Extended Book Review

A review of *Complex Systems: Chaos and Beyond, A Constructive Approach with Applications in Life Sciences*, by Kunihiko Kaneko and Ichiro Tsuda, 2000. Berlin: Springer, 273pp. ISBN 3540672028. $113.00 USD.

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Complex Systems: Chaos and Beyond is co-authored by scientist Kunihiko Kaneko and mathematician Ichiro Tsuda. It is a book about "the study of complex systems, based on, but beyond, chaos" (p. v). The authors develop notions about types and features of chaos and applications to biological systems are highlighted. Because "complex systems are such that we must postulate concepts beyond chaos," (p. vii) the authors develop novel concepts to study complex systems by making a transition from focusing on physical systems towards a focus on biological systems. Key concepts developed in the book include coupled chaos, chaotic itinerancy, descriptive instability, hidden coherence, and hierarchical clustering. Drawing from hermeneutics, the authors also develop a methodological stance: an observation process for studying complex systems. Their methodology couples theory with experiment and involves constructing basic systems, which they identify as a *constructive approach*. The author's posit that both complexity science and the complexity-informed research stance they develop in the book are central for understanding human, body, and environmental systems.

In the table of contents, section titles point to specific organic, evolutionary, and geographic notions. I focus my extended review on whether this book delivers what it promises. Specifically, I look at the novel methodology used, distinctions made, and applications offered. I also pay particular attention to the notion of coupling chaotic systems as a common characteristic among complex phenomena.

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Models, Representations, and Theories

The approach taken in the book involves a unique method that watches, composes, and theorizes. This constructive process is framed by dynamical systems theory. The authors experiment with the most universal dynamics that help in understanding classes, rather than individual cases of chaotic phenomena. They highlight the similarities between their models and reality. From the differences, novel notions are sought to explain phenomena that do not fit.

Examples of models given in the book include coupled map lattices (CMLs) and globally coupled maps (GCMs). CMLs are dynamical systems just like partial differential equations. They model systems with discrete time and space but with continuous states. This makes CMLs mostly applicable to physical systems such as crystal growth and cloud dynamics, and to biological systems with lower dimensional chaos such as the immune system. They cannot model networked systems that have local complex dynamics and global mean-field dynamics—high dimensional chaos. The authors had to extend the CML model to study systems that interact globally, rather than only locally with neighbouring agents without receiving global feedback. They develop the globally coupled map model (GCM) and suggest that GCMs are relevant to evolution and ecology. I find the application of GCMs to neuro-, cardiac and cognitive chaos particularly interesting. I will say more about GCMs later in the essay.

The authors offer both computational and visual aspects of the models. The visual representations used are based on conventional attractor dynamics, which describe more probable states of a system as basins of varied volume and depth in a rugged landscape. Kaneko and TsudaKaneoK find the attractor concept to be limited. They extend it to study higher dimensional chaotic behaviours that exhibit complex and non-stationary behaviours. They develop a novel notion of chaotic itinerancy (CI), which captures transitory dynamics that may take place in a short time frame. The concepts of CI and GCMs extend imagination about chaotic systems. Before I look at these novel ideas in more depth, let me provide a broad outline of the book.

Metaphorical or Scientific Frameworks

Chapters 1 and 2 offer a general overview. Chapter 3 focuses on CMLs. Chapter 4 is about GCMs. Biological chaos is the focus of chapter 5. Chapter 6 specifically focuses on both the structure and function of neurochaos. Chapter 7 is unique. It is a review of the book organized in series of question and answer sessions with the series editors.

A reader who wishes to review complexity science from the viewpoint of chaos will find the first two chapters intriguing. The models developed in

the two middle chapters offer a detailed outlook at chaos from the viewpoint of statistics, mathematics, physics, and chemistry. To justify the high level of abstraction involved in the review and model chapters, the authors claim the more abstract the models, the higher the power of the model in predicting universal classes of chaos. Even a reader with a background in biomathematics, is likely to occasionally get lost in the technical detail of the discussions highlighted in the first four chapters. To encourage the reader to persevere, the authors intermittently, in a way that almost gets repetitive, promise concrete and biological discussions in latter chapters.

