BEHAVIORAL AND BRAIN SCIENCES (2004) **27,** 585–602
Printed in the United States of America

Continuing Commentary

Commentary on **Ichiro Tsuda (2001). Toward an interpretation of dynamic neural activity in terms of chaotic dynamical systems. BBS 24(5):793–810.**

Abstract of the original article: Using the concepts of chaotic dynamical systems, we present an interpretation of dynamic neural activity found in cortical and subcortical areas. The discovery of *chaotic itinerancy* in high-dimensional dynamical systems with and without a noise term has motivated a new interpretation of this dynamic neural activity, cast in terms of the high-dimensional transitory dynamics among "exotic" attractors. This interpretation is quite different from the conventional one, cast in terms of simple behavior on low-dimensional attractors. Skarda and Freeman (1987) presented evidence in support of the conclusion that animals cannot memorize odor without chaotic activity of neuron populations. Following their work, we study the role of chaotic dynamics in biological information processing, perception, and memory. We propose a new coding scheme of information in chaos-driven contracting systems we refer to as *Cantor coding.* Since these systems are found in the hippocampal formation and also in the olfactory system, the proposed coding scheme should be of biological significance. Based on these intensive studies, a hypothesis regarding the formation of episodic memory is given.

Complexity is a cue to the mind

George Kampis
Department of History and Philosophy of Science, Eötvös University (ELTE), Budapest, Hungary. **kampis@axelero.hu** **http://hps.elte.hu/~gk/**

Abstract: The relevance of chaotic itinerancy and other types of exotic dynamical behavior described by Tsuda (2001) certainly goes beyond the scope of his target article. These concepts of dynamics may offer a general framework for the understanding of complexity, which could help to restructure the analysis and conceptualization of mental states in novel ways, providing insights for the philosophy of mind.

Most philosophical treatments of the classical concepts of cognition (such as volition, consciousness, intentionality, mental content, rationality) seem to be trapped in an unsafe argument that, by and large, goes like this: There are two opposing alternatives, naturalism and anti-naturalism, both with unwanted consequences. It is generally accepted that to be a naturalist is to be a physicalist and/or functionalist and to believe in the computational mind and/or physical (computational) brain. To be a anti-naturalist is (as Dennett [1995] so aptly puts it in a somewhat different context) to play tennis with the net down. If one is a anti-naturalist, then one is free from the restrictions of science, and it is easy to justify any concept, from intrinsic intentionality to wonder tissue to qualia, without having to worry how these fit into a description of the universe as a whole. There are other points of view existing somewhere between these two extremes, such as double-aspect theories, where the physical and mental aspects of material are considered distinct, but the manner in which they are distinguished is not addressed. However, this again internalizes the naturalist/anti-naturalist dichotomy. So where do we stand? Currently, few people are completely comfortable with naturalism-cum-physicalism in a strict form; functionalism is on the defense; accepting the small wonders offered by anti-naturalism is not the approach of choice. Are there other options? Maybe there are.

The above argument goes too fast. Several hidden assumptions underlie it, which together implicitly ensure a harmony of naturalism and reductionism (or eliminativism), or a unity of naturalism and computationalism. At least two of the assumptions are easy to identify. The first is that the mind is confined to a single level of phenomena (therefore, all mental events can be treated within a single explanatory scheme). The second is that mental states are homogeneous (therefore, they are all similar, constituting a natural kind).

One kind of thing makes up the mind, and one functional theory explains how it works: cognitive science has traditionally held this. However, Ryle (1949), perhaps Haugeland (1995), and more recently van Gelder (1998) laid the groundwork for a fundamental challenge to the concept of a homogeneous mind. Their concern is with the difference between mind and cognition, but their idea that the mind is somehow not one thing is far more general. Van Gelder made a significant move when he combined this philosophical idea of ontological heterogeneity with low-level functional models to form what is known as the "dynamical hypothesis" in cognition (Port 2001). This allowed for a new kind of continuation through which the other pillar of the traditionally posited unity of the mind, that of a single functional scheme, might also be discredited.

This is the point where dynamical systems of the kind studied by Tsuda enter. We can view the dynamical hypothesis as a step in a progression towards a greater flexibility of the mind: the progression begins with the rigid symbolic systems of "classical" (Fodor-style) cognitivism, and continues through connectionism to dynamical systems, and possibly beyond.

Previous attempts to use dynamical systems as models of cognition have been unsuccessful. Ten or fifteen years ago the study of complex systems consisted of only chaos, bifurcation, and self-organization – phenomena that have a technical meaning in hydrodynamics, basic-level brain theory, and the like, but apparently are not appropriate in the description of higher cognition. They are hopelessly far from anything in which the philosopher or psychologist is interested. How can we elucidate mental content, for instance? Early-day cybernetics, based on simple dynamical systems, had nothing to offer in this regard, which is one reason that cybernetics has been ignored in cognitive science. Chaos, although representing a richer class of phenomena, is no different on this score. It appears to possess physiological relevance for the brain (see Freeman 1991, which is now a classic), but it is difficult

© 2005 Cambridge University Press 0140-525X/04 $12.50
https://doi.org/10.1017/S0140525X04210135 Published online by Cambridge University Press

to see what could be gained by assuming that mental computations are chaotic, for computations are just computations. Also, chaos is, by itself, uninteresting: in a chaotic system, most things happen on the attractor, where long-term behavior always remains qualitatively the same.

