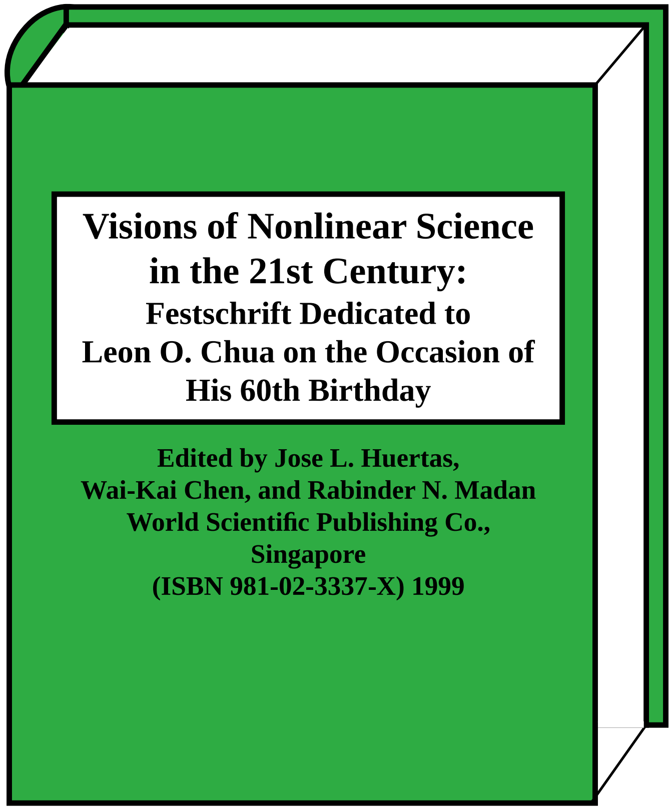


Book Review

by Guanrong Chen

Forget the idealized mathematical realm just for awhile, and take a minute to observe the natural world. See it? Isn't it quite an interesting phenomenon to find that there is almost nothing out there which is linear but is not man-made?

Linear mathematics, by which engineers usually refer to linear algebra and linear functional analysis alike, has dominated engineering and technology including the field of circuits and systems for nearly a century. This is hardly accidental: the elegant linearity has so much to offer in terms of manageable technical analysis and computation, and can always provide acceptable approximations to various types of nonlinearities. In retrospect, it would appear strange indeed that no major debate ever arose between these two seemingly opposite world views. Whether or not nonlinear mathematics and nonlinear circuits and systems theories will take the lead in the 21st century of the new millennium remains to be seen. However, what is known is that the strong demands for and rapid interest in nonlinear mathematics, nonlinear dynamics, and nonlinear circuits and systems continue to grow within the scientific and engineering communities. When this desire is heating up the atmosphere, here comes a timely new collection of overview and visionary articles written by eminent scientists (including Nobel Laureate Ilya Prigogine). It is a great pleasure to pass it along, to propel the study of nonlinear science.

This special volume collects the lectures presented in the workshop named "Visions of Nonlinear Science in the 21st Century" held in Sevilla, Spain, on July 26, 1996. The workshop was actually organized as a Distinguished Plenary Lecture Session devoted to honor Professor Leon O. Chua on the occasion of his 60th birthday, to recognize his numerous contributions to the broad field of nonlinear science.

This book has the following Table of Contents, which speaks for itself as to what it is about:

1. C. Mira: Chua's Circuit and the Qualitative Theory of Dynamical Systems, pp. 1–10
2. I. Prigogine: Nonlinear Science and the Law of Nature, pp. 11–28
3. H. Haken: Visions of Synergetics, pp. 29-68
4. L. Shilnikov: Mathematical Problems of Nonlinear Dynamics—A Tutorial, pp. 69–156
5. W. Lauterborn, T. Kurz and U. Parlitz: Experimental Nonlinear Physics, pp. 157–208

