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/S0140525X04220131 Published online by Cambridge University Press

al. 1999). This behavior appears to consist of chaotic itinerancy between attractor ruins representing synchronization and de-synchronization states. It also appears that this behavior can be regarded as chaotic itinerancy between attractor ruins (which may be described by Milnor attractors), each consisting of a set of an all-synchronization state, different kinds of metachronal waves, and small chaotic orbits linking these states. Furthermore, such chaotic itinerancy accompanies the organization and reorganization of dynamic cell assemblies. There are several examples that are believed to provide a link between physical behavior and the representation of mental states using chaotic itinerancy. These examples include dynamic memory (Tsuda 1991; 1992; Tsuda et al. 1987), episodic memory formation (Tsuda & Kuroda 2001), and category formation (Tsuda 2001). The use of chaotic itinerancy to study category formation might elucidate a typical feature of diversity expressed by chaotic itinerancy, as described by **Kampis**.

Category formation can be characterized by the following two kinds of ambivalence. We call the first kind identification and discrimination ambivalence. In this case, "similar" patterns, objects, and concepts must be classified in accordance with their similarity as belonging to the same group. Here, similarity can be represented by a certain metric. Yet, it must be possible to discriminate even similar patterns, objects, and concepts. The second kind, which we call invariance and variance ambivalence, appears especially in relation to learning over periods of time that are longer than those expected in the case of the first ambivalence. For stability of cognition, the invariance of categories is required, but to allow the learning process – a variance of classification, that is – a change of categories is necessary.

Our assertion is that chaotic itinerancy can represent the types of ambivalence described above, in principle. In typical chaotic itinerancy, the attractor ruins linked by chaotic transitory orbits do not necessarily constitute all the ruins because of the dependence of statistical properties on the initial conditions. Some particular orbit linking several attractor ruins may form the largest category of series of events – an episode – with each attractor ruin representing a distinct event. This largest category consists of several sub-episodes, some of which are "similar" and some of which are different. Actually, we found such category formation in a Cantor code with chaotic itinerancy as inputs (Tsuda 2001; Tsuda & Kuroda 2001). This is possible because chaotic itinerancy contains history-dependent information of a series of events (Kaneko 1998). This scheme of coding guarantees both identification and discrimination.

From the above-described findings, it can be seen that chaotic itinerancy may be a key type of dynamic motion capable of describing ever-changing behavior with stability, which all evolving systems should exhibit. This is nothing but an evolutionary system that **Kampis** describes as a self-modifying system (Kampis 1991). In contrast to the conventional concept of a system, according to which a system consists of well-defined units with each unit assumed to possess a definite function, we consider a self-modifying system to be a life system, in which a functional unit is formed via interactions between internal states of the system. Such a system is precisely that which we have considered a "complex system" (Kaneko & Tsuda 2001).

There is sufficient evidence supporting such a specific structure of complex systems. Among others, cell differentiation and the organization of functional modules in the brain are typical examples. Every functional module in the brain, like the visual cortex, is connected to other modules in its living state, not only structurally but also functionally. In other words, functional modules are not ready-made but, rather, order-made. They are formed almost simultaneously when a total system becomes functional. This type of formation brings about a difference between the responses of organized units in the cases where these units are isolated and are embedded in the system. Furthermore, such functional modules can vary in structure and function. A similar concept was proposed as the concept of components (Rosen 1991) and as a dynamic cell assembly (Fujii et al. 1996; von der Marlsburg 1981).

These are characteristics of ever-changing systems, which are typically described by chaotic itinerancy and may well be related to the flexible change of mental states.

ACKNOWLEDGMENT

This work is partially supported by Grant-in-Aid for formation of COE in Mathematics.

References

The letter "r" before author's initials stands for Author's Response to CC references

Chalmers, D. (1996) Does a rock implement every finite automaton? *Synthese* 108:309–33. Available at: http://www.u.arizona.edu/~chalmers/papers/rock.html. [GK]

Dennett, D. C. (1995) *Darwin's dangerous idea.* Simon and Schuster. [GK]

Freeman, W. J. (1991) The physiology of perception. *Scientific American* 264:78–85. Available at: http://sulcus.berkeley.edu/FreemanWWW/manuscripts/IE1/91.html. [GK]

(2004) Origin, structure, and role of background EEG activity: Part 1, Analytic amplitude; Part 2, Analytic phase. *Clinical Neurophysiology* 115:2089–107. [rIT]

