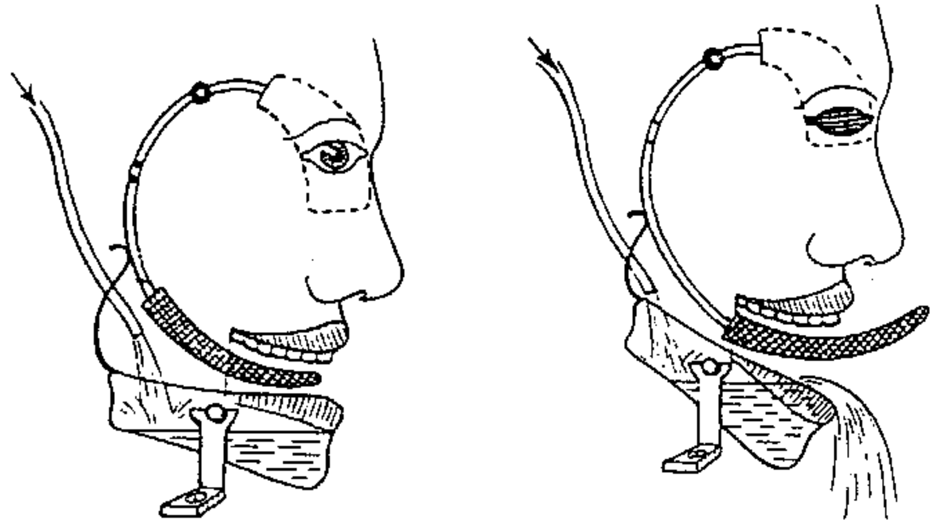
International Journal of Bifurcation and Chaos, Vol. 14, No. 2 (2004) 355–361

EDITORIAL

After Galileo Galilei, the founder of modern physics, had been condemned to lifelong house arrest by the Catholic Church in 1633 for defending Copernicus' cosmology in his *Dialogue*,[1] the French philosopher and mathematician René Descartes abandoned his intention to publish his own philosophy of nature [Descartes, 1985a, p. 141].[2] *The World*[3] appeared posthumously in 1664, 14 years after Descartes' death. It consists of two parts: the *Treatise on Light*[4] dealt with physics and a fictitious cosmology [Descartes, 2002], while in the *Treatise of Man*[5] Descartes established a mechanistic physiology [Descartes, 1972]. In this writing, he describes the human body in analogy to an automaton that is driven by several fluids, such as air, blood and the *animal spirits*, which are a very subtle matter similar to the spirit of wine [Wohlers, 2002]. Impressed and inspired by the art and skills of late renaissance engineers who built trick fountains in the gardens of, e.g. Saint-Germain-en-Laye near Paris,[6] Descartes compared this automaton with

> [...] the grottos and fountains in the gardens of our kings that the force that makes the water leap from its source is able of itself to move divers machines and even to make them play certain instruments or pronounce certain words according to the various arrangements of the tubes which the water is conducted. And truly one can well compare the nerves of the machine that I am describing to the tubes of the mechanisms of these fountains, its muscles and tendons to divers other engines and springs which serve to move these mechanisms, its animal spirits to the water which drives them, of which the heart is the source and the brain's cavities the water main. Moreover, breathing and other such actions which are ordinary and natural to it, and which depend on the flow of the spirits, are like the movements of a clock or mill which the ordinary flow of water can render continuous. External objects which merely by their presence act on the organs of sense and by this means force them to move in several different ways, depending on how the parts of the brain are arranged, are like strangers who, entering some of the grottos of these fountains, unwittingly cause the movements that then occur, since they cannot enter without stepping on certain tiles so arranged that, for example, if they approach a Diana bathing they will cause her to hide in the reeds; and if they pass farther to pursue her they will cause a Neptune to advance and menace them with his trident; or if they go in another direction they will make a marine monster come out and spew water into their faces, or other such things according to the whims of the engineers who made them. And finally when there shall be a rational soul in this machine, it will have its chief seat in the brain and will there reside like the turncock who must be in the main to which all the tubes of these machines repair when he wishes to excite, prevent, or in some manner alter their movements. [Descartes, 1972, pp. 21–22].

[1] *Dialogo Di Galileo Galilei Linceo Dove si discorre sopra i due Massimi Sistemi Del Mondo Tolemaico E Copernicao*, 1632.
[2] *Cf.* Wohlers [2002, pp. 25–30, 127–128] and Feyerabend [1993] for a discussion.
[3] *Le Monde*.
[4] *Traité de la Lumière*.
[5] *Traité de l'Homme*.
[6] For an illustration see the frontispiece of Descartes [1972].