A reader whose interest is to adopt new language and metaphors from complexity science for use in human and social science research will be relieved to finally find, in the last three chapters (chs. 5, 6, and 7), discussions and examples relevant to brain science, health care, and cognitive studies. The authors are aware of the fact that not every part of their book will be of interest to the reader. In the preface, they direct different kinds of readers to chapters that might be decipherable to them. A reader who is not seeking scientific and engineering applications of chaos is encouraged to skip chapters 2 and 3. Unfortunately, to find, for example, chapter 6 interesting one needs to have read the relevant parts in the preceding chapters.

Overall, I found the book different from many books written by adherents of complexity science, such as Steven Johnson, in that readers of these books may include non-scientific readers. The book is also different from books written by complexity scientists such as Humberto Maturana who, in addition to elaborating complexity science frameworks, devote a great part of their writing to philosophical and humanistic implications of their theories. Kaneko and Tsuda's approach is also different from that of many complexity scientists who research a specific field, such as Walter Freeman, who researches the neuroscience of animal olfactory perception. In sum, this book is more like a textbook and it is an English translation of the original 1996 publication in Japanese. I wonder whether the specific challenges of finding one's way into this book are due to the fact that the authors themselves, in the absence of a good translator, translated the English version. Perhaps more problematically, Kaneko and Tsuda wrote the book at a time when they were on a new journey to studying complexity science as a broader area under which chaos is nested. This turn to biology-oriented chaotic systems is evident in the writing. Chapters and examples about biological and social systems not only appear late in the book, but they read more like developing ideas, speculations, or updated content. In some paragraphs, where unfamiliar scientific explanations are not clear, a reader may be left to wonder whether the lack of clarity is due to translation or to transitional issues. Perhaps, the incomprehensible nature of some sections is simply a by-product of the difficulty of studying chaos.

Definitions and Distinctions

The authors show that chaos is not a newly understood phenomenon: evidence of its discovery and study can be found in ancient mythical literature. They highlight examples from Asian classics, which allude to features of chaos such as its incomprehensibility. Interestingly, Kaneko and Tsuda propose that storytelling is a methodology which humans have adapted to understand complex phenomena. The authors' interest in hermeneutics is brought into play in many sections of the book. The brain is an internal observer of the world in which it participates, the authors explain. Therefore the brain is obliged to interpret the world. At another level of analysis studies of the brain—and of the world—are interpretive. They argue that an example of hermeneutic phenomenology notions adopted in the book is an essential and universal feature of phenomena. A section in Chapter 6 specifically addresses the hermeneutics of the brain and scientific hermeneutics.

On the question of how studies of chaotic systems fit with the study of complex systems, the authors study higher dimensional chaos in order to understand complex systems. Kaneko and Tsuda define chaos and other complex science terms from a computationalist point of view. I find their definition for emergent properties as not built-in characteristics that emerge beyond what was initially programmed interesting. The authors challenge common dichotomies such as top-down/bottom-up, universality/uniqueness, and stability/diversity. In some cases, such as in their methodology that involves the triad of theory, experiment, and application, they see trichotomies as superior to dichotomies. In my view, moving beyond dichotomies to trichotomies may not be a radical proposal. Complexity researchers can escape many limiting distinctions. When the authors introduce complexivist notions such as coupled chaos the discussion is more fruitful. For instance, for the top-down vs. bottom-up duality, they explain that an emergent property is not simply a bottom-up case. There might be feedback or instruction from the emergent top to the generating bottom. Also, it might not be possible to draw a sharp boundary between bottom and top levels for chaotic systems: a small difference at the micro generating bottom level is amplified at the macro emergent top level.

