argument hinges on the comparison of six different mathematical theories capable of conceptualizing situations under uncertainty, concluding that some may complement or reinforce one another.

MOLES, ABRAHAM A. en collaboration avec Elisabeth Rohmer. *Les sciences de l'imprécis.* Paris. Le Seuil, 1990.

Instead of trying to banish imprecision, Moles presents a veritable epistemology and methodology of the vague-a science of the imprecise. Drawing on examples from both the human and social sciences and the'exact', sciences, he suggests that the former may in fact be the more advanced.

NASH, SARA, ed. *Science and Uncertainty: Proceedings of a Conference held under the Auspices of IBM United Kingdom Ltd., London, March 1984.* Northwood: Science Reviews Ltd., 1985.

——. *Science and Complexity: Proceedings of an Interdisciplinary IBM Conference, London, February 1985.* Northwood: Science Reviews, Ltd., 1985.

In the lead article of the second volume Ilya Prigogine gives a capsule version of his ideas concerning time and the »creation of complexity through mechanisms of bifurcation (23). Others include accessible forays into quanturn physics and cosmology, 'paranormal' phenomena, parallel computer systems, orthography and speech synthesis. The first volume brings together, in a likewise readable vein, articles relating uncertainty to such topics as clay minerals and the origin of life, fractals, fuzzy reasoning, consciousness, and molecular fossils.

NICOLIS, GR£GOIRE & ILYA PRIGOGINE. *Exploring Complexity: An Introduction.* New York: W. H. Freeman and Company, 1989 [originally published in German as *Die Erforschung des Komplexen.* Munich: Piper, 1987].

Significant for its title and presentation, this work concentrates explicitly on a new vocabulary of complexity through investigations of single topics. These authors, who have been in the forefront of research into nonequilibrium states and nonlinear dynamical systems, synthesize the arguments of this rapidly developing field centering on natural complexity seen as part of everyday experience and conceptualized as complex behavior. Limitations in predictability and self-organization of real systems are presented as intimately related to the inseparable notions of time and irreversibility.

PACKEL, EDWARD W. & J. F. TkAUB. »Information-based Complexity.« *Nature,* CCCXXVIII, 6125, 2 July 1987, 29-33.

Packel and Traub discuss computational complexity arising from partial, contaminated and priced information as opposed to discrete combinatorial problems. Thermodynamics, parallel computation and information theory are addressed and some applications are suggested.

PELITI, L. & A. VULPIANI, eds. *Measures of Complexity: Proceedings of the Conference, Held in Rome September 30-October 2, 1987.* Berlin: Springer, 1988.

The editors cite the tendency to recognize the emergence of a »science of complexity« which should deal with the universal features of complex systems-abstracting from the peculiar aspects of the different systems under investigation^ If there is anything to this, they argue, there should be some way to measure this complexity. The papers collected here explore the possibility in Boolean networks, spin glass models, neural networks, randomwalks and surfaces, technological systems, biology, automata, ecology and more.

YAGER, R. R., S. OVCHINNIKOV, R. M. TONG & H. T. NGUYEN, eds. *Fuzzy Sets and Applications: Selected Papers by L. A. Zadeh.* New York: John Wiley & Sons, 1987.

HAACK, SUSAN. »DO We Need 'Fuzzy Logic'?« *International Journal of Man-Machine Studies,* XI, 4, July 1979, 437-45.

KLIR, GEORGE J. & TINA A. FOLGER. *Fuzzy Sets, Uncertainty, and Information.* Edgewood Cliffs: Prentice Hall, 1988.

In these fundamental papers Zadeh distinguishes between classical, two-valued logic which »encompasses a variety of logical systems, all of which share the basic assumption that truth is two-valued« (15) and many-valued or *»fiizzy logic...* that underlies inexact or approximate reasoning« (16) which allows all truth values between zero and one. He recognizes the incompatibility between precision and complexity« (23) and defines some of the elementary concepts of probability theory in the more general setting of fuzzy events, considers the possibility of a general theory of decision-making in such an environment, explores the interplay between possibility and probability in human decision-making and develops a theory of possibility based on fuzzy sets-a fuzzy variable is associated with a possibility distribution in much the same way as a random variable is associated with a probability distribution. Susan Haack critically assesses fuzzy logic as simply multi-valued, which in fact introduces complexity and artificial precision. She also argues that the »linguistic arguments for fuzzy logic are confused« (445). Klir and Folger offer an overall introduction to the field.

WEAVER, WARREN. »Science and Complexity.« *American Scientist,* XXXVI, 4 (Autumn), October 1948, 536-44.

In this classic, and prescient, paper Weaver distinguishes among the simple problems of classical physics with few variables, *disorganized complexity* with many variables amenable to description by statistical methods, and a middle region of *organized complexity* in which problem solving depends on »analyzing systems as organic wholes« (539). This latter comprises the third great advance to be made by science »over the next 50 years« for which he predicts the importance of computers and »'mixed team'« (541), interdisciplinary, research.

II. MACROSTRUCTURES: SYSTEMS AND THE HUMAN SCALE

BERTALANFFY, LUDWIG VON. *General Systems Theory: Foundations, Development, Applications.* Revised Edition. New York: George Braziller, 1968.

This collection of von Bertalanffy's articles, beginning chronologically with his 1940 introduction of the »theory of the organism as an open system« (vii), offers a panorama of the development of the field as it evolved from the realm of mathematics and computer science to »herald a new world view of considerable impact... in the gamut of disciplines from physics and biology to the behavioral and social sciences and to philosophy« (vii). General systems theory has generated a voluminous literature; anti-reductionist in thrust, the emphasis is placed on systems as a unit rather than the units of the system and the search for common characteristics of all systems.

MORRISON, PHILIP, PHYLIS MORRISON & THE OFFICE OF CHARLES AND RAY EAMES. *Powers of Ten: A Book About the Relative Size of Things in the Universe and the Effect of Adding Another Zero.* New York: Scientific American Library, 1982.

This is an imaginative pictorial representation-the authors zoom in and out, by factors of ten, through a series of photographs from the microscopic to the cosmic-of how scale influences our perception of reality.

PINES, DAVID, ed. *Emerging Syntheses in Science: Proceedings of the Founding Workshops of the Santa Fe Institute, Santa Fe, New Mexico.* Redwood City: Addison-Wesley, 1988.

The papers and remarks bound together in the Pines volume describe and give examples of the »widespread rearrangement of subjects« (9) and the collapsing disciplinary boundaries in contemporary scientific research. In view of these developments structures of knowledge formation like the Santa Fe Institute are proposed as alternatives to research universities.

WIENER, NORBERT. *Cybernetics: Or Control and Communication in the Animal and the Machine,* Second Edition. Cambridge: MIT Press, 1961 [first edition published 1948].

This is the enormously influential progenitor of a general theory of control, communication and information processing, taking into account feedback and nonlinearity in living and nonliving-self-regulating-systems. In this second edition Wiener adds chapters on learning and self-reproducing machines and brain waves and self-organizing systems.

A. Entropy

ATKINS, P. W. *The Second Law.* New York: Scientific American Books, 1984.

This is a straightforward, popular, nontechnical introduction to the concept of entropy as the key to natural change. The history and fundamentals of the idea are explained in relation to immediately accessible models such as engines and refrigerators and such contemporary work as population dynamics and dissipative structures. The volume is profusely illustrated and includes some simple computer programs in BASIC implementing questions discussed in the text.

DENBIGH, K. G. & J. S. DENBIGH. *Entropy in Relation to Incomplete Knowledge.* Cambridge: Cambridge Univ. Press, 1985.

This is a careful discussion of entropy in relation to thermodynamics, statistical mechanics and information theory with the general aim of clarifying the role of the observer. The authors argue that thermodynamic entropy as originally defined was thoroughly objective and the advent of statistical mechanics did nothing to change that. As regards information theory, the language in which it is couched takes on a subjective character due to the subjective interpretation of probability on which it is based. Finally, they conclude that *irreversibility* is more fundamental than is the concept of entropy, and also more widely applicable... [and] fully objective« (118).

GEORGESCU-ROEGEN, NICHOLAS. *The Entropy Law and the Economic Process.* Cambridge: Harvard Univ. Press, 1971.

Georgescu-Roegen's book explores the relationship between economics and ecology. The discussions, from the diverse perspectives of mathematics and the sciences, philosophy, and the social sciences, are linked by the concept of entropy and focused through reflections on change, chance, order, cause, time, size, evolution and more.

RIFKIN, JEREMY WITH TED HOWARD. *Entropy: A New World View.* Afterword by Nicholas Georgescu-Roegen. New York: Viking, 1980.

Rifkin gives a popular account of the Second Law of Thermodynamics and a rather pessimistic assessment of its significance for the contemporary world. This discussion of the ultimate physical bounds within which society evolves becomes an attack on progress through economic growth and the »Newtonian world machine paradigm« (6), the consequence of which must be a transition to a »Solar new Age« (196).

WICKEN, JEFFREY S. »Entropy and Information: Suggestions for Common Language.« *Philosophy of Science,* LIV, 2, June 1987, 176-93.

This is a salutary discussion of the confusion arising from the cross-disciplinary use of the term »entropy«. Wicken argues that the concept has not been generalized, offers some examples and makes »some suggestions for restricting both entropy and information to specific arenas of discourse« (176).

B. Dynamical Systems

BARNSLEY, MICHAEL F. & STEPHEN G. DEMKO, eds. *Chaotic Dynamics and Fractals.* Orlando: Academic Press, 1986.

Many of the articles published in this collection are quite technical. Among the more accessible are Stephen J. Wilson's paper on cellular automata and particularly Joseph Ford's fine review article which discusses determinism and Gödel's theorem, algorithmic complexity theory and quantum chaos.

CASTI, JOHN L. *Alternate Realities: Mathematical Models of Nature and Man.* New York: John Wiley and Sons, 1989.

——. *Searching for Certainty: What Scientists Can Know About the Future.* New York: William Morrow and Company, 1990.

Within the format of a text on mathematical modeling, Casti's 1989 book explores the relationships among such topics as chaos, game theory, cellular automata and catastrophe theory as applied to the real-world of fluids, artistic forms, evolution and more. Each chapter is completed with questions, problems, exercises and comments on references. *Searching for Certainty* explores predictability and computability and renders intelligible fundamental questions centering on complexity which are at the frontier of contemporary mathematical thought. Again, Casti includes an excellent annotated bibliography of the areas covered.

EKELAND, IVAR. *Mathematics and the Unexpected.* Foreword by Felix E. Browder. Chicago: Univ. of Chicago Press, 1988. [Translation from the French by the author of his *Le calcul, l'imprévu. Les figures du temps de Kepler à Thom,* 1984].

This slim volume makes an excellent popular introduction to nonlinear science, order, and chaos-»the spectacular progress that mathematics ha[d] made in understanding time and change« (xi). Ekeland proceeds from celestial mechanics and classical determinism to the insights of Poincaré and contemporary developments in complexity, time, dissipative systems and catastrophe theory.

FARMER, DOYNE, ALAN LAPEDES, NORMAN PACKARD, BURTON WÈNDROFF, eds. *Evolution, Games and Learning: Models for Adaptation in Machines and Nature, Proceedings of the Fifth Annual International Conference of the Center for Nonlinear Studies, Los Alamos, NM 8 7545, USA, May 20-24, 1985. Physica D: Nonlinear Phenomena,* 22D, 1986.

These papers, which examine systems as disparate as neural processes and cellular automata to ant colonies and artificial life, focus on adaptive behavior, the common nonlinear thread manifested in evolution, games and learning. The short but incisive introduction by Farmer and Packard draw out the questions which »cry out for *synthesis* rather than reduction« in this »new wave science« where research on systems involving at least two time scales is based on simulation and cuts across disciplinary lines.

