*Roland Fischer*

# THE TIME-LIKE NATURE OF MIND

•

# ON MIND FUNCTIONS AS TEMPORAL PATTERNS OF THE NEURAL NETWORK

"Mind, for anything perception can encompass, goes (therefore) in our spatial world more ghostly than a ghost. Invisible, intangible, it is a thing not even of outline; it is not a 'thing'. It remains without sensual confirmation, and remains without it for ever."
(Ch. Sherrington, 1953. *Man on his Nature*).

It follows from the temporal nature of mind—the main concern of this essay—that mind functions are not localized in brain space. "*Time* is extendedness, probably of the mind itself", concludes Saint Augustine in Book XI of his *Confessions* (26.33), and, in our days, this extendedness can be made visible through an oscilloscopic "line" or trace of slow potentials. These graded, additive (not all-or-none) autorhythmic and seemingly self-generating potentials are primary events recorded at synapses. Autorhythmic brain structures (Zabara, 1973) appear to be the source of time frames, while a change in time frames (as reflected in the EEG) leads to synchronization and desynchronization of brain structures respectively. Synchronization forms a homogeneous time domain, such as obtained during rhythmic exercises, chanting, listening to music and mental processes that are the hallmark of religious practices (Rogers, 1973). Desynchronization of brain structures on the other hand marks a functional independence of neuronal elements with each element available for separate channels of data processing, for example, during hallucinogenic drug-induced central sympathetic arousal, that is, a waking dream state (Fischer, 1979).

As far as *space* is concerned, the concept dates back to Euclid (300 B.C.) whose deductive geometry constituted for more than 2000 years the basis for our view of space as a huge box, a unique container with all objects suspended in "container-space". Ideas concerning space underwent in the past 150 years a radical change, and, according to the now prevailing view, reality is defined as the actualizing appearance of observational relations. Although mathematics and modern physics use symbols, some of which correspond to locations in "space and time", these cannot actually be locations in any one-level "physical"space and time, since they are indefinite, general and potential operators which actualize only as a result of a particular observation (Fischer, 1969), Hence, matter, space and time, reality, present, past and future become interconnected concepts. Through the observer—in the present—the *interaction* with that which is to be observed, i.e., the observation, becomes an irreversible *factum*, i.e., that which has been made to happen in the past. Note that there are present options and future possibilities but no alternatives in the past since everything (truth, reality, causality...) appears to have been predetermined *ex post facto*, that is, in the past. Hence "present fact" is a contradiction in terms, "future facts" are non-existent, and a "past fact" is a pleonasmus.

Determinism is concerned with the actualization of the possible through generation of information (entropy reduction), and it is impossible to discern whether a *factum* is due to the irreversibility of time, or whether the two concepts refer to the same phenomenon.

What determines the course of future possibilities? Clearly, and strangely, the shape of the future depends to a large extent on *expectations* that are grounded in and built upon past (i.e. determined) experience. Things had to happen, as they have happened.

## IS MIND A FUNCTIONAL PROPERTY OF BRAIN-MATTER IN OUR MIND?

The postulate that space is not an empty container but a material *plenum*, was first forwarded by Aristotle's pupil Theophrastus (Jammer, 1960). The properties of space-time, then, become dependent on matter, and space-time is to be regarded as the property of spatio-temporal extension of matter. Einstein phrased this in popular language: "If all material things disappeared out of the universe, classical physics says that space and time would be left. According to relativity, time and space disappear together with the things" (cited by Clark, 1971). Hence, space-time is a "thing", and some of its properties are determined or modified by matter.

The school of Parmenides and Zeno, in Elea (490-430 B.C.), adhered to and perpetuated the concept that space is a filled *plenum*, and in our days it is Bohm (1980) who has extended and further specified the ideas of Parmenides by describing the filled *plenum* as a sea of energy. The forms of the flux appear as ripples or wave patterns on the surface of this sea; and matter, as we know it, is a small wave-like excitation on top of this vast sea of energy. Hence, the universe of matter (in our sense experience) is treated by Bohm as a comparatively small pattern of excitation.

Harry Kopf (1977), while adhering to Bohm's view that space is "solid" and matter is simply a wave phenomenon within the solid block we know as space, additionally proposes that matter is moving at the velocity, c, (relative to space), and that light is stationary, or more precisely, that light is a standing wave in space.

We can see now—according to Klopf—why we perceive emptiness when peering into space. This is the correct perception for



https://doi.org/10.1177/039219218903714703 Published online by Cambridge University Press

a wave phenomenon peering into its own medium. On the other hand, when we as matter waves interact with other matter waves, we discover that we and the other matter waves cannot occupy the same space at the same time; this, then, is the perception of "solid" matter.

It should be emphasized at this point that Klopf does not question the mathematics of Einstein's special theory of relativity; Klopf's questions are addressed to the physical interpretation of the mathematics.

What is time? Time may be a topological operator on space: the motion of matter waves along the fourth (locally specified) spatial dimension, and mental phenomena, that is, mind, and matter waves are to be seen as one and the same.

H.G. Wells (1947) in *The Time Machine* anticipated the concept of time as an experience of moving (and time as a moving experience): "There is no difference between Time and any of the three dimensions of space except that our consciousness moves along it."

If space-time can be regarded as a property of matter (*a priori*), then, mind function—conceptualized as oscillating time patterns of neuronal firing—is clearly a functional property of brain matter. Is space-time another interactional—observer-dependent—property or manifestation? If so, mind may be seen as a self-observing "property", like taste, smell, sound, light, and touch. Or more precisely: mind *is* matter's self observation.