6. M. Lakshmanan: Nonlinear Physics: Integrability, Chaos and Beyond, pp. 209–282
7. A. V. Holden: Nonlinear Science—The Impact of Biology, pp. 283–332
8. R. Seydel: Nonlinear Computation, pp. 333–372
9. E. Doedel: Nonlinear Numerics, pp. 373–406
10. C. Mira: Some Historical Aspects of Nonlinear Dynamics—Possible Trends for the Future, pp. 407–456
11. C. Grebogi, Y.-C. Lai and S. Hayes: Control and Applications of Chaos, pp. 457–496
12. W. Porod: Quantum Dot Devices and Quantum-Dot Cellular Automata, pp. 495–528
13. L. O. Chua: CNN—A Paradigm for Complexity, pp. 529–837

As stated by the editors in their Forewords, and as can be sensed from the Table of Contents above, the Workshop invited "a few eminent scientists, who have made major contributions in different areas of nonlinear science and technology, to deliver a formal lecture on their visions of the great challenges and possible payoffs from nonlinear science, mathematics and technology, for the 21st century". The hope was that "the thoughtful ideas and positions to be advocated by these distinguished lectures will help to identify important but tractable research directions in nonlinear science, and to provide leadership and inspiration to future generations of researchers for solving many fundamental problems from such multidisciplinary areas as neural networks, artificial intelligence, nano–technology, nonlinear dynamics, nonlinear mathematics, self organization, complexity, artificial life, etc." The intention was profound, and the accomplishment has been inestimable.

The book is opened by a short article on introduction to Chua's circuit, to announce the theme of the Workshop and this special collective volume. Among Chua's many fundamental contributions, perhaps his circuit is one that is the most well known to our society and beyond. It is simple yet elegant and all-rounded, and is indeed a wonderland of nonlinear dynamics such as bifurcations and chaos [1], which is used also as the basic cell in a discrete Cellular Neural Network (CNN)—another great invention of Chua [2].

Forget the idealized mathematical realm just for awhile, and take a minute to observe the natural world. See it? Isn't it quite an interesting phenomenon to find that there is almost nothing out there which is linear but is not man-made?

. . . continued on Page 28

Classical science emphasized stability and equilibrium; now we see instabilities, fluctuations and evolutionary trends in a variety of areas ranging from atomic and molecular physics through fluid dynamics, chemistry and biology to large scale systems of relevance in environmental and economic science.

Book Review … continued from Page 27

The Nobel Laureate lecture follows next. The lecture starts with some inspiring statements: "In recent years a radical change of perspective has been witnessed in science following the realization that large classes of systems may exhibit abrupt transitions, a multiplicity of states, coherent structures or a seemingly erratic motion characterized by unpredictability often referred to as deterministic chaos. Classical science emphasized stability and equilibrium; now we see instabilities, fluctuations and evolutionary trends in a variety of areas ranging from atomic and molecular physics through fluid dynamics, chemistry and biology to large scale systems of relevance in environmental and economic science." This lecture points out that for well-defined dynamical systems (chaos, nonintegrable systems in the thermodynamic limit), it is now possible to formulate the basic laws of the probabilistic level. "This leads to an extension of classical and quantum theory to include time symmetry breaking. This leads to a unification of the time reversible description of dynamics and the evolutionary view of thermodynamics." It is believed that quantum chaos is "at the core of the solution of the quantum paradox".

Visions of synergetics are discussed next. The study of synergetics deals with open systems, composed of many individual parts that interact with each other to produce various forms of spatial, temporal, spatiotemporal or functional structures via self-organization. Mathematically, it requires to analyze and solve nonlinear partial stochastic equations in general, and study their solutions in neighborhoods of those points where the solutions change their dynamical behaviors qualitatively. Basic concepts of stability and instability, control parameters, order parameters, and the so-called slaving principle are important in the investigation. This article put together all these fundamentals, reaching out to some discussion on new computers and devices with brain-like functions.

Those who are interested in higher-dimensional systems with heteroclinic chaos must know the theory of Leonid Shil'nikov [3], who provides the reader with his broad view of some interesting mathematical problems in nonlinear dynamics here in the book. Emphasis is on attractors, especially hyperbolic attractors, and on features of higher-dimensional systems in the Newhouse regions. A new type of chaotic attractor, the so-called "wild" strange attractors of topological dimension three, are discussed in detail, with examples and some challenging research topics given in the article.