NICOLIS, J. S. *Dynamics of Hierarchical Systems: An Evolutionary Approach.* Berlin: Springer, 1986.

This book is concerned with the »new and exciting multidisciplinary area of the evolution of 'large-scale' dynamical systems« (vii). This not overly technical treatment looks at spherical waves as information carriers, information theory, game theory, chaos and strange attractors with the aim of explaining »on the basis of known dynamical laws of physics, the *communication* that takes place between... two systems« (4).

RUELLE, DAVID. *Elements of Differentiable Dynamics and Bifurcation Theory.* Boston: Academic Press, 1989.

This very fine book is »intended only as an *introduction* to differentiable dynamics, with emphasis on bifurcation theory and hyperbolicity, as needed for the understanding of complicated time evolutions occurring in nature (turbulence and chaos)« (vii). Ruelle includes problems and a good bibliography.

SMALE, S. »Differentiable Dynamical Systems.« *American Mathematical Society Bulletin,* LXIII, 6, Nov. 1967, 747-817.

SMALE, STEVE. *The Mathematics of Time: Essays on Dynamical Systems, Economic Processes, and Related Topics.* New York: Springer, 1980.

Smale reviews work done on differentiable dynamical systems up to the appearance of this influential article and sets out, rather technically, many new ideas and directions, including the famous »horseshoe« and torus attractor. The 1980 publication reproduces the above article along with others treating global analysis, mathematical economics, reviews of catastrophe theory-of which he admits to a personal negative bias-and personal recollections, numbering among them the origin of the horseshoe.

STEIN, DANIEL L., ed. *Lectures in the Sciences of Complexity: The Proceedings of the 1988 Complex Systems Summer School Held June-July, 1988 in Santa Fe, New Mexico.* Redwood City: Addison-Wesley, 1989.

This substantial collection would be worthwhile if only for David Campbell's »An Introduction to Nonlinear Dynamics.« Other lectures and seminars cover »active research in a wide spectrum of different areas broadly related to what has come to be called complexity research« (xvii).

1. GAME THEORY

BOMZE, IMMANUEL M. & BENEDIKT M. POTSCHER. *Game Theoretical Foundations of Evolutionary Stability.* Berlin: Springer, 1989.

Bomze and Pötscher concentrate on the mathematical aspects of the game theory approach to evolutionary stability, with considerable reference to the relevant literature, as applied to inherited behavioral patterns. They propose a unifying framework to subsume most other models.

COLMAN ANDREW M. *Game Theory and Experimental Games: The Study of Strategic Interaction.* Oxford: Pergamon, 1982.

Colman focuses on applications taken from political science, philosophy, biology and economics in this exploration of gametheoretical strategies.

MAYNARD SMITH, J. »Game Theory and the Evolution of Behavior.« *Behavioral and Brain Sciences,* VII, 1, Mar 1984, 95-125.

Maynard Smith's article outlines evolutionary game theory which analyzes »the evolution of behavior, or... other aspects of the phenotype, when fitnesses are frequency dependent« (95). The more than twenty pages of open peer commentary are most engaging.

VON NEUMANNJOHN & OSKAR MORGENSTERN. *Theory of Games and Economic Behavior.* Third Edition. Princeton: Princeton Univ. Press, 1953 [first edition published 1944].

JONES, A.J. *Game Theory: Mathematical Models of Conflict.* Chichester: Ellis Horwood, 1980.

The development of game theory may be traced directly to von Neumann and MorgenstenTs technical and encyclopedic exposition. In it they explore the two-player zero-sum games and extend the theory through n-person and non-zero-sum games. Their concept of equilibrium is based on each player choosing a strategy to maximize the minimum gain (maximin) or to minimize the maximum loss (minimax) that can be imposed on him. They also examine mixed strategies in which probabilities are used to determine choices in the light of the utility of different outcomes. Jones offers a good introduction.

2. CELLULAR AUTOMATA

VON NEUMANN, JOHN. *Theory of Self-Reproducing Automata.* Edited and completed by Arthur W. Burks. Urbana: Univ. of Illinois Press, 1966.

BURKS, ARTHUR W., ed. *Essays on Cellular Automata.* Urbana: Univ. of Illinois, 1970.

The study of cellular automata in mathematics involves techniques for the construction or modeling of complex systems from large numbers of simple elements, acting together according to simple rules, whose evolution is determined by the development of elements nearby. As cellular automata may be viewed as computational systems, their analysis, particularly through direct simulation, is particularly adapted to computers and graphical simulation. Burks offers a series of essays which elucidate John von Neumann's pioneering work in the field.

WOLFRAM, STEPHEN, ed. *Theory and Applications of Cellular Automata (including selected papers 1983- 1986).* Singapore: World Scientific, 1986.

Current interest in cellular automata is due in large part to the work of Stephen Wolfram and his »Statistical Mechanics of Cellular Automata,« reprinted in this collection, is a good introduction. Besides theory and computational approaches, he includes applications to turbulence and order in chemistry, biology, thermodynamics and hydrodynamics and an excellent annotated bibliography.

3. CATASTROPHE THEORY

ARNOLD, V. I. *Catastrophe Theory.* Second, Revised and Expanded Edition. Translated from the Russian by G. S. Wasermann Based on a Translation by R. K. Thomas. Berlin: Springer, 1986 [first edition published 1983].

This is a short, concise, but scathingly critical introduction. Despite its non-mathematical cast it illustrates the development of the mathematics of singularity and bifurcation theory. The »Bibliographical Comments« (95-108) include literature in Russian and translated from Russian.

MEES, ALISTAIR I. »The Revival of Cities in Medieval Europe: An Application of Catastrophe Theory.« *Regional Science and Urban Economics,* V, 4, Dec. 1975, 403-25.

Mees examines a simplified model which assumes a free market and utility maximization. He applies catastrophe theory to the expansion of trade to interpret the growth of cities.

PETITOT, JEAN, dir. *Logos el théorie des catastrophes: A partir de l'œuvre de René Thorn.* Genève: Patiño, 1988.

This set of colloquium papers presents an especially wide spectrum of ideas with roots in catastrophe theory. Mathematics and physics are covered, as well as morphogenesis, linguistic structures, and epistemological and philosophical questions.

POSTON, TIM & IAN STEWART. *Catastrophe Theory and its Applications.* London: Pitman, 1978.

Poston and Stewart present a mathematical exposition of catastrophe theory as »an expansion of, or a development within the calculus« (vii-viii). In order to overcome the misconception that catastrophe theory is purely qualitative, they survey a number of quantitative studies of physical, biological and ecological systems and include a section treating the social sciences and an extensive bibliography.

THOM, RENE. *Structural Stability and Morphogenesis: An Outline of a General Theory of Models,* Translated from the French edition, as updated by the author, by D. H. Fowler. With a Foreword by C. H. Waddington. Reading: W. A. Benjamin, 1975 [originally published as *Stabilité structurelle et morphogénèse: Essai d'une théorie générale des modèles.* Reading: W. A. Benjamin, 1972].

——. *Mathematical Models of Morphogenesis.* Translated by W. M. Brookes & D. Rand. Chichester: Ellis Horwood, 1983 [updated and augmented by the author from the second edition of the original French *Modèles mathématiques de la morphogénèse.* Paris: Christian Bourgois, 1980].

This initial, essential, exposition of catastrophe theory is concerned with form and the structural stability allowing the observance of similarities. Thom proposes models based on qualitative mathematics, a geometry of processes which he asserts reflect the way in which we perceive the world. His analysis eschews the style of formal mathematics and explores examples from disciplines as diverse as biology, linguistics, and optics. In his second volume Thom offers a concise exposition of catastrophe theory and applications from biology, social science and linguistics.

VARIAN, HAL R. »Catastrophe Theory and the Business Cycle.« *Economic Inquiry,* XVII, 1, Jan. 1979, 14-28.

FISCHER, EDWIN 0. & WERNER JAMMERNEGG. »Empirical Investigation of a Catastrophe Theory Extension of the Phillips Curve.« *The Review of Economics and Statistics,* LXVIII, 1, Feb. 1986, 9-17.

In Varian's application, catastrophe theory is applied to a simple macroeconomic model. Kaldor's business cycles and the possibilities of rapid recoveries and deep depressions depending on the nonlinear characteristics of investment and savings behavior are examined. Fischer and Jammernegg propose catastrophe theory as a useful tool in the analysis of such real-world phenomena as abrupt changes, multimodality, and hysteresis, which the assumptions of economic theory often rule out.

WILSON, A. G. *Catastrophe Theory and Bifurcation: Applications to Urban and Regional Systems.* London: Croom Helm, 1981.

Although primarily an introduction to catastrophe theory for those interested in cities and urban planning, this treatment includes applications from physical chemistry, biology, ecology, and economics and integrates discussions of other approaches such as the Brussels school's and central place theory.

ZEEMAN, E. C. *Catastrophe Theory: Selected Papers, 1972- 1977.* Reading: Addison-Wesley, 1977.

SUSSMANN, HECTOR J. & RAPHAEL S. ZAHLER. »Catastrophe Theory as Applied to the Social and Biological Sciences: A Critique.« *Synthase,* XXXVII, 2, February 1978, 1 17-216.

The first is a collection of studies, many now classic, applying catastrophe theory in the biological, social, and physical sciences by one of the first to recognize and develop the possibilities inherent in René Thorn's ideas. The critique of Thorn and Thorn's reply at the end are not to be missed. Sussman's highly critical paper evaluates »the usefulness of CT as a tool for extra-mathematical applications« (1 18). After some introduction to the fundamentals (not including the butterfly catastrophe or the idea of structural stability and Thorn's theory of morphogenesis), the major portion of the article examines the work of E. C. Zeeman and his coworkers.

4. CHAOS

ABRAHAM, NEAL B., ALFONSO M. ALBANO, ANTHONY PASSAMANTE & PAUL E. RAPP, eds. *Measures of Complexity and Chaos.* New York: Plenum Press, 1989.

»This volume serves as a general introduction to the state of the art of quantitatively characterizing chaotic and turbulent behavior« (v). The authors explore new applications casting complexity as an even richer subject than chaos. A bibliography of recent literature, arranged both by methodology and subject, is appended to the introduction.

BRIGGS, JOHN & F. DAVID PEAT. *Turbulent Mirror: An Illustrated Guide to Chaos Theory and the Science of Wholeness.* Illustrations by Cindy Tavernise. New York: Harper and Row, 1989.

This is an attractive, well-written, nontechnical popularization, entertaining and accessible even to the younger reader, of the major concepts involved in chaos theory. (The importance of this class of books in legitimating these ideas to the public at large is analogous to the outpouring in the 1950's of popularizations of relativity theory and atomic physics.)

FORD, JOSEPH. »HOW Random is a Coin Toss?« *Physics Today,* XXXVI, 4, Apr. 1983, 40-47.

Determinism provides the backdrop for Ford's fine introduction to the differences between orderly and chaotic behavior. »Algorithmic complexity theory, the computability of numbers and the measurability of the continuum« (40) are called into play.

LUNDQVIST, STIG, NORMAN H. MARCH & MARIO P. Tosi, eds. *Order and Chaos in Nonlinear Physical Systems.* New York: Plenum Press, 1988.

Lundqvist, March and Tosi present material from mathematical and solid-state physics, chemistry, hydrodynamics, and optics. Besides Lundqvist's introduction to the field and its fundamental concepts, particularly useful are Calogero and Degasperis, reprinted article on solitons and both the Percival and Hao discussions of symbolic dynamics.

a. Historical accounts

HAO, BAI-LIN, ed. *Chaos.* Singapore: World Scientific, 1984.

This fine, historically oriented collection of classic papers, dealing in the main with dissipative systems, has a good introduction and a comprehensive bibliography up to 1983.