The authors make a useful distinction between low-dimensional and high-dimensional chaos. The models and notions they develop may be delimited to a given class of chaos. For instance, CMLs, as is the case with partial differential equations and cellular automatons, are applicable to low-dimensional chaos, whereas GCMs are applicable to high-dimensional chaos. Also, they classify chaos according to whether it is spatial, temporal, or spatiotemporal chaos. Distinctions such as chaotic/not-chaotic are

rendered questionable by the nature of human observation itself. Systems that behave chaotically without observation may demonstrate ordered behaviour with observation. The authors refer to this phenomenon as *descriptive instability* and posit the brain may be such a system. Furthermore, the dynamics of the observation process may be inseparable from the dynamics of the system itself. To observe is to couple two systems: the observer and the observed. The observer and the observed become a larger system which embeds the observation process. In my view, this take on observation as an operation that couples systems is central to understanding complex systems. It is akin to theories of distinctions and observation as I study them (Namukasa, 2005).

Global Coupling

With their globally coupled map (GCM) model, Kaneko and Tsuda study chaos among collective and networked systems such as ecological and bodily systems. With respect to ecology, they seek to answer questions about how stability and diversity are correlated, how vital points form around species that might appear unimportant in ecosystems, and how diversification and differentiation happen in evolution. For the body, they seek to understand how interactions work in the cells of the immune system. They explore the structure and the functions of the brain to answer questions about the nature of many-to-many correspondences of neurons. In this section of the book review, I look at how the GCM model is applied to cognitive studies. This aspect appears immediately relevant to human and social scientists.

Chaotic systems might be individual systems or they might be what Maturana (1988) refers to as composite systems that are made up of multiple individual elements, themselves systems. The authors use *coupled systems* to refer to such composite systems. Two or more chaotic systems may interact to form a global, coupled chaotic system. A coupled chaotic system might also be constituted by non-chaotic systems. The authors explain that coupling chaotic systems might lead to synchronization to form a non-chaotic, or partially synchronized, global system. Moreover, a non-chaotic, coherent coupled system may temporarily drift into a chaotic system. Put differently, it is not only with the help of the observer that a system could become chaotic or non-chaotic; but it is also with the help of time—when a system is coupled with time. In globally coupled systems, such as in an economic system, ecological system, or a social system, there are two dynamics: the local agent-chaotic dynamics, and the global mean-field dynamics.

During the coupling process, local chaos, say the dynamics of each species, interacts with global feedback, the dynamics of the whole ecology.

Two or more local systems that are coupled synchronize or desynchronize depending on the relative strength of local chaos and global coupling. When global coupling is large and local chaos is weak, synchronization happens. Thus, the collective dynamics of coupled systems ranges from a completely ordered, synchronized state with one cluster (one attractor) via a partially ordered state with many clusters whose waves are synchronized, to a completely disorganized state with no clusters. A coupled system may shift through all these states in a short time. The authors refer to the transitory dynamic, represented by a drift through varied degrees of synchronization, as *chaotic itinerancy*. In such a case the attractors are non-stationary. The authors refer to such attractors, which do not fit the classical definition of attractors, as *attractor ruins*. Like classical attractors, attractor ruins can be approached and inhabited by the system. In education, when classical attractors that may not be exited are used to understand human behaviour a deterministic picture is painted: Change is triggered by catastrophic forces or happens after a long time. The difference with attractor ruins is that after some time these attractors can be, due to chaotic instabilities, exited for another attractor or to higher dimensional chaos.

Local structures within a collective, coupled system, and at a time when it is coherent, have a few degrees of freedom, while those within a disorganized system have high degrees of freedom; they are not *slaved*, or determined by synchrony. A common visual of coupled chaotic systems is one shown in cardiac monitors of patients where the itinerancy among waves of cardiac chaos may indicate gradation of health. Complete synchrony, which is characterized by zero degrees of freedom, is not usually a desirable state! Another clinical application of this concept involves epileptic seizures.