There is a parable about the nature of this self-observation. Sir Russel Brain (1958) in *The Nature of Experience* has a story to tell about two tables, a story that is presented by Eddington and Bertrand Russell.

"One (of the tables, he said) has been familiar to me from my earliest years. It is a commonplace object of that environment which I call the world. How shall I describe it? It has extension; it is comparatively permanent; it is coloured; above all it is *substantial*... Table number 2 is my scientific table... It does not belong to the world previously mentioned—that world which spontaneously appears around me when I open my eyes, though how much of it is objective and how much subjective I do not here consider... My scientific table is mostly emptiness. Separately scattered in that emptiness are numerous electric charges rushing about with great speed; but their combined bulk amounts to less than a billionth of the bulk of the table itself... There is nothing *substantial* about my second table."

It is not very hard to discern, however, that there are more than two tables. In fact, there are as many tables as there are levels of abstraction and specialized languages (of biochemistry, physiology, botany, physics, mathematics, and so forth...). But a basic distinction has to be made: the first table, the substantial one, exists, *objectified* in sensory-motor closure—a touchy perceptual experience in space—while *all* other tables are *subjectified* in the cognitive time domain of the mind.

Could oscillating neuronal time patterns be involved in the induction of thought? The electrical oscillations of the neural mass—that is the dynamics of the interaction of $10^{12}$ profusely interconnected neurons represent a Hegelian change from quantity into a new quality: the brain's self-experience as time production. The electrical oscillations are independent of the location and time history of the subcortical input, and can persist in the cortex (Numez, 1974; p. 426). The nature of the oscillations depends on the relative abundance of excitatory and inhibitory connectors and on the physiological state (level of arousal) of the brain.

Kandel of Schwartz (1985), and others, postulate changes in synaptic connectivity during the learning-to-expect phase of central nervous system development. However, such functional changes in the nervous system were observed only in non-vertebrates, that is, specifically in gastropod molluscs exposed to stimulus routines and responses described in behavioral terms that should have been reserved to vertebrates: habituation, associative conditioning, operant conditioning, and the like. We assert, therefore, that a model in which cognition and recognition is represented as a complex of time pattern with no spatial localization is a more suitable model of adult mind function in humans.

Pringle (1976) points out that it is only in the vertebrates and especially in mammals that we have *evidence* of the gradual loss of localization that occurs in ascending pathways. Perhaps this is so, ponders Pringle, since a mammal has to rely more on learning during the animal's own life time and less on genetically fixed innate patterns of (localized) behavior; another corollary would imply that only those animals are conscious in which the transformation into time pattern proceeds to a sufficient extent. Furthermore, there could be a degree of consciousness depending on the extent to which the time patterns achieve spatial spread. Indeed, all sensory exits of the human nervous system project into motor systems, or, to put it differently, sensory chronology "makes sense" only when re-expressed as a spatially coherent motor event. The proof of the sensory pudding is in the motor eating.

Is the perception of time related to sensory experience? Oscillatory brain mechanism—in the frequency range of 30 to 40 Hz seem to be essential for the identification of sensory events. When these neuronal oscillations are suppressed, for example, during general anaesthesia, sensory events (or data content) cannot be experienced and hence the perception of time comes to a halt. Patients often report that no time at all has elapsed after the anaesthesia was administered, whereas time estimation after sleep can be astonishingly accurate. Madler and Pöppel (1987) recorded auditory evoked potentials (in response to 2000 successive clicks, each lasting for 0.1 ms and 70 dB above the normal hearing level) prior to and immediately after induction of general anaesthesia in 30 patients undergoing surgery; they found that general anaesthesia suppressed the characteristic neuronal oscillations of central origin that were triggered by the auditory stimuli.

How, then, are we going to answer the question posed in the subtitle of this section: is mind a functional property of (brain)matter in our mind? Like another question: "has this sentence thirtythree letters?"—our question contains its own reply (its time-like medium being the message). Mind is both creating-processing of information *and* it is the re-entrant form in a recursion. The recursion also marks the limits of the mind's interpretive repertoire, that is a functional property of (brain-)matter in our mind.

## The Logarithmic Life Spiral: as an Image of the Time-like Quality of the Evolving Mind

One could argue that a transformation of spatial information into the time-like domain is the story of the evolving mind—the his-



https://doi.org/10.1177/039219218903714703 Published online by Cambridge University Press

tory of matter becoming conscious of itself through self-observation and self-interpretation. The steps of this unitary transformation process—evolution, learning, perception and dreaming (and hallucination or day-dreaming)—proceed at an exponentially progressing time rate of change in the direction of decreasing entropy, and may be visualized as an exponential (logarithmic) life spiral of time (Fischer, 1966, 1967 a), an evolving process that can generate information with minimal entropy expenditure. In 1979 Bateson (p. 148) re-discovered and elegantly rephrased our concept: "Thought and evolution are alike in shared stochasticism... One system is within the individual and is called learning; the other is immanent in heredity and population and is called evolution."

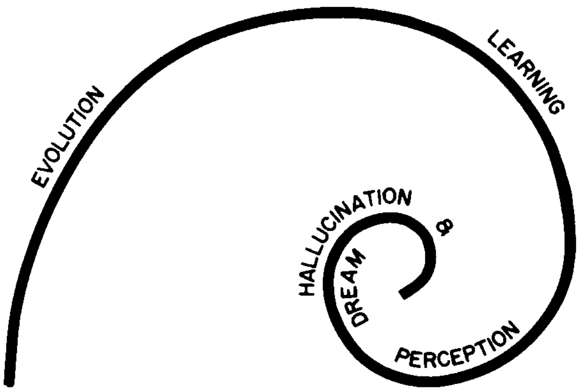


*Fig.*—The exponential (logarithmic) life spiral: visualizing the more and more time-like quality of mind as it comes into being through evolution, learning, perception, hallucinations and dreaming. These steady states (and adaptive as well as optimizing processes) require less and less energy to generate information with increasing efficiency.