Chaotic itinerancy (CI), however, is fundamentally different, and I believe it may change our thinking about what can be achieved by dynamical systems and minds. CI is a chameleon. It can behave like one particular type of system for some time, then make a transition and behave like some other particular system, and so on, indefinitely. Although generated by a single set of equations, at a phenomenological level the process does not seem to follow any fixed rules. Yet it can be controlled, or at least this is a feasible expectation. For this reason, CI may be an ideal tool for the understanding of mental processes that form and break their own rules. Part of this anticipated development is already visible in Tsuda's memory model.

The problem of conceptualizing complexity is another matter. Complex dynamical systems of the type studied by Tsuda and some other authors, including Kaneko (1998; see also Kaneko & Tsuda 2001), realize a wide spectrum of behaviors. This has far-ranging philosophical implications. Putnam (1988) may be right, after all, in his claim that every natural system can behave like any other. With Tsuda's work we start to understand that for a complex system every model can be justified. What is more, perhaps every physical system is capable of exhibiting chaotic itinerancies and other similarly rich processes. If this is true, every physical system may literally be able to realize every computational behavior. Opponents of Putnam's idea (such as Chalmers 1996) tend to assume that a system is basically something perfectly well-defined and, therefore, that the construction of a single system capable of behaving like many different systems must be seen as a dirty trick. CIs can realize such a situation quite naturally. This is a further example where the benefits of an advanced analysis made possible by the new paradigm of complex systems becomes apparent.

ACKNOWLEDGMENTS

The author thanks the Fujitsu Company and Professor Susumu Kunifuji for support that made possible the preparation of this commentary.

Author's Response

Chaotic itinerancy is a key to mental diversity

Ichiro Tsuda

Department of Mathematics, Hokkaido University, Sapporo 060-0810, Japan.
tsuda@math.sci.hokudai.ac.jp
http://www.math.sci.hokudai.ac.jp/~tsuda/

Abstract: Kampis proposes the study of chaotic itinerancy, pointing out its significance in domains of cognitive science and philosophy. He has discovered in the concept of chaotic itinerancy the possibility for a new dynamical approach that elucidates mental states with a physical basis. This approach may therefore provide the means to go beyond the connectionist approach. In accordance with his theory, I here highlight three issues regarding chaotic itinerancy: transitory dynamics, diversity, and self-modifying system.

The main characteristics of chaotic itinerancy (CI) are summarized as follows (Kaneko & Tsuda 2001; 2003; Tsuda 2001), although not all characteristics are necessarily required:

1. There appears a relatively large number of modes possessing neutral stability, as well as definite stable and unstable modes.
2. There appears a highly ordered but irregular temporal structure, and hence the appearance of history-dependent transitions.
3. Chaotic itinerancy differs from simply chaotic behavior in the sense that these transitions can be characterized as transitory dynamics through which the system moves between low-dimensional attractor ruins and high-dimensional chaotic states.
4. The statistical convergence of physical quantities is absent or extremely weak.
5. The system does not possess tracing properties.

There is a mathematical basis for each of the above-stated characteristics. In a system that possesses the pseudo-orbit tracing property, it is guaranteed that its mathematical trajectories can be correctly traced in numerical simulations. Typical chaotic systems possess this property, but some chaotic systems do not. In such systems, it is not possible to properly trace each trajectory in simulations. This lack of the pseudo-orbit tracing property leads to another instability, which differs from the orbital instability that chaotic systems inherently possess – that is, instability with regard to computation, description, and/or observation. Therefore, contrary to the picture presented by **Kampis**, a factor for renewing a system itself exists even in conventional chaos, in principle. However, as Kampis correctly points out, this property is not enough to realize an actual renewal process. Even if such a property does not exist, it is possible to obtain precise statistical properties, which reflect the properties of an attractor as a whole. Actually, this attractor-tracing property exists even in conventional chaos. On the other hand, the statistical properties of chaotic itinerancy do not necessarily provide information about the overall attractor (Sauer 2000; 2003; Tsuda & Umemura 2003). Chaotic itinerancy therefore appears to be a new type of dynamic behavior that goes beyond the attractor concept. It is thus seen that chaotic itinerancy can be considered a form of transitory dynamics that might appear to be "non-stationary" in short-time observations.

In dynamical systems exhibiting chaotic itinerancy, there come to exist transition rules between attractor ruins. The nature of these rules is determined by chaotic itinerancy itself. The dynamical orbit is attracted to the ruins, and in this situation the number of effective degrees of freedom remains relatively small. Therefore, the system can be described with only a few modes. While the system remains in such a space, other modes become activated. As a result, the system can no longer be confined in such a space. Because there are restricted regions that can act as exits, there are a number of selected orbits that can leave (Kaneko 1998). When an orbit leaves this space, the number of effective degrees of freedom increases, and there results a large diversity of states. After some time, the orbit is attracted to another ruin, where a different set of effective modes describe the system. In such a way, such dynamical systems exhibit history-dependent activity.

In the study of dynamical behavior in a neural network model with nearest-neighbor couplings, we recently identified a mechanism involved in chaotic transitions between synchronized and de-synchronized states (Tsuda et al. 2004). Such transitions have been observed in animal and human brains (Freeman 2004; Gray et al. 1992; Lampl et

https://doi.org/10.1017/S0140525X04210135 Published online by Cambridge University Press