Fujii, H., Ito, H., Aihara, K., Ichinose, N. & Tsukada, M. (1996) Dynamical cell assembly hypothesis – Theoretical possibility of spatio-temporal coding in the cortex. *Neural Networks* 9:1303–50. [rIT]

Gray, C., Engel, A. K., Koenig, P. & Singer, W. (1992) Synchronization of oscillatory neuronal responses in cat striate cortex: Temporal properties. *Visual Neuroscience* 8:337–47. [rIT]

Haugeland, J. (1995) Mind embodied and embedded. *Acta Philosophica Fennica* 58:233–67. [GK]

Kampis, G. (1991) Self-modifying systems in biology and cognitive science. Pergamon Press. [rIT]

Kaneko, K. (1998) On the strength of attractors in a high-dimensional system: Milnor attractor network, robust global attraction, and noise-induced selection. *Physica D* 124:308–30. [GK, rIT]

Kaneko, K. & Tsuda, I. (2001) *Complex systems: Chaos and beyond – A constructive approach with applications in life sciences.* Springer. [GK, rIT]

Kaneko, K. & Tsuda, I., eds. (2003) Focus issue: Chaotic itinerancy. *Chaos* 13:926–1164. [rIT]

Lampl, I., Reichova, I. & Ferster, D. (1999) Synchronous membrane potential fluctuations in neurons of the cat visual cortex. *Neuron* 22:361–74. [rIT]

Port, R. F. (2001) Dynamical systems hypothesis in cognitive science. In: *Encyclopedia of cognitive science,* ed. Amy Lockyer. MacMillan. Available at: http://www.cs.indiana.edu/hyplan/port/pap/dynamic.cognition.sglspc.htm. [GK]

Putnam, H. (1988) *Representation and reality.* MIT Press. [GK]

Rosen, R. (1991) *Life itself: A comprehensive inquiry into the nature, origin, and fabrication of life.* Columbia University Press. [rIT]

Ryle, G. (1949) *The concept of mind.* Hutchinson. [GK]

Sauer, T. (2000) *Abstracts for SIAM Pacific Rim Dynamical Systems Conference, August 9–13, 2000, Maui, HI,* No. 51. Society for Industrial and Applied Mathematics. [rIT]

(2003) Chaotic itinerancy based on attractors of one-dimensional maps. *Chaos* 13:947–52. [rIT]

Tsuda, I. (1991) Chaotic itinerancy as a dynamical basis of hermeneutics of brain and mind. *World Futures* 32:167–85. [rIT]

(1992) Dynamic link of memories – Chaotic memory map in nonequilibrium neural networks. *Neural Networks* 5:313–26. [rIT]

https://doi.org/10.1017/S0140525X04220131 Published online by Cambridge University Press

(2001) Toward an interpretation of dynamic neural activity in terms of chaotic dynamical systems. *Behavioral and Brain Sciences* 24:793–847. [rIT]
Tsuda, I., Fujii, H., Tadokoro, S., Yasuoka, T. & Yamaguti, Y. (2004) *Journal of Integrative Neurosciences* 3:159–82. [rIT]
Tsuda, I., Koerner, E. & Shimizu, H. (1987) Memory dynamics in asynchronous neural networks. *Progress of Theoretical Physics* 78:51–71. [rIT]
Tsuda, I. & Kuroda, S. (2001) Cantor coding in the hippocampus. *Japan Journal of Industrial and Applied Mathematics* 18:249–58. [rIT]
Tsuda, I. & Umemura, T. (2003) Chaotic itinerancy generated by coupling of Milnor attractors. *Chaos* 13:926–36. [rIT]
Van Gelder, T. J. (1998) The dynamical hypothesis in cognitive science. *Behavioral and Brain Sciences* 21:1–14. Available at: http://www.cogsci.soton.ac.uk/bbs/Archive/bbs.vangelder.html. [GK]
von der Marlsburg, C. (1981) The correlation theory of brain function. *Internal Report* 81(2). Goettingen, Max Planck Institute for Biophysical Chemistry. [rIT]

Commentary on **Bernhard Hommel, Jochen Müsseler, Gisa Aschersleben, & Wolfgang Prinz (2001). The Theory of Event Coding (TEC): A framework for perception and action planning. BBS 24(5):849–878.**