GLEICK, JAMES. *Chaos: Making a New Science.* New York: Viking Penguin, 1987.

A popular, nontechnical introduction to the ideas and protagonists of chaos theory in the form of a narrative history. Gleick attributes the emergence of chaos theory to a few individuals-a »great man« view of history-and focuses primarily on the research dealing with the structures of order embedded in chaotic systems: universality and strange attractors. The order-out-of-chaos perspective receives short shrift.

STEWART, IAN. *Does God Play Dice? The Mathematics of Chaos.* Cambridge: Basil Blackwell, 1989.

Notwithstanding the title, this book is suitable for the general reader. The historical perspective presented-the text moves from Galileo and the Enlightenment through probability and statistics to Poincaré and a comprehensive overview of recent work on dynamical systems-is premised on a view of the world which evolved from the unpredictable, then to its opposite, and finally to the contemporary realization that simple fully deterministic rules in nature can give rise to unpredictable or chaotic dynamical behavior. Although the order-out-of-chaos perspective is given scant attention Stewart gives a good account of the relationship between chaos and fractals.

b. Order-in-chaos, strange attractors, universality

BABLOYANTZ, A.,J. M. SALAZAR & C. NICOLIS. »Evidence of Chaotic Dynamics of Brain Activity During the Sleep Cycle.« *Physics Letters,* 111A, 3, 2 Sept. 1985, 152-56.

This paper reports the existence of chaotic attractors during sleep stages two and four and the decrease in dimensionality of the underlying fractal attractor as deep sleep sets in, implying that »the dynamics becomes more coherent during deep sleep« (155).

BLEHER, S., E. OTT & C. GREBOGI. »Routes to Chaotic Scattering.« *Physical Review Utters,* LXIII, 9, 28 Aug. 1989, 919-22.

The authors, using mostly analytic rather than mathematical arguments, show that the route to chaos in a class of classical scattering problems such as those found in chemical reactions, fluid dynamics, and the three-body gravitational problem may be of two different types: either abrupt or through period-doubling bifurcations.

CAMPBELL, DAVID & HARVEY ROSE, eds. *Order in Chaos: Proceedings of the International Conference on Order in Chaos held at the Center for Nonlinear Studies, Los Alamos, New Mexico 87545, USA, 24-28 May 1982. Physica D: Nonlinear Phenomena,* 7D, 1983.

These papers make up this entire volume of *Physica D.* Besides overviews, topics include experimental observations; mathematical properties and model systems; dimension, fractal structures, and coherence versus chaos; transition to chaos in maps of the circle; fluids and vortices; and quantum chaos.

CVITANOVIC, PREDRAG, ed. *Universality in Chaos,* Second Edition. Bristol: Adam Hilger Ltd., 1989 [first published 1984].

This fine compendium of reprints of seminal papers-essential to the specialist-incorporates recent work including the »reinjection of techniques of statistical mechanics into the description of dynamically generated strange sets« [xi].

ECKMANN, J.-P. & D. RUELLE. »Ergodic Theory of Chaos and Strange Attractors^ *Reviews of Modern Physics,* LVII, 3, Part 1, July 1985, 617-56.

In this review article Eckmann and Ruelle proceed »from the definitions of dynamical systems theory to a discussion of those quantities accessible today through the *statistical* analysis of time series for deterministic nonlinear systems« (653). Covered are such topics as characteristic exponents, entropy, and information dimension. They include a discussion of experimental aspects and a fine reading list.

ECKMANN, J.-P. »Roads to Turbulence in Dissipative Dynamical Systems.« *Reviews of Modern Physics,* LIII, 4, Part I, Oct. 1981, 643-54.

D'HUMIERES, D., M. R. BEASLEY, B. A. HUBERMAN & A. LIBCHABER. »ChaOtic States and Routes to Chaos in the Forced Pendulum.« *Physical Review A,* XXVI, 6, Dec. 1982, 3483-96.

KADANOFF, LEO P. »Roads to Chaos.« *Physics Today,* XXVI, 12, Dec. 1983, 46-53.

PROCACCIA, ITAMAR. »Universal Properties of Dynamically Complex Systems: The Organization of Chaos.« *Nature,* CCCXXXIII, 6174,16 June 1988, 618-23.

Eckmann's review article examines three routes to chaos in theory and experiment-the Ruelle-Takens-Newhouse scenario, the Feigenbaum scenario, and the Pomeau-Manneville scenario and explains and compares their mathematics. The phase-locked-loop electronic circuit of D'Humieres et al. exhibits symmetry breaking before period doubling which does not always result in complete bifurcation cascades; two intermittent, unstable states are often observed. Kadanoff examines a simple model of transition to chaos and discusses »how the features of this model can be, and have been observed in hydrodynamic systems« (47). Procaccia presents more recent work on the »borderline of chaos« and asserts that »a grammar of chaos, which sheds light on universal properties of complex systems, is emerging« (618).

FEIGENBAUM, MITCHELL J. »Universality in Complex Discrete Dynamics.« *Los Alamos Theoretical Division Annual Report: July 1975-September 1976,* LA-6816-PR, July 1977, 98-102.

——. »Quantitative Universality for a Class of Nonlinear Transformations.« *Journal of Statistical Physics,* XIX, 1, July 1978, 25-52.

——. »The Universal Metric Properties of Nonlinear Transformations.« *Journal of Statistical Physics,* XXI, 6, Dec. 1979, 669-706.

——. »Universal Behavior in Nonlinear Systems.« *Physica D: Nonlinear Phenomena,* 7D, 1983, 16-39.

Feigenbaum discovered a universal order in the descent to chaos and added a new constant, 8, the rate of onset of turbulence, to the scientific literature. As an external parameter is varied, certain simple systems whose evolution is periodic-such as oscillators, populations, and fluids-begin to show complex aperiodic behavior. A characteristic route for such a system to follow is period doubling. Feigenbaum shows that for a system with such qualitative properties its quantitative properties are determined. The final piece is a review article.

FROEHLING, HAROLD, J. P. CRUTCHFIELD, DOYNE FARMER, N. H. PACKARD & ROB SHAW. »On Determining the Dimension of Chaotic Flows.« *Physica D: Nonlinear Phenomena,* III D, 3, Aug. 1981, 605-17.

Using standard multilinear regression techniques the authors outline a method for determining the approximate fractal dimension of an attractor which they further show to be measurable »even when only a single time-varying quantity is available for analysis« (605).

GLASS, LEON & MICHAEL C. MACKEY. *From Clocks to Chaos: The Rhythms of Life.* Princeton: Princeton Univ. Press, 1988.

Glass and Mackey offer an excellent introduction to complex dynamics of biological systems. Of particular interest is the discussion of »dynamical diseases« that result from perturbations in physiological rhythms. Includes a fine bibliography.

GRANDMONT, JEAN-MICHEL & PIERRE MALGRANGE. »Nonlinear Economic Dynamics: Introduction.« *Journal of Economic Theory,* XL, 1, Oct. 1986, 3-12.

DAY, RICHARD H. »Emergence of Chaos from Neoclassical Growth.« *Geograhical Analysis,* XIH, 4, Oct. 1981, 315-27.

——. »The Emergence of Chaos from Classical Economic Growth.« *Quarterly Journal of Economics,* XCVIII, 2, May 1983, 201-13.

ROSSER, JR., J. BARKLEY. »Chaos Theory and the New Keynesian Economics.« *The Manchester School of Economic and Social Studies,* LVIII, 3, Sept. 1990, 265-91.

Grandmont and Malgrange review a wide spectrum of work applying nonlinear dynamics in the economic arena noting that the most important limitation is that the research is confined to perfectly competitive models. This article is one in a series of conference papers on »Nonlinear Economic Dynamics« presented in this issue *of Journal of Economic Theory.* Richard Day outlines how non-linearities in both classical and neoclassical models of economic growth can lead to irregular, chaotic, fluctuations and concludes that observed unpredictability and structural change are endogenous to the models. Rosser distinguishes between economic schools of thought and then delves into chaos theory as applied to a wide range of different economic models.

GRASSBERGER, PETER & ITAMAR PROCACCIA. »Characterization of Strange Attractors.« *Physical Review Letters,* L, 5, 31 Jan. 1983, 346-49.

Grassberger and Procaccia introduce a rapidly converging measure of »strangeness« and its relation to the fractal dimension and information entropy of an attractor.

GUCKENHEIMER, JOHN. »Bifurcations of Dynamical Systems.« in Guckenheimer, John, Jürgen Moser & Sheldon E. Newhouse. *Dynamical Systems: C.I.M.E. Lectures, Bressanone, Italy, June 1978.* Boston: Birkhäuser, 1980.

Guckenheimer examines systems whose topological character changes as one or more parameters are varied. He discusses the Lorenz attractor, bifurcations in the forced van der Pol equation, kneading sequences in dynamical processes, and some applications.

HFINON, M. & Y. POMEAU. »Two Strange Attractors with a Simple Structures in Roger Temam, ed. *Turbulence and Navier Stokes Equations: Proceedings of the Conference Held at the University of Paris-Sud, Orsay, June 12- 13, 1975.* Berlin: Springer, 1976.

H£NON, M. »A Two-Dimensional Mapping with a Strange Attractor.« *Communications in Mathematical Physics,* 1, 1976, 69-77.

FRANCESCHINI, VALTER & CLAUDIO TEBALDI. »Sequences oflnfinite Bifurcations and Turbulence in a Five-Mode Truncation of the Navier-Stokes Equations.« *Journal ofStatistical Physics,* XXI, 6, Dec. 1979, 707-26.

COLLET, P., J.-P. ECKMANN & H. KOCH. »Period Doubling Bifurcations for Families of Maps on R^N.« *Journal ofStatistical Physics,* XXV, 1, May 1981, 1-14.

H6non and Pomeau outline the Lorenz attractor and a simple mapping designed to exhibit the properties of the Lorenz system but easier to explore over a longer time period. The work on what has become known as the »H6non attractor« is repeated practically verbatim in the second paper. In other work on higher dimensional strange attractors Franceschini and Tebaldi show experimental compatibility with Feigenbaum's theory of universality and »close analogy with the Lorenz model« (707). Collet, Eckmann and Koch demonstrate why this »is true in the discrete time case« (2).

HOLDEN, ARUN V., ed. *Chaos.* Princeton: Princeton Univ. Press, 1986.

Chaotic activity in such different types of systems as physiological models, electronic oscillators, lasers, iterative maps, and the Lorenz equations is discussed-in addition to introductory material on chaos and attractors-showing how complicated solutions may arise in a universal way.

Li, TIEN-YIEN & JAMES A. YORKE. »Period Three Implies Chaos.« *The American Mathematical Monthly, LXXXII, 10,* Dec. 1975, 985-92.

Li and Yorke propose the period three theorem, and its proof, concerning chaotic behavior. They formally define »chaotic« for the first time as describing a non-periodic {P(x)} sequence.

LIBCHABER, A. & J. MAURER. »A Rayleigh-B6nard Experiment: Helium in a Small Box.« in T. Riste, ed. *Nonlinear Phenomena at Phase Transitions and Instabilities.* New York: Plenum Press, 1982.

Building on earlier work, Libchaber and Maurer open a portal on experimental observation of hydrodynamic instabilities in a restricted case with few degrees of freedom, which allows for the definition of »some simple bifurcations to turbulence« (259). They conclude that qualitatively the Feigenbaum model seems correct but quantitatively there are discrepancies which may be due to the observance of only the first bifurcations.

LORENZ, EDWARD N. »Deterministic Nonperiodic Flow.« *Journal of the Atmospheric Sciences,* XX, 2, Mar. 1963, 130-41.

—.»The Mechanics of Vacillations *Journal of the Atmospheric Sciences,* XX, 5, Sept. 1963, 448-64.