The logarithmic spiral was first considered by Descartes (1638) and then by Torricelli. John Bernoulli wished to have the "wonderful" spiral incised on his tomb: Eadum mutata resurgo (cited by Fischer, 1967, p. 443).

Why does the evolution of mind (at this stage) culminate in dreams and hallucinations? Thinking, reverie, dreaming and hallucinations are meant here to signify inspired imagination: the rhetoric and semantics of mental images.

Dreams, that is, in particular, the rapid eye movement state of sleep, and hallucinations—or waking dreams—are intense, aroused experiences without the desire and the ability to verify them by touch (high sensory to motor ratio!). Measurable (verifiable) things that appeared become unmeasurable appearances of things (Fischer, 1969). Montaigne, when meditating about thinking and feeling, sometimes describes them as 'reverie': "Sleeping we are awake and waking asleep" (cited by Starobinski, 1987). In this sense, thinking as a state of heightened awareness is indistinguishable from dreaming and hallucinations in which the author is present as a spectator at the birth of his own creative imagination.

While asleep and dreaming, Descartes worked out an interpretation of his two previous dreams and that of the ongoing dream, thereby conceiving the foundations of a wonderful discovery ("mirabilis scientiae fundamenta"—analytical geometry) that is said to be the greatest single step ever made in the history of the exact sciences (von Franz, 1952, p. 57).

Every word said by Charles Dickens's characters was distinctively heard by him (Lewes, 1961, p. 66, cited by Parrinder, 1981, p. 1), and there is good evidence that James Joyce, too, was hearing imaginary voices that resound in his books as rambling voices of an interior monologue—to give just a few examples.

When depicting the story of the evolving mind as a logarithmic life spiral, one can straighten out each curved portion demonstrating the steady state nature (the non-equilibrium state of an open system) of evolution, learning, perception and hallucinations.

*Evolution* is a steady state represented by a straight line on a log-log plot relating metabolic body-size and lifespan. (Recall Huxley's allometric equation (1932) $M = k.W^n$). The plot displays 63 species of mammals (from the shrew to the whale); moreover, the highly significant relation between body size in $kg^{3/4}$ (space), and lifespan (time) also holds true on the single organ level, for example, when plotting brain weight (in $kg^{3/4}$) against life span. The approximately two-fold superpredictor of lifespan is shown by the tighter clustering to the regression lines and specifically man's closer fit within the relationship. Since man lives three times longer than expected in terms of his body size, the closer fit may indicate that man's brain and its mind may be involved in the prolongation of lifespan (Fischer & Rockey, 1968, p. 269). Hence, man's longevity exemplifies well the more time-like than space-like nature of mind.

*Learning*, another adaptational process, is also a steady state; hence, cumulative learning curves follow a straight line in log-log coordinates. They can be described as power functions of the general form $P = k.t^n$, where P is a cumulative measure of performance and it is practice time or number of trials (Stevens & Savin, 1962).

What has been said about learning in relation to evolution, can be said in principle about *perception* in relation to learning. Another straight line relationship is obtained in log-log coordinates when plotting stimulus-magnitude against psychological magnitude. The relationship implies that the sensation grows as a power function of the stimulus magnitude, or $R = k.S^n$ where the constant, k, depends on the unit of measurement, and the value of the exponent, n, may vary from one sensory continuum to another (Stevens, 1959).

*Hallucinations* can be plotted, as perceptions have been, as a psychophysical power function, while the perceptual task is performed by subjects under the influence of a hallucinogenic drug. Such psychoactive drugs—like psilocybin, and $\Delta^9$-THC, for example—do not not alter the straight line relationship between log S (stimulus) and log R (response); however, the exponent (representing the slope) is lowered by psilocybin and raised by $\Delta^9$-THC, whereas the constant, (representing the intercept) undergoes changes in the opposite direction (Shaffer, Hill & Fischer, 1972).

We have invoked the image of the evolving mind as an ongoing process along a logarithmic (life) spiral, the steps of which consists of: evolution, learning, perception and hallucinations (or waking dreams). Each sequential step represents a steady state, as well as an optimization process that is actualizing in a less and less space-like (non-localizable), i.e., a more and more time-like dimension (Fischer & Rockey, 1967 b). If we place the logarithmic spiral into a log-log coordinate system, we instantaneously realize that the straight-line relationship in evolution, learning, perception, hallucination and dreaming represent the perceptual-conceptual log-log laws of our own nature.



https://doi.org/10.1177/039219218903714703 Published online by Cambridge University Press

## The Nature of Time and Chaos

But what is the nature of time? Time is not a physical entity that actualizes through observation, but a relational concept referring to the causal relations of events. The infant gradually learns to perceive causal relations as a temporal order and by age seven children have understood the nature of causation and the structuring of relational roles in both the real world and in language. They are learning to be in time, that is, to antedate personal experiences, the fragments of causal chains. The sequential ordering of the fragments is compression of information, the antedated remembrance of things present.