Abstract of the original article: Traditional approaches to human information processing tend to deal with perception and action planning in isolation, so that an adequate account of the perception-action interface is still missing. On the perceptual side, the dominant cognitive view largely underestimates, and thus fails to account for, the impact of action-related processes on both the processing of perceptual information and on perceptual learning. On the action side, most approaches available conceive of action planning as a mere continuation of stimulus processing, thus failing to account for the goal-directedness of even the simplest reaction in an experimental task. We propose a new framework for a more adequate theoretical treatment of perception and action planning, a theory postulating that perceptual contents and action plans are coded in a common representational medium by feature codes with distal reference. Accordingly, perceived events (perceptions) and to-be-produced events (actions) are equally represented by integrated, task-tuned networks of feature codes – cognitive structures we call event codes. We give an overview of evidence from a wide variety of empirical domains, such as spatial stimulus-response compatibility, sensorimotor synchronization, or ideomotor action, showing that our main assumptions are well supported by the data.

Does TEC explain the emergence of distal representations?

Mark Siebel

Department of Logic and Philosophy of Science, University of Leipzig, 04107 Leipzig, Germany. **siebel@uni-leipzig.de**
http://www.uni-leipzig.de/~logik

Abstract: Hommel et al. (2001) try to explain the emergence of distal representations by an evolutionary account which includes their theory of event coding. A closer look at the way the terms "distal representations" and "representations of events" are defined reveals, however, that their hypothesis of a common code for perceived and to-be-produced events is in fact superfluous. Moreover, it shows that they mix up empirical facts with conceptual/definitional facts in the second assumption of their explanation.

In the "Epilogue" to their target article (sect. 5), Hommel et al. (2001) ask: "How is it possible that our mental experience refers to events in the outer world [. . .], given the fact that it derives from events in our bodies and our minds?" They try to answer that question by an evolutionary account which includes their theory of event coding. First, at some point in evolution, a common representational system for both perceived and to-be-produced events evolved as a means to plan action. Second, the most efficient way of implementing such a system is by creating distal representations. Put together, "the invention of identical codes for perceived and to-be-produced events implies the construction of reality" (sect. 5).

Obviously, the emphasis here is on "identical." Hommel et al.'s main topic, the hypothesis of a common code, holds the central position in this explanation. A closer look, however, reveals that recourse to commonality is in fact superfluous. If an agent has representations for events, he already possesses distal representations, regardless of whether they are couched in a common representational medium.

My argument is quite simple. Question 1: What is a distal representation? Answer: By calling a representation "distal," we say something about its extension. A distal representation is a representation of a distal entity; it is a representation that does not refer to something inside the agent but to entities in the outer world. For example, a representation of spikes in Susan's brain does not belong to her distal representations because its extension does not consist of things in her environment.

Question 2: What is a representation of a perceived or to-be-produced event? Part 1 of the answer is as before: By calling something a "representation *of*," we say something about its extension. A representation of a perceived or to-be-produced event is a representation that refers to such an event. Part 2 of the answer: In the context of Hommel et al.'s article, "event" does not mean "event inside the agent" but, rather, "outer event"; therefore, a representation of an event is a representation whose referent is an occurrence in the person's environment. For example, a representation of electrical activity in Susan's visual cortex is not among her representations of a perceived or to-be-produced event, in the relevant sense of "event."

With these definitional facts in mind, it is clear why recourse to a common code plays no role in Hommel et al.'s explanation. A representation of a perceived or to-be-produced event is, by definition, a distal representation because it refers to a distal entity. Hence, if, at some point in evolution, a species acquires the ability to represent perceived events, or the ability to represent to-be-produced events, or both, then by definition this is sufficient for having distal representations. It does not matter at all whether those different kinds of events are coded within a common format. Even if the structure of the representations standing for perceived events differs widely from the structure of the representations standing for to-be-produced events, they are nonetheless distal representations because being such a representation means nothing else than representing entities in the outer world. It is not "the invention of identical [!] codes for perceived and to-be-produced events" that "implies the construction of reality," but just the invention of – whatever – codes for events.

Hommel et al.'s explanation therefore boils down to: We have distal codes because evolution has provided us with codes for perceived and to-be-produced events as a means to plan action. Here, their second assumption plays no role anymore. In light of my remarks, this should not come as a great surprise because the assumption sounds somewhat odd anyway. Hommel et al. claim that

https://doi.org/10.1017/S0140525X04220131 Published online by Cambridge University Press