—.»The Problem of Deducing the Climate from the Governing Equations.« *Tellus,* XVI, 1, Feb. 1964, 1-11.

SPARROW, COLIN. *The Lorenz Equations: Bifurcations, Chaos, and Strange Attractors.* New York: Springer, 1982.

Lorenz's papers present the results of his experiments with simple mathematical weather-atmospheric flow-models. His discovery of the sensitivity of these systems to small perturbations or slightly differing initial conditions leading to instabilities was seminal to subsequent work on chaos and strange attractors in dynamical systems. The Lorenz equations and their almost endless extensions and generalizations are treated by Sparrow.

MAY, ROBERT M. »Biological Populations with Nonoverlapping Generations: Stable Points, Stable Cycles, and Chaos.« *Science,* CLXXXVI, 4164,15 Nov. 1974, 645^7.

MAY, ROBERT M. & GEORGE F. OSTER. »Bifurcations and Dynamic Complexity in Simple Ecological Models.« *The American Naturalist,* CX, 974 (July-Aug.), Aug. 31, 1976, 573-99.

GUCKENHEIMER, J., G. OSTER & A. IPAKTCHI. »The Dynamics of Density Dependent Population Models.« *Journal of Mathematical Biology,* IV, 2, 1977, 101-^7.

SCHAFFER, W. M. »Stretching and Folding in Lynx Returns: Evidence for a Strange Attractor in Nature?« *The American Naturalist,* CXXIV, 6, Dec. 1984, 798-820.

MAY, R. M. »Chaos and the Dynamics of Biological Populations.« *Proceedings of the Royal Society of London,* Series A, CDXI11, 1844, 8 Sept. 1987, 27^44.

May's 1974 paper examines chaotic behavior in nonlinear, density-dependent, difference equations. May and Oster's discussion of the bifurcation process and chaos as the foundation for an analysis of insect population fluctuations serves as a good introduction to the period doubling phenomenon for quadratic maps. Guckenheimer et al. present a theoretical analysis of the mathematics of density-dependent population models. They demonstrate the existence of a strange attractor on a Leslie model with two age classes and generalize their conclusions to higher dimensions and continuous models. Schaffer looks at data on the Canadian lynx cycle and argues that the sheetlike orbits in phase space are due to a low-dimensional strange attractor. May's 1987 review, presented in the context of a fine series of discussion papers on »Dynamical Chaos«, concludes that Simple models can give »qualitative insights into many population phenomena in the natural world« (40) and that the »existence of chaotic regimes of dynamical behavior... invalidate standard techniques for analyzing population data to reveal density-dependent mechanisms« (27).

MAY, ROBERT M. »Simple Mathematical Models with very Complicated Dynamics.« ***Nature,*** CCLXI, 5560,June 10, 1976, 459-67.

May's review article discusses maps of the unit interval onto itself, difference equations and period doubling in population dynamics and mentions such applications as Lorenz's »butterfly effect« and phase transitions in fluids. It makes an excellent short initiation to scientific studies of chaos.

METROPOLIS, N., M. L. STEIN & P. R. STEIN. »On Finite Limit Sets for Transformations on the Unit Intervals *Journal of Combinatorial Theory,* Series A, XV, 1, July 1973, 25-44.

This paper marks an important step towards Feigenbaum's specification of universality in the transition to chaos. In describing the iterative properties of a class of many-to-one transformations of the unit interval into itself the authors find an infinite sequence of finite or denumerable limit sets. They observe repeatingly ordered feedback patterns (in the same sort of equation studied by Lorenz), independent of numerical values.

NICOLIS, JOHN S. *Chaotic Dynamics Applied to Biological Information Processing.* Berlin: Akademie Verlag, 1987.

In this short book Nicolis explores information transactions among biological organisms. He attributes the clear distinction between laws (non-linear dynamics) which processes follow at the hardware or physical level and the rules (markov chains) followed at the software or symbolic level, to different time scales. It is claimed that »symbolic processes *are* chaotic manifestations of collective properties of physical systems-at a higher hierarchical level; 'Decision making', and 'free will', are *deterministic* since they are harnessed by natural laws, but *unpredictable* since they are chaotic; the same thing could be claimed for music and language« (11). The purpose, then, is the »problem of generation, storage and dissipation of information in physical and biological systems via dynamical processes« (12). The selfreferential nature of the systems studied lead to the association of truth with self-consistency and rationality with evolutionary stability.

PACKARD, N. H., J. P. CRUTCHFIELD, J. D. FARMER & R. S. SHAW. »Geometry From a Time Series.« *Physical Review Letters,* XLV, 9, 1 Sept. 1980, 712-16.

The authors develop a key technique for the construction of a finite-dimensional phase-space picture from time series data from which they determine the dimensionality of the system's attractor.

PICKOVER, CLIFFORD A. »Visualizing Chaos: Lyapunov Surfaces and Volumes^ *IEEE Computer Graphics and Applications,* X, 2, Mar. 1990, 15-19.

Pickover discusses graphics techniques for »visualizing a large class of graphically interesting manifestations of chaotic behavior arising from dynamic Systems« (15).

RUELLE, DAVID. »Strange Attractors.« *Mathematical Intelligencer,* II, 3, 1980, 126-37.

This review article gives a popular presentation of the concept and some history of its origin.

RUELLE, DAVID. *Chaotic Evolution and Strange Attractors: The Statistical Analysis of Time Series for Deterministic Nonlinear Systems.* Cambridge: Cambridge Univ. Press, 1989.

This brief and succinct introduction is divided into two sections, the first dealing with the concept of chaos for deterministic systems and the second with the ergodic theory of chaos including such topics as the invariant probability measure, characteristic exponents, entropy, information dimension, and resonances.

RUELLE, DAVID & F. TAKENS. »On the Nature of Turbulence.« *Communications in Mathematical Physics,* XX, 1971, 167-92.

In this key paper on turbulent systems, Ruelle and Takens advance a new hypothesis to explain the onset of turbulence and turbulent regimes. They invent the term«'Strange* attractor« to portray the finite dimensionality which they argue characterizes the evolution of such systems.

SAPERSTEIN, ALVIN M. »Chaos-A Model for the Outbreak of War.« *Nature,* CCCIX, 5966, 24 May 1984, 303-5.

GROSSMANN, SIEGFRIED & GOTTFRIED MAYER-KRESS. »Chaos in the International Arms Race.« *Nature,* CCCXXVII, 6209, 23 Feb. 1989, 701-4.

Saperstein examines several arms race models. He presents the outbreak of war as a breakdown in predictability-loss of stability-in which small perturbations lead to unanticipatable solutions to the dynamical equations of the model. Grossmann and Mayer-Kress present several simple nonlinear models noting that Saperstein's one-dimensional model is too restricted. They propose that chaos and stability analysis are necessary but not to be overlooked are the »roles of psychology, fanaticism and accident in the international competition in armaments« (704).

SHAW, ROBERT. »Strange Attractors, Chaotic Behavior, and Information Flow.« *Zeitschrift fuř Naturforschung* XXVIa, 1, Jan. 1981, 80-112.

In this wide ranging paper Shaw argues that chaotic behavior is *completely ubiquitous* in the physical world« (107). Borrowing from information theory he characterizes the onset of turbulence as the passage of the system from an

information sink to an information source. Strange attractors transmit perturbations from the microscale to the macroscale. The implications according to Shaw are that the nineteenth century view of the world as a machine is wrong not only in the small but also in the large. »The constant injection of new information into the macroscales may place severe limits on our predictive ability, but it as well insures the constant variety and richness of our experience« (108).

SHAW, ROBERT. *The Dripping Faucet as a Model Chaotic System.* Santa Cruz: Aerial Press, 1984.

Data from the dripping faucet experiment serve as the context for Shaw's thoughtful and reflective discussion of models and the relationship of information and entropy to prediction.

TAKENS, FLORIS. »Detecting Strange Attractors in Turbulences in D. A. Rand & L. -S. Young, eds., *Dynamical Systems and Turbu- lence, Warwick 1980: Proceedings of a Symposium Held at the University of Warwick 1979/80.* Berlin: Springer, 1981.

In this influential paper, Takens outlines a method of ascertaining the presence of a strange attractor directly from experimental data.

c. Order-out-of-chaos

ALLEN, P. M. »Evolution, Modelling, and Design in a Complex Worlds *Environment and Planning B,* DC, 1, Mar. 1982, 95-111.

Allen employs the concept of dissipative structures and evolution through bifurcation to explain the development of form. He uses origami, markets, and urban systems to illustrate the emergence of qualitative change.

HAKEN, HERMANN. *Synergetics: An Introduction, Nonequilibrium Phase Transitions and Self-Organization in Physics, Chemistry and Biology.* Berlin: Springer, 1977.

In his analysis of self-organization, the third edition of which inaugurated the Springer Series in Synergetics, Haken examines chance, probability, and necessity, deterministic motion, first independently then paired. This Science of cooperation investigates the joint action of many subsystems and the role of fluctuations Finding that seemingly different systems behave analogously, the differences becoming progressively apparent as the systems are examined in finer and finer detail.

LOYE, DAVID & RIANE EISLER. »Chaos and Transformation: Implications of Nonequilibrium Theory for Social Science and Society.« *Behavioral Science,* XXXII, 1, Jan. 1987, 53-65.

This is a survey article which covers nonequilibrium and self-organizing theories in the natural sciences and relates them to the social sciences sketching

»how advancement at both levels *could* help gain a peaceful as well as humanistic 'order out of chaos', in this troubled world of ours.«

NICOLIS, G. & I. PRICOCINE. *Self-Organization in Nonequilibrium Systems: From Dissipative Structures to Order through Fluctuations.* New York: John Wiley & Sons, 1977.

PRIGOGINE, ILYA. *From Being to Becoming: Time and Complexity in the Physical Sciences.* San Francisco: W. H. Freeman and Company, 1980.

PRIGOGINE, ILYA & ISABELLE STENGERS. *Order out of Chaos: Man's New Dialogue with Nature.* Foreword by Alvin Toffler. New York: Bantam Books, 1984 [based on the French *La nouvelle alliance: Mitamorphose de la science.* Paris: Gallimard, 1979].

Nicolis and Prigogine present a technical exposition of self-organization, »characterized by the appearance of dissipative structures through the amplification of appropriate fluctuations« (5), as an example of »nonequilibrium as a source of order« (4). Bifurcation theory, catastrophe theory and the role of fluctuations are brought to focus on the problem of constructing solutions when instability sets in. Examples are drawn from chemistry and biology including evolution and population dynamics. The 1980 volume covers much of the same ground in a somewhat less technical vein. Prigogine and Stengers deal with the philosophical and epistemological implications inherent in the work on self-organizing systems-»the conceptual transformation of science from the Golden Age of classical science to the present« (10). They relate this transformation to the contemporary research in thermodynamics focusing on nonlinearity, instability and fluctuations, which is challenging Newtonian mechanics. The irreversibility of the evolution of far-from-equilibrium systems, characterized by self-organizing processes and dissipative structures, determines an arrow of time. The authors speculate on the interconnectedness of chance and necessity and the reconciliation of being and becoming. Rather than its opposite, chaos is both the source and confederate of order. The second edition of *La nouvelle alliance* [1986] includes an important preface not reproduced in *Order out of Chaos.*

RADZICKI, MICHAEL J. institutional Dynamics, Deterministic Chaos, and Self-Organizing Systems.« *Journal of Economic Issues,* XXIV, 1, Mar. 1990, 57-102.

This article examines the impact of studies of deterministic chaos and self-organizing systems on institutional economics in which the computer plays a central role producing pattern models.

YATES, F. EUGENE, ed., ALAN GARFINKEL, DONALD O. WALTER & GREGORY B. YATES, ass. eds. *Self-Organizing Systems: The Emergence of Order.* New York: Plenum Press, 1987.