But—cosmo-logically speaking—why is the direction of time in which disorder increases the same as that in which the Universe expands? If one believes that the Universe will expand and contract again, this becomes a question of why we should be in the expanding phase, rather than the contracting phase. One could answer that conditions in the contracting phase would not be suitable for the existence of intelligent beings who could ask such a question. Human beings have to consume food, i.e., an ordered form of energy, and convert it into themselves and heat, i.e., a disordered form of energy. Thus, intelligent life could not exist in the contracting phase of the Universe—that is a state of almost complete disorder or thermal equilibrium (Hawking, 1987). This is why we observe, at a rate of change, that is, biological time (coupled to our metabolic rate) thermodynamic and cosmological arrows of time to point in the same direction. Thus, life and its evolving time-like mind follow the path of "order from disorder", that is, by taking energy from the outside and transforming it within themselves to a lower entropy state. Life is a quasi-stable, far-from-equilibrium dissipative structure that maintains its systemic organization or negentropy at the expense of the global entropy budget.

The time spiral of life (or the life spiral of time) evolves via bifurcations and autocatalytic non-linear processes, and the development of entropy production, growth, complexity and cycling. The most recent dynamic dimension that is added to cope with the thermodynamic constraint of life is the quest within and "beyond chaos" (Rössler, 1983). The distinction between noise and chaos is analogous to the difference between the noise of a crowd at a ball game and the noise of a family dispute (Skarda & Freeman, 1987).

We may now conceptualize mind as a time-like systemic operation that with minimal energy expenditure* can generate information by experiencing, itself. The *"spontaneous"* firing activity, a basal chaotic state, pervades normal cortical function (Freeman, 1987), and is a precondition of the brain's self-experience. Moreover, if we consider both excitatory and inhibitory afferent nerves as feedback pathways—the excitatory afferents determining positive feedback and the inhibitory afferents determining negative feedback—the concept of stimulus becomes irrelevant since the feedback signals (a function of the afferent impulse traffic) indicate the relatively instantaneous value of the response. "Spontaneous" activity then is a response without a stimulus (Zabara, 1972).

According to Skarda and Freeman (1987), the brain relies on chaotic activity for all perceptual processes and functions as a controlled source of noise, as a means to ensure continual access to previously learned sensory patterns and as a means for learning new sensory patterns. This chaos is controlled noise with defined properties; it is not stochastic (Garfinkel, 1983, Rössler, 1983) but deterministic in the sense that it can be reliably simulated by solving sets of coupled non-linear ordinary differential equations.

## Order from Chaos

Skarda and Freeman (1987) have recently developed an ingenious model to describe the neural dynamics involved in odor recognition and discrimination. Their data are congruent with and support the hypothesis that neural dynamics is heavily dependent on chaotic activity. The theory for perception that was developed

* The human brain deep in thought consumes about 14 w of power (Johnson, 1980), and most of the power is required to maintain the brain's responsivity, that is, a receptive state of spontaneous neuronal firing activity. Cerebral efficiency, calculated according to Brillouin amounts to 69 percent; hence, during sleep the brain is doing a job *more efficiently* than the heart, notes Johnson.



https://doi.org/10.1177/039219218903714703 Published online by Cambridge University Press

holds that sensory information is brought to the olfactory bulb by action potentials on particular axons, and that it is rapidly integrated with past experience by a self-organizing mass action process involving the entire bulb. This process is manifested as a broad spectrum of chaotic background activity and in oscillatory bursts that appear repeatedly in the EEG. Moreover, (preliminary) results in vision show that the visual cortical EEG resembles the olfactory EEG in several respects, and that differences may be in part attributable to differences in anatomical structure between visual and olfactory cortices (Freeman & van Dijk, 1987).

The authors suggest that without chaotic activity the neural system cannot add a new odor to its repertoire of learned odors. Chaos provides the system with a deterministic "I dont know" state within which new activity patterns can be generated. A "chaotic well" enables the system to avoid all of its previously learned activity patterns and to produce a new one that can drive the formation of a new nerve cell assembly by strengthening synapses between pairs of neurons having highly correlated activity. (A nerve cell assembly refers to a subset of neurons that constitute perhaps 1-5% of the particular perceptual network and operates in a static non-linearity.) Thereby chaos allows the system to escape from its established repertoire of responses in order to add a new response to a novel stimulus under reinforcement (Freeman, 1987). What are the conceptual implications of this position? History is not represented as a stored image of the past; nor is the present a mirror of the environment. Instead, environmental events are specified by states of neural activity that are the result of the neuronal system's internal organization and dynamics. In this sense, the neural structure *uses* information to *create* its own internal states, which acquire meaning (Werner, 1987).

Clearly, chaotic destabilization provides a better description of the essentials of neural functioning than the concept of pattern completion, conclude Skarda and Freeman (1987): in an alert, motivated animal, input destabilizes the system, leading to further destabilization and a bifurcation to a new form of patterned activity. Convergence to an attractor in one system (the olfactory bulb, for example) in turn destabilizes other systems, (for example, the motor system), leading to further state changes and ultimately to manipulation of and action within the environment. Based on their research, Skarda and Freeman (1987) postulate that behavior can best be modeled as a sequence of ordered, stable states in an evolutionary trajectory. The key property of brain dynamics and, in fact, of consciousness is to govern "the next move" through control of body movement in space for self-promoting purposes. Hence, mental activities may be "thought of" as muscular acts (Fischer, 1986, p. 3) since relaxation of striated (voluntary) muscle activity results in an experience of the void—with electromyographic recording registering zero potential.