(a) (b)

Fig. 1. A manneristic trick fountain: The *Germaul* of Hellbrunn Palace at Salzburg. (a) A constant current of water is accumulated in the tub. (b) When the mass of water reaches a certain threshold, the tub loses its balance and the moving lever rolls the eyes and pokes the tongue out of the faces (from [Helminger & Schally, 2002], © Colorama Verlag Salzburg, Austria, 2002). This simple automaton can be described by an integrate-and-fire model that is often used in neural modeling [Koch & Segev, 1998].

This hydrodynamic physiology (see also the Fig. 1) was resumed again in Descartes' last writing, in the *Passions of the Soul*,[7] in order to sketch an empirical psychology [Descartes, 1985b].

In this preface, we are going to compare Descartes' ideas with contemporary thoughts of cognitive and computational neuroscience. Replacing Descartes' intriguing *spring metaphor of the body*, nowadays many cognitive psychologists like to talk about the *computer metaphor of the brain* [Pylyshyn, 1986; Thagard, 1996]. During the last decades, beginning with the seminal works of McCulloch and Pitts [1943]; Wiener [1948]; Hebb [1949]; Hodgkin and Huxley [1952]; Miller [1956]; Chomsky [1957] and von Neumann [1958], physics and physiology, cognitive and computational neuroscience have come together[8] to encounter the great enterprise describing *Cognition and Complex Brain Dynamics* by successfully using mathematical methods and concepts from natural sciences, and more recently, modern ideas from nonlinear dynamics (cf. [Eeckman & Bower, 1993; Engbert *et al.*, 1998; Koch & Segev, 1998; Koch, 1999; Kelso, 1999]).

This special issue of the *International Journal of Bifurcation and Chaos* presents recent highly interdisciplinary works of researchers in the fields of nonlinear physics, psychology, linguistics, computer science, mathematics, psychiatry, and physiology, who met at the workshop on "Analyzing and Modeling Event-Related Brain Potentials — Cognitive and Neural Approaches" held at the University of Potsdam, Germany, in fall 2001, and was sponsored by the *Deutsche Forschungsgemeinschaft*[9] within the research group on "Conflicting Rules in Cognitive Systems". This special issue focusses on analyzing neurophysiological data and neural modeling. On the one hand, it emphasizes phase synchronization, independent component analysis (ICA) and symbolic dynamics of electroencephalographic data (EEG). On

[7] *Passions de l'Ame*, 1649.
[8] See the excellent tutorial of Freeman [1992].
[9] German Research Foundation.

the other hand, neural field theories, cellular neural networks (CNNs), and neural network models of brain oscillations are discussed.

The first tutorial by Başar gives a survey of the macrodynamics of the brain and its relation to event-related brain potentials (ERPs) which provide important online insights into brain dynamics during cognitive processes. Başar *et al.* discuss the role of brain oscillations measured by the EEG and ERPs in a system theoretic framework. Conflicts in cognitive systems are often related to ambiguity in sensory perception or language processing. The second tutorial by Saddy and Uriagereka introduces the problems of ambiguity and ambiguity resolution in natural languages, while Frisch *et al.* discuss a paradigmatic example of conflicting rules and their ERP correlates in processing ambiguous German sentences. Based on these findings, beim Graben *et al.* present a possible way to model ambiguity resolution in language processing by dynamical systems. Three papers are devoted to ambiguity in visual perception: Allefeld and Kurths [b] present results of synchronization during the perception of virtual figures while Kornmeier *et al.* investigate ERPs elicited by recognizing ambiguous figures. Eventually, Gál *et al.* discuss a CNN model of visual illusions.

In his *Treatise of Man*, Descartes explains how the above-mentioned animal spirits are separated from the blood and how they reach the pineal gland in the middle of the brain [Descartes, 1972, pp. 19–20]. From there, the spirits flow into the brain vesicles through many nozzles covering the surface of the gland [Descartes, 1972, pp. 21, 79], thus forming velocity and pressure fields of spirits within the vesicles. In contemporary physics, the dynamics of fluids obey partial differential equations constituting field theories. Field theoretic approaches are also very helpful in modeling brain dynamics as can be seen in the contributions by Jirsa and Wright *et al.*, respectively.