This massive collection covers the »variety, order, and their becomings« (1) in nature from the multiple viewpoints of physics, dynamics and thermodynamics, biology and evolution, epistemology and control theory. Abraham and Shaw present a particularly good introduction to the visual representation of dynamical systems.

5. FRACTAL GEOMETRY

BATTY, M. & P. A. LONGLEY. »Fractal-based Description of Urban Form.« *Environment and Planning B: Planning and Design,* XIV, 2, May 1987, 123-34.

This paper aims at »extending fractal geometry from nature to systems which are formed from combinations of man-made and natural processes« (124). An overview of fractal dimension is offered along with two computer methods-structured walk and equipaced polygon-for approximating curve length at different scales. These ideas are applied to the urban boundary of Cardiff.

BURROUGH, P. A. »Fractal Dimensions of Landscapes and Other Environmental Data.« *Nature,* CCXCIV, 5838, 19 Nov. 1981, 240-42.

Burrough examines a variety of environmental variables and concludes that they may have a wide range of fractal dimensions indicating that interpolation mapping may not be appropriate in certain cases« (241).

FALCONER, KENNETH. *Fractal Geometry: Mathematical Foundations and Applications.* Chichester. John Wiley & Sons, 1990.

This remains a fine presentation, but for the specialist, of the solid mathematics underpinning the fascinating world of fractals, even though »measure theoretic ideas have been kept to a minimum [and]... some of the harder or more technical proofs are either just sketched or omitted altogether (x).

GOLDBERGER, ARY L., VALMIK BHARGAVA, BRUCE J. WEST & ARNOLD J. MANDELL. »On a Mechanism of Cardiac Electrical Stability: The Fractal Hypothesise *Biophysical Journal, XLVIII,* 3, Sept. 1985, 525-28.

Considering the His-Purkinje network fractal, this work »supports a connection between nonlinear structure, represented by the fractal conduction system, and physiologic nonlinear function, manifest in the power-law spectrum of the ventricular depolarization waveform« (528).

MANDELBROT, BENOIT B. *The Fractal Geometry of Nature.* Updated and Augmented. New York: W. H. Freeman and Company, 1983.

This is the essential, fascinating, encyclopedic exposition of fractals. Not overly technical, it covers all aspects of the field showing how »formless« shapes whose dimension is not a whole number actually depict the complexity of irregular and fragmented shapes in nature. In this recasting of earlier works Mandelbrot demonstrates how fractal geometry attaches to a neglected tradition in mathematics and underlines his own fundamental contributions. He includes an excellent bibliography. (His 1975 *Les objects fractals: forme, hasard et* *dimension* was published in French by Flammarion in the series Nouvelle Bibliothèque Scientifique directed by Fernand Braudel. A »much modified and augmented second version« was published by W. H. Freeman in 1977 as *Fractals: Form, Chance, and Dimension.* It placed emphasis on the links between fractal geometry and its mathematical precursors.)

PEITGEN, H-O. & P. H. RICHTER. *The Beauty of Fractals: Images of Complex Dynamical Systems.* Berlin: Springer, 1986.

The Peitgen and Richter book goes far beyond »Computer art« or a do-it-yourself for imaging complex dynamical systems. The renderings are exquisite and the mathematics of the constructions absorbing, but further interest lies in the invited articles treating both art and science, particularly Mandelbrot's »Fractals and the Rebirth of Iteration Theory,« in which he explains fractal geometry as carving out a »middle third« between Euclid and chaos by contrasting »orderly« and »disorderly chaos« (1 57). Includes a very short but essential bibliography.

SANDER, LEONARD M. »Fractal Growth Processes.« *Nature,* CCCXXII, 6082, 28 Aug. 1986, 789-93.

This review article concentrates on scaling properties-the hidden order in complex patterns-which allow for the classification of non-equilibrium growth processes, and models for their computer simulation.

6. ANTICIPATORY SYSTEMS

ROSEN, ROBERT. *Anticipatory Systems: Philosophical, Mathematical and Methodological Foundations.* Oxford: Pergamon Press, 1985.

Rosen explores systems in which the future, rather than the present or the past, determines change in the present. His formal analysis examines internal predictive models from the cellular to the physiological and behavioral levels including social and political activity.

7. LIVING SYSTEMS

DEGN, H., A. V. HOLDEN & L. F. OLSEN, EDS. *Chaos in Biological Systems.* New York: Plenum Press, 1987.

Much of the material in this book will be accessible only to the initiated. Taken as a whole, however, it does suggest a ubiquity in nature of dynamical systems subject to chaotic regimes and holds out the hope of some understanding of the rules governing such systems, albeit at the price of predictability inherent in such analyses.

EIGEN, MANFRED, BJÖRN F. LINDEMANN, MANFRED TIETZE, RUTHILD WINKLER-OSWATITSCH, ANDREAS DRESS, ARNDT VON HAESELER. »HOW Old Is the Genetic Code? Statistical Geometry of tRNA Provides an Answer.« *Science,* CCXLIV, 4905, 12 May 1989, 673-79.

The conclusion that the genetic code is almost as old but not older than the Earth is less important than the determination that »interpretable data exist that permit inferences about such early stages of life as the establishment of the genetic code.«

LANGTON, CHRISTOPHER G., ed. *Artificial Life: The Proceedings of an Interdisciplinary Workshop on the Synthesis and Simulation of Living Systems, held September, 1987 in Los Alamos, New Mexico.* Redwood City: Addison-Wesley, 1989.

These papers extend the »empirical foundation upon which biology is based *beyond* the carbon-chain life that has evolved on Earth... [by] locating *life as we know it* within the larger picture of *life as it could be«* (1). The approach to these complex systems is »bottom up« in which simple rules govern local interactions but no rules determine the behavior of a population at the global level. Higher level dynamics and structures are seen as emergent and compete for local support where they organize the »behavior of the lowest-level entities by establishing the context within which those entities invoke their local rules and, as a consequence, these structures may *evolve* in time»(xxii). An excellent annotated bibliography is provided.

LOVELOCKJ. E. *Gaia: A New Look at Life on Earth.* Oxford: Oxford Univ. Press, 1979.

Lovelock conceptualizes the whole Earth as a single living system. He pieces together indications of the validity of his hypothesis of the biosphere as a »self-regulating entity with the capacity to keep our planet healthy by controlling the chemical and physical environment (ix) on a grand tour of the scientific disciplines.

RENSING, L., U. VAN DER HEIDEN & M. C. MACKEY, eds. *Temporal Disorder in Human Oscillatory Systems: Proceedings of an International Symposium, University of Bremen, 8-13 September 1986.* Berlin: Springer, 1987.

The idea that »dynamical diseases« may develop »because of pathological alterations in underlying physiological control parameters« (4) analogous to bifurcations in mathematical models is explored by numerous authors in a wide variety of human systems.

WATSON, JAMES D. *The Double Helix: A Personal Account of the Discovery of the Structure of DNA, Text, Commentary, Reviews, Original Papers.* Gunther S. Stent, ed. New York: W. W. Norton & Company, 1980.

DAVIS, JOEL. *Mapping the Code: The Human Genome Project and the Choices of Modern Science.* New York: John Wiley & Sons, 1990. Much of the value of this edition of Watson's autobiographical memoir, whose implications contributed... to the demise of the traditional view of the scientific enterprise as an autonomous exercise of pure reason by disembodied, selfless spirits, inexorably moving toward a true knowledge of nature« (ix) lies in the supplementary material which evokes the context of the discovery which heralded the era of molecular biology. Joel Davis explores the controversies surrounding the sciences, politics, business, and ethics involved in the mapping of the human genetic code. He includes a useful glossary and bibliography.

WILSON, EDWARD O. *Sociobiology: The New Synthesis.* Cambridge: The Belknap Press of Harvard Univ. Press, 1975.

RUSE, MICHAEL. *Sociobiology: Sense or Nonsense?* Second Edition. Dordrecht. D. Reidel, 1985 [first edition published 1979].

LEWONTIN, R. C, STEVEN ROSE & LEON J. KAMIN. *Not in Our Genes: Biology, Ideology, and Human Nature.* New York: Pantheon Books, 1984.

KITCHER, PHILIP. *Vaulting Ambition: Sociobiology and the Quest for Human Nature.* Cambridge: MIT Press, 1985.

These books offer a sampling of the aspects the sociobiology debate has taken since the original position, »of the biological basis of all social behavior,« was articulated in Wilson's massive, slickly produced study of 1975. Ruse offers a sympathetic defense of the idea and an update of the literature. In the comprehensive critical study of Lewontin et al. arguments bearing on sociobiology and biological determinism, IQ patriarchy and psychiatry are used to explore the relationships among science, belief systems and the political economy of contemporary society. Kitcher's skeptical appraisal attempts to distinguish between serious claims about the relationship between biological processes and animal society and pop sociobiology »pronouncements about human nature« (435).

WINFREE, ARTHUR T. *When Time Breaks Down: The Three-Dimensional Dynamics of Electrochemical Waves and Cardiac Arrhythmias.* Princeton: Princeton Univ. Press, 1987.

Winfree applies topological models to biological systems in which time may be associated with phase and therefore circular rather than linear. He explores examples which seem to exhibit singularities and suggests that sudden cardiac death is such an instance.

a. Evolution

BOWLER, PETER J. *Evolution: The History of an Idea.* Revised edition. Berkeley, University of California Press, 1989 [originally published 1983].

Bowler's book is a successful, balanced and in-depth introduction to the major concepts and historical controversies marking the development of evolutionary theory and capped off with a 57 page bibliography. He also treats ancillary questions in cosmology, geology and taxonomy, and social and ethical implications. Creationism as well as the most recent cladist, punctuationist and Lamarckian debates are afforded ample treatment.

BROOKS, DANIEL R. & E. O. WILEY. *Evolution as Entropy: Toward a Unified Theory of Biology.* Second Edition. Chicago: Univ. of Chicago Press, 1988 [first edition published 1986].

WEBER, BRUCE H., DAVID J. DEPEW &JAMES D. SMITH, eds. *Entropy, Information, and Evolution: New Perspectives on Physical and Biological Evolution.* Cambridge: MIT Press, 1988.

The Brooks and Wiley book sparked much of the current interest in the relationship between evolutionary theory and thermodynamics. It attempts a unification of biology and physics by characterizing the evolution of biological systems as that of non-equilibrium entropie systems in which increasing entropy leads to self-organization and complexity. They also stress the importance of historical constraints over selection or adaptation. The papers in Weber et al. tend towards a unification of thermodynamics and evolutionary biology. A common theme is that fundamental characteristics of biological systems follow directly from physical laws. Of particular interest are the discussions of information by Wicken and Collier, and their divergences.

ELDREDGE, NILES. *Time Frames: The Rethinking of Darwinian Evolution and the Theory of Punctuated Equilibria.* New York: Simon and Schuster, 1985.

GOULD, STEPHEN JAY & NILES ELDREDGE. »Punctuated Equilibria: The Tempo and Mode of Evolution Reconsidered.« *Paleobiology,* III, 2, Spr. 1977, 1 15-51.

Informal and very readable, the first item is Eldredge's version of the premises and implications of the idea of punctuated equilibria which takes species as real entities and asserts that »most anatomical change in evolution seems to go hand in hand with the origin of new species« (15). The original, highly influential 1972 paper by Eldredge and Stephen. Jay Gould, »Punctuated Equilibria. An Alternative to Phyletic Gradualism« is reproduced as an appendix. The 1977 article is a reply to the critics of that paper. The authors argue that »virtually none of the examples brought forward to refute our model can stand as support for phyletic gradualism« (115) Particularly stimulating is the statement that »[p]hyletic gradualism was an a priori assertion from the start-it was never 'seen' in the rocks; it expressed the cultural and political biases of 19th century liberalism« (115). Part V of their paper, »Towards a General Philosophy of Change,« examines the ideological foundations and implications of the competing models.