With this in mind, chaos, through a "destabilizing trajectory" creates a new form of activity, and it is this "order from chaos" that at last appears to bridge the yawning gap between a level of intentional behavior and a neurophysiological level of explanation. Is the destabilizing chaotic trajectory a dynamic linkage between neuronal micro-elements and the macro-feature of consciousness? Dynamical system theory remains a mathematical formalism, an abstraction that models the human universe, and attractors, in particular, denote geometric models for the local asymptotic behavior of a system. It would seem, therefore, absurd to account for the origin and functions of the abstracting mind in terms of its own abstractions... (un-) fortunately, we are blessed with no other but such circular epistemological options. What, in effect, does bridge the gap between mind and (brain-) matter is the recursive logic and language that we have in mind.

## The Distinction between (Brain-)Matter and Mind may be a Distinction between Quantity and Quality

A "Hegelian change" of quantity into quality occurs when quantity—the continuous variable—is sorted out by the mind as a distinct quality. Gradually shortening wavelengths, for example, are experienced as qualitative changes in colors, and gradually increasing frequencies as qualitative changes in musical pitches. These transformations of quantity into a new and distinct quality are seen by Harnad (1987, p. 4) as an analog-to-digital transformation that recodes the continuous region of a physical variation as a discrete labeled equivalence class.

We can express the change of quantity into quality in mathematical language. Imagine a dynamical system described by a set of differential equations. If we gradually change the parameters in the equations, the behavior of the system will also change gradually: for example, if the behavior is to oscillate, then the period and the amplitude of the oscillations will change gradually. But ultimately as we continue to change the parameters we reach a threshold of "bifurcation", at which the behavior changes dramatically. The system, to give an example, may cease to oscillate and start to grow exponentially.

And now the question may be ventured: Could it be that observation itself, i.e. perception-cognition or *interaction* with the observed, transforms parameters in the new system and thus triggers a threshold of bifurcation at which behavior dramatically changes into a new quality? That new (more time-like than space-like) quality may be the radiant redness of an apple, the juicy taste of a fruit, or the provocative smell of a pheromone, i.e., categories that actualize through simple non-linear interaction with only few components. Qualities are localized nowhere and exist as an active state of the system observer *cum* observed.

The experience of self-awareness or self-perception may be another categorical perception, a new quality that is experienced as an active "I observe myself"-state that originates from the recursive interaction of an organism's observations of the analog data structures (images) of the needs and desires that it was generating. Self-awareness, that is, the awareness of self-organization or self-regulation (Deshmukh, 1987) may emerge from an underlying chaotic process that selectively amplifies small fluctuations and transforms them into a coherent active state, that is, a mind-function. Self-awareness as the awareness of self-organization is a richer metalinguistic autological domain (Löfgren, 1983, p.222) than the circular (self-) reference that it turns into an ordinary well-defined reference. At the same time, self-awareness serves as its own proof of consistency.

Hence the distinction between (brain-)matter and mind can be seen as a distinction between quantity—that is, the profusely (through sub-systems) interconnected activity of about $10^{12}$ neurons—changing into a new quality: the exponentially progressing time-like phenomenon of the brain's self-experience.—But bear in mind that quantity and quality—and for that matter—(brain-) matter and mind are not intrinsic physical and logical properties or structures, but are themselves interpretations of how these complementary structures interact with each other.

## BEARING IN MIND THE BRAIN'S SELF-EXPERIENCE

Let me focus on the proposition that (brain-)matter and mind are complementary domains that form a hermeneutic circle. The proposition may be illustrated by an astute formulation of Henry Ey (1963, p. 64): "The brain is the only organ that develops by experiencing itself." The hermeneutic circle is formed between development that depends on self-experience, and self-experience that depends on development. We cannot explain nor understand "the brain's self-experience" until we have found a formal system of rules for describing this competence. But at the same time we have to realize that the rules used in the formalization of "the brain's self-experience" are not necessarily the same rules that produce the brain's self-experience. Organismic performance and neural dynamics, for example, may be formalized within thermodynamic and informational models, respectively; but explaining organism as heat engines, and neural dynamics as computation, does not mean that organisms perform like heat engines, or brains as computers do. It is particularly difficult to apply a rule-governed, formal system for the description of the self-competence of brain-mind, while claiming that neural dynamics is heavily dependent on chaotic activity that, in turn, is not rule-governed. To circumvent the difficulty, we are forced to highlight certain key concepts that contribute to the understanding of the brain's self-experience, and give-up the attempt of integrating these concepts within a formalized system. The key concepts are: rhythmicity, excitability, re-entrant propagation and self-organization.

*Rhythmicity* and *excitability* may be already observed in simple oscillating chemical reactions, for example, the Belousov-Zhabotinsky (BZ) reaction, a redox system, featuring a stable symmetry-breaking dissipative structure that undergoes self-organization under conditions not too far from equilibrium. In the Belousov-Zhabotinsky reaction (in which Zhabotinsky (1967) replaced Belousov's original citrate by mallonate) the citric acid solution cycles rhythmically: the yellow of oxidized cerium ions fade while they in turn oxidize the citric acid and then return in the next minute as bromate ions oxidize the reduced cerium. Stable oscillations in redox potential have been recorded by Crowley & Field, (1986). These oscillations were then coupled electrically (while running in separate stirred tank reactors), and a variety of coupled behaviors could be observed, such as drifting, quasi-periodicity, chaos, synchronization, entrainment, and annihilation of oscillations in one or both oscillators. The source of the observed chaos could be directly linked to the presence of a strange attractor that owed its existence to a "Smale horseshoe map", i.e. one that maps a region back into itself (Crowley & Field, 1986).

Like any other attracting-cycle oscillator, Belousov's reaction system is susceptible to phase resetting by a discrete impulse (of ultraviolet light, for example). Assembled three-dimensionally—like circadian clocks, cardiac pacemakers, or any other limit-cycle oscillator—the reaction can be entrained by periodic perturbations (Dolnik, *et al.*, 1984, cited by Winfree, 1987 a, p. 164).