In the brain model of Descartes, many valves at the entries of the neurons are situated on the other side of the ventricles [Descartes, 1972, pp. 79, 84]. In another famous metaphor Descartes compares the animal spirits with the air flowing through an organ [Descartes, 1972, p. 71]: The heart pumping the spirits into the brain corresponds to the organ's bellows and the brain vesicles to the wind chambers. A nerve is regarded as consisting of a fine tube where the spirits may flow through and inside the tube of a thin cable.[10] These cables are connected with the sensor organs at the periphery of the body on one side, and with the valves embedded in the surface of the vesicles on the other side in the same manner as the cables of an organ connect the keys with the valves between the wind chamber and the pipes.

The cover inset of this special issue is taken from Descartes' *Treatise of Man* [Descartes, 1972, p. 93] to illustrate the organ metaphor: The portrayed person on the left-hand side is looking at its mirrored counterpart. The visual stimulus causes physiological changes at the retina of the eyes such as pressing the keys of the organ. The light ray B, e.g. projects onto the retinas of both eyes at the points 3, thus pulling the cables through the nerve fibers 3–4. Then the valves 4 in the brain vesicle are slightly opened [Descartes, 1972, p. 84].[11] Now, the animal spirits are able to flow from the nozzle b at the surface of the pineal gland H through the opened valves 4 into the neurons 3–4, thereby increasing the pressure on the valves 4 and opening them further [Descartes, 1972, p. 85; Descartes, 1985b, pp. 331–332].[12] The spirits flowing through the optical nerves 3–4 cause movements and adaptation of the eyes [Descartes, 1972, pp. 56, 98; Descartes, 1985b, p. 332]. In our special issue, retinal models are discussed by Werblin and Roska, Bálya *et al.* and Gál *et al.*, while Engbert *et al.* present

[10] One might speculate what Descartes had in mind here: Did he know that the axons of nerve fibers (the "cable") are often isolated by sheaths of myelin (the "tube")?

[11] That is exactly the way, how the mechanoreceptors of the sense of touch work: By stressing the cell membrane, ion channels are opened, such that sodium ions can flow into the sensory neuron [Kandel *et al.*, 1995].

[12] This positive feedback loop is quite reminiscent to the genesis of action potentials in the Hodgkin-Huxley dynamics [Hodgkin & Huxley, 1952].

a dynamical model of eye movements in reading. In Descartes' picture, simultaneously, the animal spirits are also flowing from nozzle b into the nerve 8 which innervates the muscle 7 thus increasing the pressure of spirits here, entailing its contraction and movement of the arm [Descartes, 1972, p. 93], in analogy to the air flowing from the wind chamber of the organ into the pipes.

In Descartes' physiology, the whole stimulus A-B-C yields an image 1-3-5 at the retina of the eyes. This image is propagated through the nerves to the inner surface of the brain vesicle, where it is regained in the pattern of opened valves [Descartes, 1972, p. 84]. Additionally, Descartes assumes that the local changes within the spirit field propagate this pattern to the surface of the pineal gland H [Descartes, 1972, p. 85]. Hence, he describes a retinotopic map from the eye's retinas via the pattern at the vesicle to the surface of the gland. Many contributions to this special issue deal with such topographic maps. These are papers of Lourenço, Werblin and Roska, Bálya *et al.* and Gál *et al.*, respectively.

In the cover inset we arranged the original and the mirrored counterpart of Descartes' figure such that both portraits form an ambiguous figure, known as the *vase versus faces* ambiguity, where either the foreground, the portraits, or the background, the vase, attracts attention. Lourenço has modeled attention by controlling chaos in dynamical systems; whereas Kornmeier *et al.* consider a possible model of ambiguity processing by a bistable dynamical system. Descartes explains attention by the degree of opening of the nerve tubes [Descartes, 1972, p. 97]. Interestingly, he is also able to describe ambiguous perception. Opening the valves 4 leads to a local subpressure in the field of spirits which bends the pineal gland into the direction of the most opened valves [Descartes, 1972, pp. 91, 96–97], thus changing the retinotopic map between nozzles and valves [Descartes, 1972, pp. 95–96]. When, for example, nozzle b was assigned to both valves 4 before bending the gland, the mapping might be between nozzle c and the valves 4 afterwards. Thereby, the conflicting perceptions of an ambiguous figure can be explained by different retinotopic maps between the surface of the gland and the surface of the vesicle. Furthermore, the pineal gland serves also as the interface between the mind and the body in Descartes' conception [Descartes, 1985b, pp. 340, 341, 343, 344]. In our modern scientific language one can therefore interpret the inclination of the gland as a *control parameter* which is tuned by the soul in order to force an unambiguous interpretation of sensory data. This is remarkably similar to the approaches of Kornmeier *et al.* and beim Graben *et al.* for ambiguity resolution. A further picturesque, though fashionable nonlinearly striking idea in Descartes' physiology is that the pineal gland is sensitive to and thereby amplifies small fluctuations which are either caused by material change [Descartes, 1972, p. 91; Descartes, 1985b, p. 349] or by Free Will [Descartes, 1972, p. 343], thus serving as an interface between the body (*res extensa*) and the mind (*res cogitans*). However, this assumption raises a serious metaphysical question: how is such interplay between different "substances" conceivable [Velmans, 2002]?