Applications, Examples, and Relevance

The section on coupled chaos raises central questions: Do chaotic activities such as synchrony, coincidence, and correlation, whether spatial or temporal, mark a global dynamic as well as a functional connection? This appears to be the way it is widely taken in studies of brain functions, but is it the same for the study of human collectives and other coupled systems? The role of spatial patterns and synchronization of brain electromagnetic activities in understanding not only the structure, but also the functions of the brain is a common idea. Freeman and associates (Freeman 1991) studied chaotic neuronal activities in the olfactory bulb to understand odour perception.

Kaneko and Tsuda in an interesting manner elaborate on the practical implications of the form, geometry, and topology of coupled chaos. Their study of coupled chaos in bodily systems is novel. A more recent development of Kaneko and Tsuda's work is that they also look *outside* the

brain. They examine the collective chaotic activity of the heart rhythm, the respiration cycle, and the hormonal cycle. This look at collective bodily chaos is significant, but even more interesting is the way they study this coupled chaos by using surface and peripheral recordings of finger blood pressure. Here experimental data of cardiac and capillary attractors obtained from electrocardiograms of various subjects' fingers is studied. In the book, graphs illustrate unique capillary chaos of a premature baby in an incubator as compared to the same baby just out of the incubator, of a patient with a slight migraine when he or she performs tasks of varied cognitive difficulty, of normal subjects as compared to psychiatric patients, of neurotic patients before, under, and after treatment; and of patients with senile dementia as compared to patients with schizophrenia. With this data, the authors ask a range of both philosophical and scientific questions.

Geometrical features of the attractors for peripheral capillary chaos may indicate degrees of mental and physical health. Drawing from hermeneutics, the authors allude to how these unique images of chaos may be used not only in care and cure, but also in learning. They further speculate that changes in features of chaos, in addition to being state indicators, might be braided into the cure or learning process itself. The aim of the use of such data is to accelerate progress. For instance, visual mental health indicators might have applications beyond being used by nurses who care for neurotic patients. These indicators, represented diagrammatically as attractors—topological shapes with specific geometrical features—could be helpful in self-care and self-cure. The visual representations, given that they are unique and can show progress, are likely to extend patients' imagination as well as offer them *more* agency in their own healing process. The possibility of looping observed data back into the healing or learning process is based on assumptions about consciousness: What is it, and does it have agency? How does it relate to the organism and the organism's brain and bodily dynamics?

Causal, Efficient Agency of Data

Kaneko and Tsuda, in a manner similar to Varela (1999), circumvent the complex discussion around discovering the neural signatures of consciousness, whether this be in the form of spatial or temporal synchrony, or even in a dynamic, transient brain *module*. Instead, they focus on how coupled chaotic activities in the brain and body can play functional roles, preserving the agency on the global scale involved in consciousness, perception, and cognition. For Valera, there is a complementary relation between upward (local, generating, or microscopic) chaos and downward (coupled, emergent, or macroscopic) chaos. Upward causation is what complexity researchers have come to commonly refer to as *emergence*.

Consciousness is now widely believed to emerge upward from the coupled activities of brain, body, and world. The agency of the coupled local systems, the neurological and physiological systems, gives rise to the global psychological system. What remains to be highlighted is how an emergent, global whole such as consciousness can have "causal, efficient agency on the very substrate giving rise to it" (Varela, 1999, p. 100).

Varela (1999) illustrates how the person who was studied clinically during epileptic seizures could, during perception activities, voluntarily affect the electrical condition of his brain. This person, suffering from "a partial drug-resistant temporal epilepsy" (p. 101), participated in simple cognitive testing while electrodes were implanted in part of his brain. Varela used this case study to answer the question of whether global, cognitive tasks could have an effective capacity that manifested as downward causation on local, epileptic zones. Could there be a reverse generative relation, when a person acted cognitively and consciously, that could modify the local neuronal activity? Varela observed positive evidence. The act of perception—the cognitive state, which the patient was engaging in during the experiment, contributed to modulating the epileptic activities towards particular unstable orbits. Varela referred to this as downward causation.