GOULD, STEPHEN JAY. »Is a New and General Theory of Evolution Emerging?« *Paleobiology,* VI, 1, Winter 1980, 119-30.

In this important paper, Gould advocates a hierarchical view of nature and »restoring to evolutionary theory a concept of organism« (119).

LASZLO, ERVIN. *Evolution: The Grand Synthesis.* Foreword by Jonas Salk. Boston. Shambhala, 1987.

Laszlo argues, theoretically and with a series of case studies, for a general theory of evolution to explain the universe and social systems as well as biological systems. In the case of human evolution, he contends that it is no longer genetic but sociocultural and that our age is not only the age of uncertainty but also the age of opportunity.

RIDLEY, MARK. *Evolution and Classification: The Reformation of Cladism.* London: Longman, 1986.

SCOTT-RAM, N. R. *Transformed Cladistics, Taxonomy and Evolution.* Cambridge: Cambridge Univ. Press, 1990.

HOENIGSwALD, HENRY M. & LINDA F. WIENER, eds. *Biological Metaphor and Cladistic Classification: An Interdisciplinary Perspective.* Philadelphia: Univ. of Pennsylvania Press, 1987.

The relationship between evolutionary theory and taxonomic theory has emerged as a significant debate. Ridley examines two main principles, phylogenetic and phenetic and the three schools, evolutionary, phenetic and cladistic, emanating from them. He attacks the fourth school, »transformed cladism« on the grounds that it seeks to dispense with evolutionary theory which is in fact necessary to it. Scott-Ram examines the debate from philosophical and methodological perspectives. As a tool he uses the distinction between theoretical and descriptive attitudes, points out the aversion to theories of process by transformed cladists and concludes that »it is difficult to understand fully any viable rationale for transformed cladistics« (184). The Hoenigswald and Wiener collection focuses on cladistics-classification based on evolutionary branching sequences-as a shared methodology between biology and linguistics and text analysis.

b. Self-organization, morphogenesis, and pattern formation

ATLAN, HENRI. *Entre le cristal et la fumie: Essai sur Vorganisation du vivaut.* Paris: Le Seuil, 1979.

Although the heterogeneous material for this wide-ranging book was assembled from various sources, the central theme remains the organization of living systems: the relation of »noise« and complexity, the dynamics of organization and their representation, open systems, irreversibility, consciousness and a science of man.

BABLOYANTZ, A. *Molecules, Dynamics, and Life: An Introduction to Self-Organization of Matter.* New York: John Wiley & Sons, 1986.

Babloyantz presents a readable and accessible synthesis of work dealing with the »self-organization of matter and its relation to living organisms« (vii) from the Brussels school perspective. The book proceeds from a general discussion of matter and elemental concepts of chemistry to entropy, thermodynamics and irreversible processes and self-organization, to end with a series of examples from the biological sciences. The chapter-by-chapter reading lists give an abbreviated overview of antecedent work.

BABLOYANTZ, AGNESSA. »Far From Equilibrium Synthesis of 'Prebiotic', Polymers.« *Biopolymers,* XI, 1 1, Nov. 1972, 2349-56.

GOLDBETER, A. & G. NICOLIS. »Far From Equilibrium Synthesis of Small Polymer Chains and Chemical Evolutions *BiophysiK* VIII, 1972, 212-26.

Babloyantz is concerned with »polymerization and conditions for abundance of biopolymers in a 'prebiotic milieu'« (2349). The model shows autocatalysis and nonlinear behavior whose multiple steady states far from equilibrium »favor the accumulation of informational biopolymers involved in a cross-catalytic cycle« (2355). Goldberger and Nicolis consider simple models for the synthesis of small polymers. The results of a thermodynamic analysis in the non-linear range is discussed in relation to prebiotic synthesis and developmental biology.

BARD, JONATHAN. *Morphogenesis: The Cellular and Molecular Processes of Developmental Anatomy.* Cambridge: Cambridge Univ. Press, 1990.

Bard offers a critical review of the present state of research and sets out several research agendas. The bibliography is large, inclusive and up-to-date.

EIGEN, M. & P. SCHUSTER. *The Hypercycle: A Principle of Natural Self-Organization.* Berlin. Springer, 1979.

Eigen proposes the hypercycle, a system or closed feedback loop as the simplest molecular organization of functionally related, cyclically linked, autocatalytic self-replicative units.

MARKUS, M, S. C MULLER & G. NICOLIS, eds. *From Chemical to Biological Organization.* Berlin: Springer, 1988.

The editors present this group of papers as in itself evidence of the emergence of »nonlinearity as a new scientific paradigm« (v) in which universalities in a variety of open self-organizing systems offer a common language to chemists, biologists, ecologists, physicists, mathematicians and medical doctors.

MEINHARDT, HANS. *Models of Biological Pattern Formation.* London: Academic Press, 1982.

Meinhardt is concerned with the problem of the control of development in the individual organism: »how cells in one part of an organism become different from those of other parts« (v). Reaction-diffusion models based on »simple, coupled biochemical interactions« (189) are examined and some computer programs for the simulation of pattern formation and interpretation are included.

MONOD, JACQUES. *Chance and Necessity: An Essay on the Natural Philosophy of Modern Biology.* Translated from the French by Austryn Wainhouse.

New York: Alfred A. Knopf, 1971 [originally published as *Le hasard et la nécessité.* Paris: Le Seuil, 1970].

LEWIS, JOHN, ed. *Beyoud Chance and Necessity: A Critical Inquiry into Professor Jacques Monod's Chance and Necessity.* Atlantic Highlands, NJ: Humanities Press, 1974.

Monod argues that the origin of life and its subsequent evolution are to be found in fortuitous events-chance at the microscopic level translated into necessity at the macroscopic level. He closes with a discussion of truth, values and the »ethic of knowledge. « The critiques published in the Lewis volume deal primarily, but not exclusively, with the implications of his theory for man.

PEACOCKE, A. R. *An Introduction to the Physical Chemistry of Biological Organization.* Oxford: Clarendon Press, 1983.

This is a fine introduction to many of the concepts and approaches, such as dissipative structures, network thermodynamics, self-organization and the evolution of macromolecules, constituting contemporary directions in research into the complexity of biological organization.

PRIGOGINE, I. & G. NICOLIS. »Biological Order, Structure and Instabilities.« *Quarterly Reviews of Biophysics,* IV, 2 & 3, Aug. 1971, 107^8.

PRIGOGINE, ILYA. »La thermodynamique de la vie.« *La Recherche,* III, 24, Juin 1972, 547-62.

PRIGOGINE, ILYA, GRÉGOIRE NICOLIS & AGNES BABLOYANTZ. »Thermodynamics of Evolutions *Physics Today,* XXV, 1 1 & 12, Nov. & Dec, 1972, 23-28 & 38^4.

Prigogine and Nicolis deal with determining the »type of events which lead from inanimate to living objects« (108) The laws of chemical kinetics and fluctuation theory are shown to be sufficient to establish the »emergence of order, the role of probabilistic and causal events, the dependence of structure on the previous history [and] the hierarchization of structures... [as] consequences of far from equilibrium thermodynamics applied to certain types of non-linear systems« (143). Prigogine's article in French asks whether the phenomena of life may be explained using concepts from physics. His discussion centers on entropy, both internal and external to the system, dissipative structures and the close cooperation between chance and necessity. The first part of the article by Prigogine, Nicolis and Babloyantz concentrates on how living systems come to terms with entropy. The second part looks at prebiotic evolution, deterministic but with the idea of »fittest« not defined as the maximum number of offspring but as maximal stability.

TURING, A. M. »The Chemical Basis of Morphogenesis.« *Philosophical Transactions of the Royal Society of London,* Series B, CCXXXVII, 641 (14 Aug. 1952), 1954, 37-72.

In this exploration of development from homogeneity into pattern, Turing was particularly concerned with a »possible mechanism by which the genes of

a zygote may determine the anatomical structure of the resulting organism« (37). Fundamental to his discussion is instability due to random disturbances. He notes that the most interesting of the six different forms this may take is the appearance of stationary waves on a ring. The examples discussed include tentacle patterns on *Hydra,* whorled leaves and phyllotaxis-the arrangement of leaves on a stem. Turing ends with the caveat that the linear processes discussed are the exception rather than the rule in living systems and suggests the use of digital computers to expand such work in the future.

WICKEN, JEFFREY S. *Evolution, Thermodynamics, and Information: Extending the Darwinian Program.* New York: Oxford Univ. Press, 1987.

Wicken extends the evolutionary project back in time to the prebiotic level. In the spirit of the Brussels school, he looks to the thermodynamics of irreversible processes to establish a causal continuity of nature unifying the emergence and diversification of life.

C. Computation

BENNETT, CHARLES H. »The Thermodynamics of Computation-a Reviews *International Journal of Theoretical Physics,* XXI, 12, Dec. 1982, 905-40.

In his discussion of computers and entropy, Bennett examines two idealized classes of machines, ballistic computers which could »compute at finite speed with zero energy dissipation and zero error« (905) and more dissipative Brownian computers whose closest analogue in nature is found in DNA. Both types, however, require programming so computations are rendered *logically* reversible. Bennett proposes how this might be done and discusses Maxwell's demon and the »relation between logical and thermodynamic reversibility« (906).

CAMPBELL, DAVID, JIM CRUTCHFIELD, DOYNE FARMER, AND ERICA JEN. »Experimental Mathematics: The Role of Computation in Nonlinear Science.« *Communications of the Association of Computing Machinery,* XXVin, 4, Apr. 1985, 374-84.

The authors discuss the contribution of computers in research into such phenomena as attractors and solitons, note that there are rigorous results that would have been impossible without them, but add that the »interplay between computational studies and mathematical theorem proving proceeds as a classic dialectic (380-81). The hardware overview considers both digital and analog devices. Although the latter have advantages in qualitative studies, it is the hybrid machines in which the two work in conjunction, expressly designed for the study of chaotic behavior, which offer the most promise. The authors close with a description of their ideal facility.

DENNING, PETER J. & WALTER F. TICHY. »Highly Parallel Computations *Science,* CCL, 4985, 30 Nov. 1990, 1217-22.

This brief article spells out the advantages of parallel over sequential computing. The multiprocessor SIMD and MIMD machines are discussed.

PICKOVER, CLIFFORD A. *Computers, Pattern, Chaos and Beauty: Graphics from an Unseen World.* New York: St. Martin's Press, 1990.

Completely devoted to digital imagery, this book offers both a popular introduction to computer graphics and their importance in mathematics, chaos theory, philosophy, and aestheticsboth analytical and heuristic-and a more technical overview of the processes by which patterns are extracted from complicated data. Chapter by chapter reading lists are provided as well as programs for reproducing many of the examples in the text.

PAGELS, HEINZ R. *The Dreams of Reason: The Computer aud the Rise of the Sciences of Complexity.* New York. Simon and Schuster, 1988.

The broad range of this book touches on »a new synthesis of science« (15), order, complexity, chaos, the life sciences, connectionism/neural nets, and attendant philosophical issues. Pagels emphasizes computer simulation for the study of complicated systems.

TURING, A. M. »On Computable Numbers, with an Application to the Entscheidungsproblem.« *Proceedings of the London Mathematical Society,* Second Series, XLII, 2144 (Nov. 12, 1936), 1937, 230-65.

——.»Computing Machinery and Intelligences *Mind,* LIX, 236, Oct. 1950, 433-60.