Back to the cover inset: In the portrait of the right hand side we have mounted a brain map of a multivariate synchronization analysis of EEG data newly developed by Allefeld and Kurths [b]. The map shows the degree of participation of the electrode sites to a mean-field phase synchronization cluster during perception of a virtual figure, a particular instance of ambiguous figures. In another paper, Allefeld and Kurths [a] present some statistical tests for phase synchronization. Synchronization measures are also used by Srinivasan to analyze perceptional conflicts in binocular rivalry. Schack uses synchronization methods to segment EEG time series into cognitive microstates that were subsequently analyzed by symbolic dynamics. Another segmentation technique based on cluster analysis is proposed by Hutt, who additionally models ERPs by fixed points in a low dimensional phase space.

Symbolic dynamics plays a prominent role in this special issue. Saddy and Uriagereka point out that symbolic dynamics is closely related to formal language theory and this relation might provide interesting insights into the interplay of natural languages and brain functioning. Engbert *et al.* utilize symbolic dynamics to describe the bifurcation diagrams of the deterministic core of their eye movement model, whereas the parsing model of beim Graben *et al.* essentially relies on symbolic dynamics and automata theory, also providing an interface to symbolic dynamic techniques in data analysis, which are applied by Frisch *et al.* for analyzing ERPs on the one hand and by Keller and Wittfeld and Steuer *et al.* for analyzing spontaneous EEG of epileptics in their respective contributions on the other hand.

The latter two papers of Keller and Wittfeld and Steuer *et al.* combine symbolic dynamics with a subsequent principal component analysis to separate different sources of variance. An appropriate alternative are methods of independent component analysis as reviewed by Müller *et al.*, who also present a technique to test whether ICA components are reliably separable. Jentzsch applies ICA to an ERP experiment investigating sequence effects in cognitive processing. A similar ERP experiment is investigated by Marwan and Meinke using recurrence plot analysis. Feldmann and Bhattacharya compute nonlinear prediction errors of spontaneous EEG in a music-perception task that is analoguous to information theoretic measures such as transfer information or mutual information. The latter is used by Galan *et al.* to detect changes of correlation in the brain of the honey bee. Eventually, Kohlmorgen and Blankertz present their approach to classify single trial ERP data using a Bayesian likelihood estimator.

A further analogy leads from Descartes' physiology to the second focus of this special issue, namely neural modeling. Descartes [1972, pp. 87–90] describes how the memory of the automaton works. The animal spirits flowing from the pineal gland towards the inner surface of the vesicles may penetrate the loose fibrous tissue of the brain, thus coining the *memory engram*, in the same manner as a bunch of needles penetrates a tightly taut canvas. Some holes will close after removing the needles while others will remain opened depending on the strength of the pricks. However, since the canvas wears out by penetrating the cloth frequently, previously closed holes will be opened much easier by penetrating the canvas at the same or neighboring sites. This picture may serve as a model of a Hebbian associator where pairs of input and output patterns, which are to be associated, are presented to a neural network whose synaptic weights are trained by the Hebb rule. Herrmann and Klaus show here that a neuron which is self-inhibiting via an autapse may form an oscillator. In a way, the Ginzburg–Landau model of Lourenço and the network-model of Huber *et al.*, who describe the time coarse of psychiatric disorders, supply other approaches to model neural oscillations.