The book under review encompasses not only theoretical and mathematical reviews like Shil'nikov's article referred to above, but also experimental studies of nonlinear dynamics, which is included next in the text. This survey gives an account of the historical development, the current state, and some possible future directions of experimental nonlinear dynamics, with special interest in acoustics, hydrodynamics, and optics. The concept of nonlinear time series analysis is introduced. Using acoustic cavitation, basic nonlinear phenomena such as nonlinear oscillations, chaotic dynamics, and structure formation, are reviewed. The first physical device that exhibits period-doubling and chaos in experiment is described and discussed. Complexity is believed to be one of the central focuses in 21st century physics, for which new experimental methodology and technology are expected.

Nonlinear physics is further discussed by the next lecture, in which integrability and chaos as two main concepts are addressed. Essentially, highly stable and exponentially localized solutions are generally associated with integrable nonlinear systems while motions sensitive to initial conditions come with chaos. These two central issues are now opening up new vistas of real-world applications and unfolding marketable technologies: optical solutions for information processing, magnetoelectronics, controlling and synchronizing chaos for communications, and so forth. Challenges and open questions along these lines are presented and detailed.

Besides physics, what about biology? "Nonlinear science has primarily developed from applications of mathematics to physics" and yet "biological sciences are emerging as the dominant growth points of science and technology, and biological systems are characterized by being information dense, spatially extended, organized in interacting hierarchies, and rich in diversity". The impact of biology on nonlinear science is discussed in the next lecture, giving examples from intracellular, cellular, tissue, organ, and integrative physiology of individuals, under the framework of the theory of synchronous concurrent algorithms. Some new research directions in population dynamics and applications to ecosystem management are outlined.

In a sense nonlinear science is built on the contemporary high-speed com-

. . . continued on Page 30

These two central issues are now opening up new vistas of real-world applications and unfolding marketable technologies: optical solutions for information processing, magnetoelectronics, controlling and synchronizing chaos for communications …

Book Review … continued from Page 29

puters. As a return, nonlinear science brings up fruitful ideas and remarkable techniques for super computing; it also provides much better understanding of many new phenomena observed from scientific computation today. Nonlinear computation and nonlinear numerics are discussed in two lectures here in the book. It is believed that topics like bifurcations and chaos, methods such as continuation and branch switching, and features of stability and sensitivity are basic ingredients in mankind's attempt to understand the real world. In this endeavor, nonlinear computation, or "computation of something that is nonlinear", is indispensable. These issues are addressed in the first article. The basic numerical method of continuation is then applied, in the second article, to illustrate the power as well as limitation of the nonlinear numerics in dynamics analysis. Future directions in algorithmic and software development are discussed.

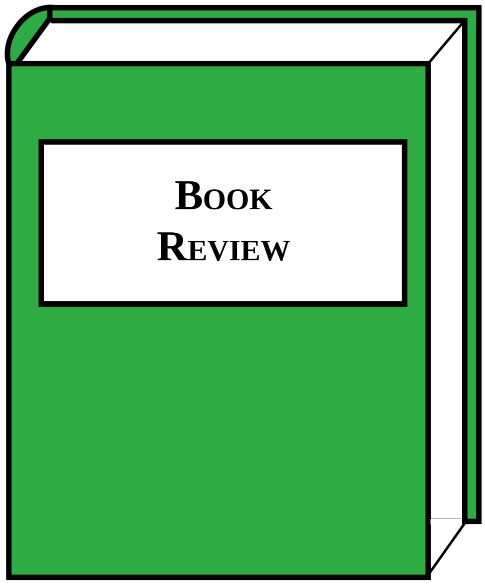
Some historical aspects of nonlinear dynamics are then presented in the following lecture, where future trends are predicted and good research topics are suggested. The review dates back to the beginning of the 20th century when Poincaré and Lyapunov started to build today's wonderland of nonlinear dynamics. It also traced back to some milestones attributed to Birkhoff, the Andronov school, and the Krylov-Bogoliubov school. The blooming of the recent dynamics studies is finally summarized in a fairly condensed format, leading readers to the valuable contemporary literature.