In the first paper Turing envisions a simple machine, eventually to be known as a »Turing machine«,capable of carrying out any conceivable calculation. In the second paper Turing considers »the question, 'Can machines think?'« (433) To do so he outlines what is now known as the »Turing tests The evaluation is based on whether, when interrogated, the behavior of the machine can be distinguished from that of a person.

1. INFORMATION THEORY

MACHLUP, FRITZ & UNA MANSFIELD, eds. *The Study of Information: Interdisciplinary Messages.* Foreword by George A. Miller. New York: John Wiley & Sons, 1983.

This is a large collection including sections on information and cognitive science, informatics, artificial intelligence, linguistics, library science, cybernetics, information and systems theory.

SHANNON, CLAUDE E. & WARREN WEAVER. *The Mathematical Theory of Communication.* Urbana: Univ. of Illinois Press, 1949.

The roots of modern information theory are to be found in Shannon's paper. He schematized communication as a system including a source, transmitter, channel-subject to »noise,« receiver, and destination. By separating information from meaning he equated information with entropy. In his commentary Weaver shows that an increase in noise is an increase in uncertainty and as uncertainty is increased, so is information; however, uncertainty due to error is undesirable and therefore not to be counted as information. But Shannon's theory does not depend on the receiver knowing the message. At this point Weaver introduces Shannon's concept of »equivocation,« information due to noise. This laid the groundwork for a view of noise as desirable and constructive as well as damaging.

2. COGNITIVE SCIENCE AND ARTIFICIAL INTELLIGENCE

ANDERSON, ALAN ROSS, ed. *Minds and Machines.* Englewood Cliffs: Prentice-Hall, 1964.

This is a fine collection of '50's and early '60's articles concerned with the »relations between * mental' and *_mechanical' events« (1) by the likes of A. M. Turing, Michael Scriven, J. R. Lucas, Keith Gunderson, Hilary Putnam, Paul Ziff, J.J. C. Smart and Ninian Smart.

CASTI, JOHN L. & ANDERS KARLQVIST, eds. *Real Brains, Artificial Minds.* New York: North-Holland, 1987.

These papers deal specifically with how brains work and particularly the relationships among what they term the *material* brain, the *mechanical* brain, and the *mathematical* brain.

GARDNER, HOWARD. *The Mind's New Science: A History of the Cognitive Revolution.* With a New Epilogue by the Author: »Cognitive Science After 1984.« New York: Basic Books, 1987 [originally published 1985].

Gardner's is a detailed and comprehensive study of this discipline, with a short history but a very long past, defined as a »contemporary, empirically based effort to answer long-standing epistemological questions-particularly those concerned with the nature of knowledge, its components, its sources, its development, and its deployment (6). He indicates five basic features and examines them in relation to six disciplines.

HAYES, PATRICK. »Trends in Artificial Intelligence.« *International Journal of Man-Machine Studies,* X, 3, May 1978, 295-99.

In this short paper, Hayes argues that »AI and general systems theory are on divergent paths« (299), the first looking for software, *computational* detail, and the second for architecture, *general properties of intelligent systems.*

HOFSTADTER, DOUGLAS R. *Godel, Escher, Bach: An Eternal Golden Braid.* New York. Basic Books, 1979.

Hofstadter's original and informative arguments as a proponent of artificial intelligence are inspired by Gödel's Theorem. The central thesis of self-reference culminating in the key concept of the »strange loop« link the Self and the mechanization of thought with analogous loops in compositions of Bach and the works of M. C. Escher.

PARTRIDGE, DEREK & YORICK WILKS, eds. *The Foundations of Artificial Intelligence: A Sourcebook.* Cambridge. Cambridge Univ. Press, 1990.

Partridge and Wilks offer a broad survey of AI by principal researchers in the field. The up-to-date annotated bibliography is particularly useful.

PENROSE, ROGER. *The Emperor's New Mind: Concerning Computers, Minds, and the Laws of Physics.* Foreword by Martin Gardner. New York: Oxford Univ. Press, 1989.

This sweeping discussion of the frontiers of modern science is marshalled by Penrose to argue against »strong AI,« the possibility of developing a computer with a real mind, and to refute logical positivism as a model of scientific explanation. Although intended for the non-specialist, the presentations can be demanding.

PYLYSHYN, ZENON W. *Computation and Cognition: Toward a Foundation for Cognitive Science.* Cambridge: MIT Press, 1984.

Pylyshyn advances the hypothesis that cognition is computation. He would like to find the functional architecture of the mind which provides its computational resources and the kind of representations which are acted upon. He argues that *cognitive generalizations...* are *encoded«* much as computer representations are-»by physically instantiated symbol structures« (258).

RUMELHART, DAVID E., JAMES L. MCCLELLAND & THE PDP RESEARCH GROUP. *Parallel Distributed Processing: Explorations in the Microstructure of Cognition.* Volume I: *Foundations;* Volume II: *Psychological and Biological Models.* Cambridge: MIT Press, 1986.

PINKER, STEVEN & JACQUES MEHLER, eds. *Connections and Symbols.* Cambridge: MIT Press, 1988.

The first two volumes, which include introductory and theoretical material along with many applications and detailed analytical discussions, set out the foundations of the connectionist approach-»long term storage takes place in the connections among units« rather than »in the state of certain units of the system« (75)-to cognitive science. This model, parallel distributed processing, or neural networks-replacing the,»computer metaphor, as a model of mind with the 'brian metaphor', as model of mind« (75)-avoids the classical approach of cognition based on representation as the manipulation of symbols in favor of models based on dense networks of simple units. The debate is taken up critically in the papers presented by Pinker and Mehler. Fodor and Pylyshyn attack connectionism, asserting that »mind/brain architecture is not Connectionist at the cognitive level« (3) and arguing that it does not recognize either a syntactic or semantic structure in representation and that if anything it might be regarded as a theory of implementation.

ROSEN, ROBERT. »Causal Structures in Brains and Machines.« *International Journal of General Systems,* XII, 2, Apr. 1986, 107- 26.

Rosen's aim is to clarify the concepts of organism and machine: which machines may be considered lifelike and which organisms machinelike. He investigates nonequivalent categories of causation, distinguishes between modeling which preserves causal structure and simulation which does not and discusses some implications for mathematics, physics, biology, and machines and brains.

SEARLE, JOHN R. »Minds, Brains, and Programs.« *The Behavioral and Brain Sciences,* III, 3, September 1980, 417-57.

SEARLE, JOHN. *Minds, Brains and Science.* Cambridge: Harvard Univ. Press, 1984.

This is the article in which Searle introduces the Chinese room experiment. He argues that intentionality is a causal feature of the brain for which instantiating a computer program is not a sufficient condition. He concludes that »strong AI has little to tell us about thinking since it is not about machines but about programs, and no program by itself is sufficient for thinking« (417). The last thirty-three pages are devoted to open peer commentary. His 1984 book restates the case further arguing the impossibility of AI: computer programs are syntactic and cannot produce semantics, thereforehey cannot become minds.

III. THE VERY BIG AND THE VERY SMALL: PHYSICS, ASTROPHYSICS, AND COSMOLOGY

CASATI, GIULIO, ed. *Chaotic Behavior in Quantum Systems: Theory and Applications.* New York: Plenum Press, 1983.

The papers in this volume explore the »the very definition of chaos in Quantum Mechanics« (v) as well as mathematical aspects of the problem and applications in such areas as nuclear physics, solid state physics, and chemistry.

CREASE, ROBERT P. & CHARLES C. MANN. *The Second Creation: Makers of the Revolution in Twentieth-Century Physics.* New York: Macmillan, 1986.

Crease and Mann successfully recount the development of particle physics up to the present day search for a single unified theory seen through the »style« and »personality« of the major protagonists-»a tale of people, not protons« (ix).

DAVIES, PAUL, ed. *The New Physics.* Cambridge: Cambridge Univ. Press, 1989.

This beautifully produced survey-large format, comprehensive coverage, clear exposition, useful illustrations-covers the entire gamut of contemporary physics. Each article-from particle physics to quantum optics, gauge theories to general relativity, chaos to quarks, far-from-equilibrium systems and self-organization to the edge of space time, and more-is written by an expert in the field. The ensemble serves as a window on the contemporary developments Davies characterizes as falling into three categories, at the frontiers of the very large, the very small and the very complex. Unfortunately there is no bibliography and citations are not referenced although some articles offer short »further reading« lists.

DAVIES, P. C. W. & JULIAN BROWN. *Superstrings: A Theory of Everything?* Cambridge: Cambridge Univ. Press, 1988.

Davies and Brown have succeeded in making superstring theory accessible. In the first section, the introduction, they show how concepts from different branches of physics must be encompassed by a »theory of everything.« In the second part superstring theory is confronted directly in interviews of exceptional clarity with four of the protagonists and five other physicists.

HAWKING, S. W. & W. ISRAEL, eds. *Three Hundred Years of Gravitation.* Cambridge: Cambridge Univ. Press, 1987.

Published to commemorate the 300th anniversary of Newton's *Philosophiae Naturalis Principia Mathematica,* this collection presents developments and prospects in such fields as gravitational radiation, galaxy formation, inflationary cosmology, quantum cosmology, and superstring unification.

HAWKING, STEPHEN W. *A Brief History of Time: From the Big Bang to Black Holes.* Introduction by Carl Sagan. Illustrations by Ron Miller. New York. Bantam, 1988.

This justly successful presentation of the development and latest (up to 1985) ideas in cosmology is written from the perspective of general relativity with the layman in mind. Of particular interest are the discussion of the »no-boundary proposal« and God's role in the universe. In this context, Hawking would have us ask not only *what* the universe is but, as well, *why* it is.

PENROSE, R. »The Role of Aesthetics in Pure and Applied Mathematical Research.« *Bulletin. Institute of Mathematics and Its Applications,* < 1> X, 7/8, July/Aug. 1974, 266-71.

LEVINE, DOV & PAUL JOSEPH STEINHARDT. »Quasicrystals: A New Class of Ordered Structures.« *Physical Review Letters,* LIII, 26, 24 Dec. 1 984, 2477-80.

—.»Quasicrystals. I. Definitions and Structures *Physical Review B,* XXXIV, 2, 15 July 1986, 596-616.

jARid, MARKO V., ed. *Introduction to Quasicrystals.* Boston: Academic Press, 1988.

Quasicrystals represent a new kind of ordered structure or phase of solid matter as distinguished from the two traditional classes of pure solids: crystal and glassy structures. The saga of the discovery has its roots in Penrose's »nonperiodic« tiling of the plane and the icosahedral analogue which Levine and Steinhardt found to have both »long-range 2D (or 3D) quasiperiodic translational order« (597). First in the series Aperiodicity aud Order, the Jaritf volume is an introduction to the basic physics of quasicrystalline order and materials.«

PRIGOGINE, I. & J. G£H£NIAU. »Entropy, Matter, and Cosmology.« *Proceedings of the National Academy of Sciences, USA,* LXXXIII, 17, Sept. 1986, 6245-49.

These authors analyze the role of irreversible processes in the development of the large scale structure of the universe concluding that either time, as irreversibility, is an illusion or »time precedes existence« (6248).

WEINBERG, STEVEN. *The First Three Minutes: A Modern View of the Origin of the Universe.* Updated Edition. New York: Basic Books, 1988 [originally published 1977].

This excellent, updated introduction to cosmology by an eminent particle theorist documents both the history of the early universe and the on-going development of cosmology itself in which the »clumpiness« of the universe has remained a problem.

IV. TIME

COVENEY, PETER & ROGER HIGHFIELD. *The Arrow of Time: A Voyage Through Science to Solve Time's Greatest Mystery.* Foreword by Ilya Prigogine. London: W. H. Allen, 1990.