Like Varela, Kaneko and Tsuda claim that consciousness and cognitive activities do indeed offer dynamical constraints to neuronal and physical activities. This research is promising for educators. There could be a way by which less motivated and slow learners could, by becoming observers of their physiological and neurological activities, intentionally accelerate their learning. At the very least there will soon be a way of investigating and monitoring the learning process clinically in neural laboratories. The idea of having learners accelerate their learning by becoming second order observers of their learning has been understood as a form of meta-cognition. This time around, with data from scientific laboratories, it involves distinct images of what happens (at a slow time scale) inside the body during learning or not learning. This is not without a cost.

Layers of electronic machines required in these experiments aside, the collected recordings and time series appear to be without patterns. To make sense of and pattern the data, electronic, statistical, and stochastic representations are used. The variables measured and the methods used, such as Lyapunov exponents, are very esoteric. Graphs ascend from time series to phase-space diagram, log-log plots, and the like. At many times three or higher dimensional graphing is used. What is measured varies from amplitude, frequency, and phases to attributes derived from these. Then there are issues about time scales and at what level of abstraction to analyze the collected data. It gets as technical, recursive, interpretive, and inter-objective as it can get.

In the raw data, the differences that make a difference are hidden by what appears to be noise or random activity. Tsuda and Kaneko observe that at many times when collective dynamics appear desynchronized and irregular there might be *hidden coherence*. The firing of neurons may appear irregular and disorganized, but there is, as evidenced by temporal variations in EEG measurements, coherent irregularity instead of deterministic chaos. In Varela's (1999) case study, the effect of cognitive activity on the epileptic zones appeared as added noise, but what appeared random hid "a finer dynamic pattern," a structure where the downward causation manifested itself (p. 101). For Freeman (1991), chaotic activity where synchronization is absent often has some underlying order. When Tsuda and Kaneko take high dimensional projections of the time series the data takes form. Electronic representations depict strange geometrical attractors with distinct shapes and size. It is at this level of observation, the level of the geometry, not statistics, of dynamical behaviour, that there are possibilities of meaningful data for both the practitioner and the subject.

To discover the implications of this strand of research for cognitive therapy requires further experimental, theoretical, and constructive study. Whether these technologies and methods will be used carefully and ethically once they are fully developed is an issue that the authors do not address. Technologies that expand what is consciously possible raise deeper philosophical and ethical issues.

Other Cognitive Applications

This book highlights other relevance of the study of chaos to understanding cognition. Many chaotic notions that are depicted in learning, memory, pattern recognition, and concept categorization are developed. These include *hierarchical dynamics* among clusters or attractors, *slaving principle* by stronger and faster global constraints, and low level *chaotic revolt* against global dynamics. The authors see clustering and hierarchical dynamics as a possible source of diversity and complexity among evolutional and developmental courses. When the slaving principle is considered together with mutual feedback and chaotic revolt, these have relevance for studying collective and emergent systems such as the mind, culture, and institutions.

For educators who are interested not only in the interaction but also in the mutual constraint and perturbation among the physical and the mental, and the collective and the individual, the dynamics of slaving and revolt, which are determined also by time scale, appear central. Does the classroom collective have a faster time scale than that of individual students? When is strong feedback from the classroom collective to individual students more desirable?

In summary, Kaneko and Tsuda introduce many novel and rich concepts. Readers who are not familiar with chaos theory may find this book helpful in outlining and applying these concepts. A reader who is a novice at systems theory may wish to read this book in conjunction with recent articles published by the authors (see for example Kaneko and Tsuda, 2003). Ultimately, the book finds its stride when it finally elaborates examples from biological and ecological systems. When it does so, it reads like a book written for ardent complexity researchers. Overall, the work of Kaneko and Tsuda deepens the understanding of physical and organic systems that do not fit conventional dynamical system theories. Because the authors explore complex and transitory dynamics that are common among higher dimensional chaotic phenomena, the book is about complex systems.

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