Two special topics of controlling chaos and nanoelectronics are discussed before the concluding chapter on Cellular Neural Networks (CNNs).

Chaos control is a new concept. Today, the question of whether or not chaos can be controlled has become history, and how to control chaos has become common knowledge within the communities of circuits and systems engineering, dynamics physics, and mathematical controls [4]. And yet, on a side note, one who is not familiar with nonlinear dynamics may wonder whether or not chaos and bifurcations are really important topics for study in the field of circuits and systems alike where the primary goals

In a sense nonlinear science is built on the contemporary high-speed computers. As a return, nonlinear science brings up fruitful ideas and remarkable techniques for super computing; it also provides much better understanding of many new phenomena observed from scientific computation today.

are stability and equilibria. Here, the word "importance" is, as usual, debatable; however, the point is that bifurcations and chaos certainly deserve a spot there today [5,6]. After about 30 years of intensive research on chaos and bifurcations, conducted mostly by dynamical analysts, it has become clear that chaos and bifurcations are not only ubiquitous in complex systems but also can be beneficial for circuits and systems engineering. The nonlinear nature of the real world, such as one's real life, have brought up a cornucopia of opportunities as well as a great deal of technological challenges to scientists and engineers—the most difficult but also the most exciting complexities in dynamics. Nonlinear circuits and systems, both theory and practice, constitute an enterprise, in which chaos, bifurcations, and fractals alike engage in interplay within a common ground of basic mathematical and physical principles. Over the last two decades, such complex dynamics have moved from being simply a curious phenomenon to one with practical value and utility. Engineers, scientists, and applied mathematicians have similarly advanced from the passive role of analyzing their behaviors to the present active role of utilizing them for real applications. Here in the book, the present lecture on control and applications of chaos discusses the issues of controlling and synchronizing chaos via feedbacks, along with application examples in secure communication and power network collapse prevention.



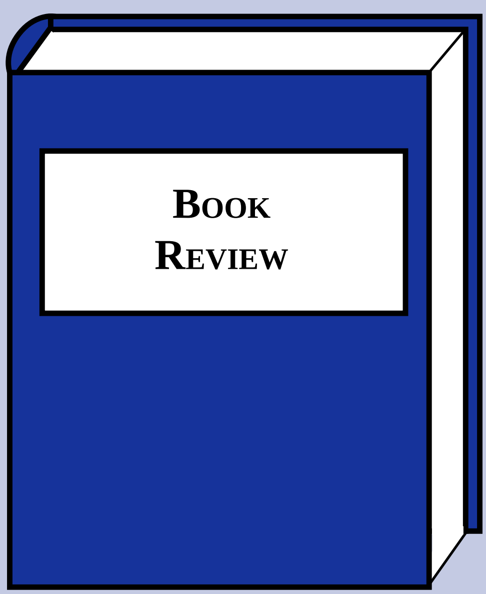
Novel nanoelectronic architecture paradigms based on cells composed of coupled quantum-dots are discussed in the second lecture within this part of the book. To date, silicon technology has been closely following a famous dictum made in 1965 by the Intel Corporation. Ever since then, the number of transistors on a chip and their performance essentially doubled every 18 months, but has been slowed recently due to some technological limitations such as the interconnect problem and power dissipation. Today, "expectations are that potential show-stoppers await conventional silicon ULSI as it approaches the nanometer regime. … However, those obstacles for silicon circuitry may present an opportunity for alternative device technologies which are designed for the nano-regime and which are interconnected in an appropriate architecture. This is the main 'vision' of this paper." Consequently, a network-theoretic descrip-

. . . continued on Page 32

Book Review … continued from Page 31

tion of Quantum-Dot Nonlinear Networks is outlined, and possible realizations of these structures in a variety of semiconductor systems, rings of tunnel junctions, and candidates for molecular implementations are discussed.