Moreover, the reagent is *excitable* (Winfree, 1987 a, p. 245). By a minor adjustment of Zhabotinsky's recipe, the reaction can be made to quit oscillating spontaneously; but, according to Winfree, its excitability and capacity to propagate chemical signals remains uncompromised. When prodded by a sufficient, spatially structured stimulus, it reveals alternative stable modes, organizing itself periodically in space and time. The result is a tiny structure woven of filaments not much thicker than living cells (about 150 microns), rotating and pulsing and radiating waves of excitation that sequence the whole liquid's reaction to rhythmical patterns. The triggering stimulus is then no longer needed: the involved structure is self-sustaining.

The BZ reaction is the best known of other related autocatalytic reactions (Epstein, *et al.*, 1983; Nicolis & Baras, 1984). Instead of proceeding swiftly and directly from reactants to products, it oscillates or periodically cycles between distinct regions of the system and its intermediate states. Such periodic cycling is related to another phenomenon, the formation of spatial structures in an initially homogeneous medium; hexagonal convection patterns arise, for example, when a pot of water is heated close to the boiling point (this is the Bénard instability phenomenon). All *spontaneously organized* forms display *basic form constants* such as rotating spirals and expanding circles (which are topological relatives). The spontaneous organization of matter, is not restricted to chemical reactions; it is a ubiquitous phenomenon that may be observed in such diverse structures as slime mold aggregates (Bonner, 1967, cited by Winfree, 1987 a, p. 175), heart arrhythmias (Winfree, 1987 b, p. 187), certain types of epileptic seizures, spreading depression, and in the spirals of galactic structures (Madore & Freedman, 1987). And, astonishingly, during hyperaroused states (psychoactive drug-induced or natural), the basic form constants also (re-?) appear and evolve into varieties of hallucinatory form constants (Fischer, 1975 a). They may arise from hyperarousal-induced chaos in the visual cortex, a chaos that is then superimposed on repetitive neural patterns: inducing order from chaos, that is, rotating retinal waves. The artistic ornamentalization and elaboration of hallucinatory form constants may be admired in the magnificent rose windows of Gothic cathedrals and the mandalas of Tantric religious art (Fischer, 1970).

*Spontaneous neuronal firing*, that seemingly random basal activity, has recently been recognized as an emergent property of interacting neurons, a property that pervades normal cortical function (Freeman, 1987). The component neurons generate their own ordered response to stimuli: they are self-organizing. There is no central processor to deal with, say, novel stimuli; learning and memory are functions distributed throughout the neural network (Skarda & Freeman, 1987). The parallel distributed processing system consists of a densely interconnected network of units that interact with one another by sending and receiving signals modulated by the weights associated with the connections between the units while relying heavily on organized feedback.

Already during development neurons are known to have *intrinsic* electrical *autorhythmicity* considered to be one of the central mechanisms in the early organization of nerve nets (Llinás, 1987, p. 348). Autorhythmicity and cell-to-cell communication through direct electrical contact (electrotonic coupling) are essential electrical substrates of the organization of embryonic brain circuits. Once the primitive network is assembled by adhesion and chemotaxis, a further selection must occur on the basis of intrinsic electroresponsiveness allowing the electrical recognition of dynamic kinship (electrical resonance) in the form of coupled oscillation. In mammals several specific ionic conductances have been described which are capable of inducing intrinsic oscillations in neuronal ensembles and endowing neurons with the ability to resonate at given stimulus frequencies (Jahnsen & Llinás, 1984).

*Re-entrance* is a required capacity of the nervous system to influence itself through connections to and from other cortical or even subcortical areas of the brain. According to Szentágothai's (1987) rough calculations, probably over 80 percent of all fibres leaving the cerebral cortex are serving direct cortico-cortical re-entrance. The total percentage of re-entrant pathways might run over 90 percent of all cortical connections. It is probably no exaggeration, remarks Szentágothai, that virtually every cortical cell has potential access, directly or indirectly, to any other point in the cortex.

How does re-entrance contribute to meaning? Whenever changes in a self-referential creature's sensations are accounted for by its voluntary movements (or *vice versa*) a sensory motor closure ensues (i.e. the proof of the sensory pudding is in the motor eating). The re-entrant form is the meaning of this *Eigenbehavior* (see Fischer, 1984). Recursion may be described as a process (or processing) through which the medium becomes the message, as, for example, in "this sentence has thirtythree letters."

The concept of *self-organization* is not free of ambiguity. Self-organization is a transitive expression but it is used as if it were intransitive, that is complete and of itself. For Bohm (1969), electrons, protons, etc. are merely names of aspects of a vast, self-regulatory, hierarchical process operating at the level of inanimate matter. Still in the inorganic realm, the growth of a crystal is another analogical model of self-organization in living matter. On the other hand, nothing arises "by itself", that is, an objective origin of anything is unthinkable without the thinking subject (Locker, 1981, p. 231). Hence, organization, including self-organization, is an attribute of the *observer* of a system rather than of the system itself (Beer, 1966, p. 357). If a system is moving towards what the observer regards as desirable ends, it is "under control''. Clearly, the observer projects his own notion of purpose on to the system. Self-organization, like knowledge, is in the eye of the beholder-observer.