Going from discrete neural networks to continuous nervous tissue leads to neural field theories which are described by Jirsa, who provides a brain-behavior-interface, and by Wright *et al.*, who address the issue of cortical oscillations at the mesoscopic scale in terms of power spectra and transfer functions. The relationship between power spectra and ERPs is considered by Başar, Başar *et al.*, and Klimesch *et al.* describing ERP components as superpositions of transient EEG oscillations in different frequency bands. Transient dynamics plays an important role in many contributions: Jirsa emphasizes that meaningful information causes qualitative changes of brain dynamics whereas beim Graben *et al.* point out that cognitive computation is essentially transient dynamics. Kornmeier *et al.* state that transients and unstable states are necessary for consciousness by quoting William James' *Principles of Psychology*, while Lourenço describes meaningful states (attentive states) as unstable periodic orbits that is also consistent with the findings on ERP analysis of Hutt and Marwan and Meinke. Freeman addresses the creation of meaning by communicating brains.

Following Wohlers [2002], the concept of information provides the mediating notion not to solve but to understand Descartes' dualism between *res extensa* and *res cogitans*

[Wohlers, 2002, pp. 67–76].[13] Wohlers argues that the mind *informs* the body [Wohlers, 2002, p. 67] as it is said in the third paragraph of the 12th rule of the *Regulae ad Directionem Ingenii* [Descartes, 1993, p. 74]: "*quit sit mens hominis*, *quit corpus*, *quomodo hoc ab illa informetur*". On the other hand, is it the light that informs the mind about things of the exterior world. Descartes' theory of light is not merely optics, it is, as [Wohlers, 2002, p. 72] points out, a theory of information transmission. However, the meaning of information is not objectively given; it is dynamically created by the mind (*res cogitans*) interacting with materially realized signs belonging to the *res extensa* [Wohlers, 2002, p. 74]. Therefore, "the answer to the question about the essence of information is the answer to the question about the unification of mind and body" [Wohlers, 2002, p. 74].

In his study *Wie unnütz ist Descartes?* ("How useless is Descartes?") Wohlers relates the metaphysical dualism between *res cogitans* and *res extensa* to an epistemological distinction: *res extensa* obeys the laws of geometry and all of which does not obey these laws cannot be *res extensa*, i.e. *res cogitans*. Things and bodies are geometrical objects from a certain point of view, thus they are *res extensa*. However, geometry itself as a mathematical science does not obey the laws of geometry and is hence *res cogitans*. Conversely, any concept of geometry, such as a geometrical object (e.g. a body as it is described by geometry) is also *res cogitans* [Wohlers, 2002, p. 75]. Descartes' dualism is therefore epistemologically necessary [Wohlers, 2002, pp. 43, 76, 133]:[14] *res cogitans* and *res extensa* are complementary in the sense of Bohr [1948][15] and depend on the perspective of an observer [Wohlers, 2002, pp. 67, 103].

Descartes' metaphors and analogies strike sometimes as picturesque and ridiculous. Is his philosophy really antiquated and useless? Wohlers provides another answer: any scientific effort aims at truth, or, at least maximal credibility. Therefore, scientists have to observe methodological rules. Truth is only achievable in pure mathematics. In the empirical sciences one has to construct theories or models describing observed data. One of those rules is to bear always in mind that scientific models are even *models*, i.e. "fables" or "fictions" [Wohlers, 2002, pp. 38, 130–131]: "'Fiction' and 'model' are two different points to the same thing, namely to nature, insofar as nature is described by the human being: 'fiction' emphasizes the human part to the objectively recognized facts, 'model' emphasizes the objective part of the human knowledge" [Wohlers, 2002, p. 42].

Now, we are able to understand why Descartes' cosmology in the *Treatise on Light* appears as a *fable*; and why Descartes does not say in the *Treatise of Man* that the human body *is* an automaton, but how an automaton must be constructed to be a *model* of the human body. He did not believe that his scientific metaphors were the plain truth. Rather, he was acutely aware that his models were just models thus observing his own scientific rule. Although our present body of knowledge exceeds that of Descartes' time by far, Descartes' *spring metaphor of the body* or his *organ metaphor of the brain* have the same conceptual status as the *computer metaphor of the brain* or any other contemporary physical or psychological theory: They are scientific fiction.

References

Atmanspacher, H., Wiedenmann, G. & Amann, A. [1995] "Descartes revisited. The endo-exo-distinction and its relevance for the study of complex systems," *Complexity* **1**, 15–21.

Bernays, P. [1948] "Über die Ausdehnung des Begriffes der Komplementarität auf die Philosophie," *Synthese* **7**, 66–70.