Finally it comes to the last and long lecture on CNN by Leon Chua. Standing alone, this is a three-part lecture of more than 300 pages. The first part introduces the concept and standard equation of CNN. The framework of classical cellular (Neumann) automata is generalized, and the CNN universal chip for implementation is described. The second part is devoted to the important subclass of autonomous CNNs where the cells have no inputs. This class of CNNs can exhibit a great variety of complex phenomena, including pattern formation, Turing patterns, knots, autowaves, spiral waves, scroll waves, and spatiotemporal chaos. It provides a unified platform for the study of nonlinear dynamics and complexity. The last part of the lecture introduces the concept of local activity dogma, which is a fundamental and qualitative principle for many complex phenomena and concepts such as synergetics, dissipative structures, self-organization, cooperative and competitive phenomena, far-from-thermodynamic equilibrium phenomena, and edge of chaos.



It should be pointed out that just like most traditional fields in science, mathematics, and engineering that have had many new branches bifurcated out from their main streams, the traditional area of classical circuits and systems has also seen dramatic separation, extension, and evolution in recent years. New research directions appear one after another, such as many of those topics surveyed in this book which have just reviewed above. These topics might not be familiar to most classic circuits and systems engineers trained in the 1950s or 1960s. One may have already noticed, however, that this actually is not a new phenomenon in the development of all kinds of science and technology, so should not be at all a surprise. A comment made by Nicholas Bourbaki in 1948 [7] best describes this phenomenon. His comment refers to the rapidly expanding situation occurring in mathematics, the oldest—perhaps also the most rigid—territory of scientific fields. “No mathematician, even were he to devote all his time to the task, would be able to follow all the details of this development. Many mathematicians take up quarters in a corner of the domain of mathematics, which they do not intend to leave; not only do they ignore almost completely what does not concern their special field, but they are unable to understand the language and the terminology used by colleagues who are working in a corner remote from their own."

To summarize, the book under review is a valuable and timely addition to the current literature, providing the reader with a broad overview of recent progress in the field of nonlinear science toward new research and developments in the 21st century. This visionary book is highly recommendable to anyone who wants to study nonlinear dynamics, circuits, devices, and systems. This field of nonlinear dynamics and nonlinear systems engineering, including not only the classical circuitry design and implementation but also their extension to the new platforms and new frameworks, is still very much in a rapidly-evolving phase. This is the case not only in deeper and wider theoretical aspects but also in many existing and emerging real-world applications. New results and new challenges about the subject continue to appear, leaving doors widely open for any individual who has the desire and courage to pursue further in this stimulating and promising direction of research.

> It should be pointed out that just like most traditional fields in science, mathematics, and engineering that have had many new branches bifurcated out from their main streams, the traditional area of classical circuits and systems has also seen dramatic separation, extension, and evolution in recent years.

References

[1.] R. N. Madan, Ed., *Chua's Circuit: A Paradigm for Chaos*. Singapore: World Scientific Publishing Co., 1993.

[2.] L. O. Chua, *CNN: A Paradigm for Complexity*. Singapore:World Scientific Publishing Co., 1998.

[3.] L. Shilnikov, L. O. Chua, A. Shilnikov, and D. Turaev, *Methods of Qualitative Theory in Nonlinear Dynamics*. Singapore: World Scientific Publishing Co., 1998.

[4.] G. Chen and X. Dong, *From Chaos to Order—Methodologies, Perspectives, and Applications*. Singapore: World Scientific Publishing Co., 1998.

[5.] G. Chen, "Chaos: Control and Anticontrol", *IEEE Circuits and Systems Society Newsletter*, March 1998.

[6.] G. Chen, J. L. Moila and H. O. Wang, "Bifurcations: Control and Anticontrol", *IEEE Circuits and Systems Society Newsletter*, June/July 1999.

[7.] N. Bourbaki, "Les Grands Courants de la Pensée Mathématique", F. Le Lionnais, Ed., Cahiers du Sud, 1948 (English translation, by A. Dresden).