In this pearl among the arrow-of-time books, Coveney and Highfield explore the problem, and its history and the personalities associated with it, that is presented by the divergence between the time-reversible mathematics of both Newtonian mechanics and the world of particle physics and the clear direction of time in the experiential world of dynamical systems. The book is nonmathematical in character with technical points and citations of research literature well covered in copious notes.

D'ESPAGNAT, BERNARD. *Une incertaine réalité: Le monde quantique, la connaissance et la durée.* Paris: Gauthier-Villars, 1985.

In linking the question of causation to the concept of time, d'Espagnat couples independent reality with timelessness or reversibility and empirical reality with irreversibility. Beside this duality he sketches a third more fundamental sort of time, tied to a deeper, obscure »réel vrai.«

GËHÉNIAU, J. & I. PRIGOGINE. »The Birth of Time.« *Foundations of Physics,* XVI, 5, May 1986, 437-43.

The authors »envisage the possibility of a 'cold big-bang mod el« in which the universe would start at zero temperature and entropy« (437). Their analysis concludes that »*time* precedes existence« (442).

GOULD, STEPHEN, J., NORMAN L. GILINSKY & REBECCA Z. GERMAN. »Asymmetry of Lineages and the Direction of Evolutionary Time.« *Science,* CCXXVI, 4807, 12 June 1987, 1437-41.

The authors propose a new arrow of time, life's arrow, based on a statistical property-bottom heavy asymmetry-of groups of clades to replace »vague, intestable, and culturally laden notions of 'progress'« (1437).

GRIFFIN, DAVID RAY, ed. *Physics and the Ultimate Significance of Time: Bohm, Prigogine, and Process Philosophy.* Albany: SUNY Press, 1986.

This collection of conference papers brings together discussions of three contemporary attacks on the conventional scientific view of time as ultimately unreal. Ilya Prigogine presents irreversibility and asymmetry as more fundamental than the symmetrical temporality of classical physics, relativity, and quantum theory; David Bohm discusses the concept of »implicate order«; and the process philosophy school contributes »pantemporalism« based on the work of Whitehead.

MIRMAN, R. »The Direction of Time.« *Foundations of Physics,* V, 3, Sept. 1975, 491 -511.

»The meaning of the phrase 'the direction of time, and the physical problems involved are considered« (492). Mirman asks us not to confuse the arrow of time with its ordering, and discusses alternate models of the universe, entropy and their relation to time.

PRIGOGINE, I. irreversibility as a Symmetry-breaking Process.« *Nature,* CCXLVI, 5428, Nov. 9, 1973, 67-71.

PRIGOGINE, ILYA. »Time, Irreversibility and Structure^ in J. Mehra, ed. *The Physicist's Conception of Nature.* Dordrecht: D. Reidel, 1973.

—.»Time, Structure, and Fluctuations.« *Science,* CC1, 4358, 1 Sept. 1978, 777-85.

—. »Tempo, Entropia, Dinamica.« *Critica Marxista,* XX, 6, nov. 1982, 35-49.

Time occupies a privileged place in Prigogine's project. The first paper presents a »rigorous * mechanical theory' of irreversibility« in which the future may be distinguished from the past (67). In the second, he distinguishes among »time associated with *motion,* time associated with *entropy* (irreversibility), [and] time associated with *dissipative structures«* (561) and justifies objectively the distinction between future and past. In the third the three aspects of time are »associated with classical or quantum dynamics... irreversibility through a Lyapunov function, and... with 'history' through bifurcations« (785). The fourth paper addresses time as the bridge linking physics, humanism and social problems.

WATANABE, SATOSI. »Creative Time.« in J. T. Frazer, F. C. Haber & G. H. Müller, eds. *The Study of Time,* vol. I. Berlin: Springer, 1972.

Watanabe argues that in an environment of increasing entropy law-like prediction is successful and effective but for systems showing decreasing entropy such as living matter »science has to be retrodictive, and under certain conditions teleological« (159). He ends with a discussion of the problem of »becoming«.

V. CULTURE AND EPISTEMOLOGY

AMSTERDAMSKI, STEFAN, HENRI ATLAN, ANTOINE DANCHIN, IVAR EKELAND, JEAN LARGEAULT, EDGAR MORIN, JEAN PETITOT, KRZYSZTOF POMIAN, ILYA PRIGOGINE, DAVID RUELLE, ISABELLE STENGERS & RENÉ THOM. *La querelle du déterminisme: Philosophie de la science d'aujourd 'huL* Paris: Gallimard, 1990.

René Thorn's original article, »Halte au hasard, silence au bruit«, reprinted here, defended »determinism« and attacked the »glorification of chance.« This volume presents the highcaliber debate-centered on order and disorder, chance and necessity, information and noise, causality and prediction-that it sparked.

ATLAN, H. »Self Creation of Meaning.« *Physica Scripta,* XXVI, 3, Sept. 1987, 563-76.

In this look at biological information that »has a meaning which manifests itself in physiological functions« (563), Atlan explores the complexity from noise principle, making use of probabilistic information theory and automata network theory. Systems which interact with their environment create meanings »at the same time when they are perceived and recognized« (575). This is less »mysterious,« than thought, he concludes, as »it is simulated by a relatively simple association of deterministic and probabilistic parallel computation (575).

BARROW, JOHN D. & FRANK J. TIPLER. *The Anthropic Cosmological Principle.* With a foreword by John A. Wheeler. Oxford: Oxford Univ. Press, 1986 [issued with corrections as a paperback in 1988].

Barrow and Tipler explore the relationship between the existence of man-carbon-based life forms-in the universe and the conditions which permit such existence. They first present the Anthropic Principle in a historical perspective as evolved from the traditional design arguments for the existence of a deity, then examine philosophical questions and a wide array of illustrations from physics and astrophysics, cosmology, quantum mechanics, and biochemistry.

BOHM, DAVID. *Wholeness and the Implicate Order.* London: Routledge and Kegan Paul, 1980.

Bohm's inquiry treats what he terms the »unbroken wholeness of the totality of existence as an undivided flowing movement without borders« (173). His concern for the relationship between reality and consciousness leads him to advance a new non-fragmented world view-with an emphasis on verbs rather than nouns-arguing that developments in science are away from the analysis of independent, divided, disconnected *»things«.* He advances a holographic theory of information storage suggesting that memory is distributed throughout the brain and a concept of *implicate or enfolded order«* in which »everything is enfolded into everything« contrasting with the predominate *explicate or unfolded order«* in which each thing lies »outside the regions belonging to other things« (177).

CAPRA, FRITJOF. *The Turning Point: Science, Society, and the Rising Culture.* New York: Simon and Schuster, 1982.

Capra sees a world in crisis, a crisis which finds its counterpart in the challenge to the mechanistic conception of the universe of Descartes and Newton by developments in twentieth century physics, developments centering on descriptions of the material world as composed of relationships rather than of separate objects. He argues that the value system associated with this latter world view seriously effects individual and social health and that a »turning point« for the planet as a whole is being reached-a transformation based on a holistic or ecological perspective.

GOULD, STEPHEN JAY. »Taxonomy as Politics: The Harm of False Classifications *Dissent,* XXXVII, 1, Win. 1990, 73-78.

Gould sees classifications as theories of order not given by nature which are often set up as dichotomies and can undermine basic integrities such as »nature and nurture.«

GOULD, STEPHEN JAY. *Wonderful Life: The Burgess Shale and the Nature of History.* New York: Norton, 1989.

Gould's book is an exciting exposition of the theme of contingency in the historical sciences. Here is the story of the proliferation of life forms in the Cambrian as preserved in the Burgess Shale formation, the original classification of these forms within the standard system at the beginning of this century, and their reinterpretation of some forty years later. Gould takes the occasion again to debunk evolution as the march of progress or as a cone of increasing diversity, substituting for them an image of diversification and decimation-history as unrepeatable and so unpredictable.

GRIFFIN, DAVID RAY, ed. *The Reenchantment of Science: Postmodern Proposals.* Albany: State University of New York Press, 1988.

This series of essays embraces such disparate fields as physics, cosmology, biology, ecology, medicine, religion, and parapsychology. Each in its own way is a move away from modern, mechanistic science to a postmodern organicism.

HAYLES, N. KATHERINE. *Chaos Bound: Orderly Disorder in Contemporary Literature and Science.* Ithaca: Cornell Univ. Press, 1990.

In this finely tuned analysis, Hayles draws parallels and traces analogies between contemporary developments in the sciences and in literature and critical theory arguing that both have roots in a common cultural matrix. She finds that both share an interest in the relation between the local and the global, the interpénétration of order and disorder and an acceptance that complex systems can be deterministic but unpredictable and acutely sensitive to initial conditions.

JANTSCH, ERICH, ed. *The Evolutionary Vision: Toward a Unifying Paradigm of Physical, Biological, and Sociocultural Evolution.* Boulder: Westview Press, 1981.

This collection of articles, particularly those of Haken, Allen, Prigogine and Jantsch, suggests the self-organization paradigm as a basis for a unification of the sciences. »The resulting transdisciplinary view of reality emphasizes creativity over adaptation and survival, openness over determinism, and self-transcendence over security« (v).

KITCHENER, RICHARD F., ed. *The World View of Contemporary Physics: Does It Need a New Metaphysics?* Albany. State University of New York Press, 1988.

In this collection of essays the authors do not recognize a clear demarcation between physics and metaphysics. They speculate on the necessity of replacing classical metaphysical positions (in vogue since Galileo and Newton) in the light of twentieth century advancements in physics. Central to the discussions is the Einstein-Bohr debate and holism; continuity and discontinuity; space and time; order and disorder.

NICHOLS, BILL. »The Work of Culture in the Age of Cybernetic Systems.« *Screen,* XXIX, 1, Win. 1988, 22-46.

Nichols poses an encounter between Walter Benjamin and contemporary cybernetic systems-computers and other microchip based systems which serve the »logic of capitalism, commodity exchange, control and hierarchy« (46). He suggests that the contradiction between the individual possessing free will and subjectivity and the cyborg whose role is of a cog in a machine may be surmounted by »seeing ourselves as part of a larger whole that is self-regulating and capable of long-term survival« (45).

PRIGOGINE, ILYA. »Science, Civilization and Democracy: Values, Systems, Structures and Affinities.« *Futures,* XVIII, 4, Aug. 1986, 493-507.

Both science and mankind are in an age of transition according to Prigogine. He discusses time-reversible, deterministic classical science and observes that we live in a pluralistic world of both reversible and irreversible, deterministic and stochastic phenomena. His fmding that the universe has a history which includes complexity supposes a new dialogue of man with man and of man with nature in which nature is treated as active rather than passive with science going »beyond a purely conservative approach to global problems, as is usually the case in the 'ecological', point of view« (506).

SANTOS, BOAVENTURA DE SOUSA. *Introdugco a uma ^Ciencia P6s-Moder-* naPorto: Edigões Afrontamento, 1989.

Santos paints our contemporary epoch as one of transition from the reigning paradigm of modern science to a new, postmodern one and examines the epistemological consequences.

SOBCHACK, VIVIAN. »A Theory of Everything: Meditations on Total Chaos.« *Artforum,* XXX, 2, Oct. 1990, 148-55.

This article catalogues some of the »primary themes and aesthetic features that many cultural critics see as characteristic of post-modern representation and that apply equally aptly to models of chaos theory« (153).

STENGERS, ISABELLE, dir. *D 'une science fa I 'autre: Des concepts nomades.* Paris. Le Seuil, 1987.

This collection of articles explores the construction of the meaning of such concepts as complexity, order, law and causality and correlation as they are adopted, discussed and reinvented across disciplines by working scientists.

YANG, ALICE, org. *Strange Attractors: Signs of Chaos,* exhibition catalogue. New York: The New Museum of Contemporary Art, 1989.

This stimulating catalogue consists of both reproductions from and commentary on the exhibition and an article by Laura Trippi relating »chaos science« and the arts.