Moreover, the observer's interpretive point of view determines the criteria by which the observation is categorized; a table, for example, when viewed as consisting of electrons, is a deterministic system, while a macroscopically perceived table (on which one can have breakfast) represents a probabilistic structure, that, as a result of being observed, changes into itself at each instant of time (Uribe, 1981, p. 50). Notwithstanding, noise (fluctuations) superimposed can change the qualitative behavior of a deterministic system, particularly the nature of the attractors (Érdi, 1984); hence noise-induced transitions can play an active and constructive role in the organization of ordered structures. A model of neural computation, for example, in which noise, rather than chaos, plays an important role is Sejnowski and Hinton's (1985) model of image recognition in the visual cortex.

But how does chaotic behavior relate to the concept of self-organization? And, what is self-organization, after all? We have seen that autorhythmicity is a basic feature of the brain's ability to organize its own space-time patterns of function and thereby its own structure. Skarda and Freeman's main point is not that brain activity conforms to the dynamics of chaos, but that the brain generates chaotic activity as an essential precursor to the emergence of ordered states (1987, p. 187), i.e., behavior that was previously thought to require rules and the manipulation of symbols.

We may now attempt to answer the question: what is self-organization? Just as apparent chaos in a system is a measure of the observer's own ignorance (projected into the system), so self-organization is a measure of the information which a system appears to exhibit (but which in fact, the observer projects into the system). It seems that the capability of the observer to reflect and project information is constrained at the upper and lower level of his own ordered informational states. Chaos is, therefore, observed beyond the least and most ordered state of such a hierarchy.

It should not go unmentioned that the ''observer'' was already—although not explicitly—included in a definition pro-



https://doi.org/10.1177/039219218903714703 Published online by Cambridge University Press

posed by von Foerster (1974, p. 23), using Shannon's Redundancy: A system is "self-organizing" if the rate of change of its redundancy is positive. In other words, high initial redundancy is a necessary (but not sufficient) condition for self-organization to occur. The system must also possess enough inertia, *i.e.*, its resilience must suffice to keep small perturbations from immediately destroying it (Atlan, 1987). The initial redundancy is used up in the process, unless additional mechanism (on a different level) can again recharge the system in redundancy. For Atlan (1987) the role of the paradoxical sleep and dream state is an example of such a recharging of our neural functional redundancy so as to keep our non-directed learning capacities going.

At last, we may define *self-organization*, or better, *spontaneous organization* (SO), as both a factual property of material processes or systems *and* a reflection of ordered (expectant, purposeful) informational states which systems appear to exhibit (but which, in effect, the observer projects into the system). SO systems interact with an environment which possesses available energy and enables the system to dissipate it (not too) far from equilibrium at the expense of the environment (entropic drift!). The dissipation proceeds along a specific trajectory exhibiting spatially invariant (imposed) configurations that *delay* the dissipation of energy. The delay (in living systems) can be equated with lifespan that unfolds at a particular metabolic rate (Fischer, 1988). SO systems contain catalytic and/or feedback processes enabling an observer to describe them in terms of non-linear differential equations. This definition of spontaneous organization implies that SO—like the rest of the material world—is both real and in the eye of the beholder; it actualizes in the very moment of observation, and exists exactly as long as those fleeting moments last (irrespective of whether the observation concerns chemical reactions in the laboratory, galaxies, or neural structures).

Neither the SO of the BZ reaction, nor the bitterness of quinine, (or the sweetness of sugar, the shape and color of leaves, or the sound of thunder, and so forth) are properties of a system or structure. Perceptual and conceptual properties actualize through and refer solely to the interaction between observer and observed. Hence, observation—the maker and taker of properties—through interactional perception-(re-)cognition, that is, central nervous system modeling as self-experience, is subject not only to the laws of nature but also to the laws of our (delayed) existence—compare the speed of light with that of nervous conduction—*i.e.*, the laws of our own nature.

*

Having interpreted the meaning of such key-concepts as rhythmicity, excitability, re-entrant propagation, and spontaneous (or self-)organization—we may again reflect upon the time-like nature of mind and the mind-like nature of time: two domains that coalesce in conscious being. Living beings spontaneously organize themselves in time as dissipative structures (not too) far from equilibrium, and in this sense, time *is* being. Time is being for Angelus Silesius, the German mystic and "*cherubinische Wandersmann*": "*Du selber machst die Zeit, das Uhrwerk sind die Sinnen*" (You are yourself the maker of time, your senses are the clock-work; quoted by Fischer, 1966). Mind and time thus co-exist and beget each other in interdependent and "recursive complementarity" (an expression of Caley & Sawada, 1986), and what they bring forth is information. *Information here* is interchangeable with *form* or εἶδος as the immanent Platonic idea.

Let me give a specific example of this interchangeability. Instead of referring to the bodily *form* or phenotype of an attractive and young woman, we rather emphasize the (genetic) *information* that is contained in the ova (the genotype) of the attractive idol (from εἶδος). This coded information shall bring forth other women and men, since information deserves its name only if it can create more information. The continuing creation of individuals of the same species is, therefore, a creation of species-specific time, and, interchangeably, information may be utilized as a measure of form (von Weizsäcker, 1985).

The evolutionary life-spiral of our Figure reveals the time-like nature of mind, that is, the less and less space-like (energy) and more and more time-like (information) character of the evolving mind. A fundamental aspect of information is its role in the representation of the universe within the neural net of about ten billion interconnected neurons. Within this staggering quantity "the mind may be regarded as a field in the accepted physical sense of the term. But it is a non-material field. It cannot be compared with the simpler non-material fields that require the presence of matter (e.g. gravity)... Nor does it necessarily have a definite position in space. And so far as present evidence goes it is not an energy field in any physical sense, nor is it required to contain energy in order to account for all known phenomena in which mind interacts with brain" (Margenau, 1984).