[13] According to Wohlers' interpretation of Descartes there is no problem to be solved: the dualism is itself a solution, namely of the epistemological problem to distinguish between true knowledge (as in mathematics) and empirical understanding (as in physics). This will be explained subsequently.

[14] Cf. [Atmanspacher *et al.*, 1995].

[15] Cf. [Bernays, 1948] and [Velmans, 2002].

Bohr, N. [1948] "On the notions of causality and complementarity," *Dialectica* **2**, 312–319.

Chomsky, N. [1957] *Syntactic Structures* (Mouton, Den Haag).

Descartes, R. [1972] *Treatise of Man* (Harvard University Press, Cambridge), translated by T. S. Hall.

Descartes, R. [1985a] *Discourse on the Method*, The Philosophical Writings of Descartes, Vol. 1, eds. Cottingham, J., Stoothoff, R., Murdoch, D. & Kenny, A. (Cambridge University Press, Cambridge), pp. 111–151.

Descartes, R. [1985b] *Passions of the Soul*, The Philosophical Writings of Descartes, Vol. 1, eds. Cottingham, J., Stoothoff, R., Murdoch, D. & Kenny, A. (Cambridge University Press, Cambridge), pp. 328–404.

Descartes, R. [1993] *Regulae ad Directionem Ingenii* (Felix Meiner, Hamburg).

Descartes, R. [2002] *The World or Treatise on Light*, http://www.princeton.edu/˜hos/mike/texts/descartes/world/worldfr.html.

Eeckman, F. H. & Bower, J. M. (eds.) [1993] *Computation and Neural Systems* (Kluwer, Boston).

Engbert, R., Scheffczyk, C., Krampe, R. T., Kurths, J. & Kliegl, R. [1998] "Symbolic dynamics of bimanual production of polyrhythms," in *Nonlinear Analysis of Physiological Data*, eds. Kantz, H., Kurths, J. & Mayer-Kress, G. (Springer, Berlin), pp. 271–283.

Feyerabend, P. [1993] *Against Method* (Verso Books, NY).

Freeman, W. J. [1992] "Tutorial on neurobiology: From single neurons to brain chaos," *Int. J. Bifurcation and Chaos* **2**, 451–482.

Hebb, D. O. [1949] *The Organization of Behavior* (Wiley, NY).

Helminger, B. & Schally, S. [2002] *Hellbrunn. Ein Führer durch Wasserspiele, Park und Schloß* (Colorama Verlag, Salzburg).

Hodgkin, A. L. & Huxley, A. F. [1952] "A quantitative description of membrane current and its application to conduction and excitation in nerve," *J. Physiol.* **117**, 500–544.

Kandel, E. R., Schwartz, J. H. & Jessel, T. M. (eds.) [1995] *Essentials of Neural Science and Behavior* (Appleton & Lange, East Norwalk).

Kelso, J. A. S. [1999] *Dynamic Patterns. The Self-Organization of Brain and Behavior* (MIT Press, Cambrigde).

Koch, C. & Segev, I. (eds.) [1998] *Methods in Neuronal Modelling. From Ions to Networks* (MIT Press, Cambridge).

Koch, C. [1999] *Biophysics of Computation. Information Processing in Single Neurons* (Oxford University Press).

McCulloch, W. S. & Pitts, W. [1943] "A logical calculus of ideas immanent in nervous activity," *Bull. Math. Biophys.* **5**, 115–133.

Miller, G. A. [1956] "The magic number seven, plus or minus two: Some limits on our capacity for processing information," *Psychol. Rev.* **63**, 81–97.

Pylyshyn, Z. W. [1986] *Computation and Cognition: Toward a Foundation for Cognitive Science* (MIT Press, Cambrigde).

Thagard, P. [1996] *Mind. Introduction to Cognitive Science* (MIT Press, Cambridge).

Velmans, M. [2002] "How could conscious experiences affect brains?" *J. Conscious. Stud.* **9**, 3–29.

von Neumann, J. [1958] *The Computer and the Brain* (Yale University Press, New Haven).

Wiener, N. [1948] *Cybernetics or Control and Communication in the Animal and the Machine* (MIT Press, Cambridge).

Wohlers, C. [2002] *Wie unnütz ist Descartes?* (Königshausen & Neumann, Würzburg).

Peter beim Graben, Douglas Saddy and Jürgen Kurths
University of Potsdam, Germany