And Eccles (1987) concludes that mental events (the mind) acting as a field in the manner postulated by Margenau could effect changes in the spatio-temporal activity of cortical columns or modules without violating conservation laws. Since some fields, such as the probability field of quantum mechanics, carry neither energy nor matter, the "stuff" of mind (described in the language of substance, carrying matter and energy) prevails as sub-stance: a formless fundamental constituent of matter on the level of nuclear particles. This sub-stance has to be subjected to observation (or measurement, i.e., self-reflective awareness or consciousness) in order to be transubstantiated to substance. It is observation that creates knowledge (information) of substance with form in time, and re-orders past, present, and future as points fused to a sequence. Unperceived sub-stance—we assume—consists of untouchable and imperceptible "noumenological" parameters, like strangeness, spin, and so forth, and only the re-ordering of these parameters, like the re-ordering of quarks, for example, produces what we recognize as an observable continuum of mass or charge. Analogously, a re-ordering of points through vision (the mind's eye) creates an observable continuum: a line.

In short, the proton and the electron are still insubstantial entities, and form does not arise prior to an observation-created re-ordering into the atomic realm. Whether on the perceptual, the cosmological, or the sub-atomic level: observers generate their universe whenever they make an observation. Diderot said it jubilantly: "*Nous sommes l'univers entier.*"

Roland Fischer
(07190-*Esporles. Mallorca*)

## REFERENCES

ATLAN, H. (1987), "Self-creation of meaning". *Physica Scripta 36*, 563-576.
BATESON, G. (1979), *Mind and Nature, a Necessary Unity*. New York, Dutton.
BEER, S. (1966), *Decision and Control*. London, Wiley.
BOHM, D. (1969), "Further remarks on order". In *Towards a Theoretical Biology, 2,* Waddington, C.H. (ed.) Edinburgh, Biological Sciences & Edinburgh University Press.
— (1980), *Wholeness and the Implicate Order*. London, Routledge & Kegan Paul.
CALEY, M.T. & SAWADA, D. (1986), "Recursive complementarity". *Cybernetica 29*, 263-275.
CLARK, R.W. (1971), *Einstein*. New York, World Publ., p. 386.
CROWLEY, M.F. and FIELD, R.J. (1986), "Electrically coupled Belousov-Zhabotinski oscillations". In *Lecture Notes in Biomathematics 66*, Othmer, H.G. (ed.), Heidelberg-New York, Springer.
DESHMUKH, V.D. (1987). "Oscillatory neural ectoderm (one)". *Medical Hypotheses 23*, 107-108.
ECCLES, Sir JOHN (1987), "Brain and mind, two or one?" In *Mindwaves*, C. Blakemore & S. Greenfield (eds.), Oxford, Blackwell.
EPSTEIN, I.R., KUSTEN, K., de KLEPPER P. & ORBAN, M. (1983), "Oscillating chemical reactions". *Scientific American 248*, 96-108.
ÉRDI, P. (1984), "Self-organizing mechanisms for the formation of ordered neural mappings". *Biol. Cybernetics 51*, 93-101.
EY, H. (1963), *La Conscience*. Paris, Presses Universitaires de France.
FISCHER, R. (1966). In *The Voices of Time*. Fraser, J.T. (ed.), New York, Braziller; pp. 357-382 & 657-666.
— (1967 a), In *Interdisciplinary Perspectives of Time*. Fischer, R. (ed.) *Annals of the New York Academy of Sciences 138*, 440-488.
— & ROCKEY, M.A. (1967 b), "A steady state concept of evolution, learning, perception, hallucinations and dreaming". *Intl. Journ. Neurology 6*, 182-201.
— (1968), "Psychophysics of excitation and tranquilization from a steady state perspective". *Neurosciences Research 1*, 263-314.
— (1969), "The perception-hallucination continuum". *Diseases of the Nervous System 30*, 161-171.
— (1970), "Über das rhythmisch-Ornamentale im halluzinatorisch-Schöpferischen". *Confinia Psychiatr. 13*, 1-25.
— (1975), "Cartography of inner space". In *Hallucinations*. Siegel, R.K. & West, J.L. (eds.) New York, Wiley.
— (1979), In *Expanding Dimensions of Consciousness*. Sugerman, A.A. & Tarter, R.E. (eds.) New York, Springer.
— (1984), "Comments on the structure of ancient wisdom". *Journ. Social & Biol. Structures 7*, 387-389.
— (1986), In *Handbook of States of Consciousness*. Wolman, B. & Ullman, M. (Eds.). New York, Van Nostrand; pp. 395-427.
— (1988), "La différence". *Science 240*, 130.
FOERSTER, von, H. (1967). "Time and Memory". In *Interdisciplinary Perspectives of Time*, Fischer, R. (ed.), *Annals of the New York Academy of Sciences 138*, Art. 2; pp. 866-873.
FRANZ, von, M.L. (1952), "Der Traum des Descartes", in *Zeitlose Dokumente der Seele*. Studien aus dem C.G. Jung Institut Zürich, III. Zürich, Rascher Verlag.

FREEMAN, W.J. (1987), "Simulation of chaotic EEG patterns with a dynamical model of the olfactory system." *Biol. Cybern. 56*, 139-150.

— & van DIJK, B.W. (1987), "Spatial pattern of visual cortical fast EEG during conditioned reflex in a rhesus monkey". *Brain Research 422*, 267-276.

GARFINKEL, A. (1983), "A mathematics for physiology". *Am. J. Physiol. 245*, (Regul. Integr. Comp. Physiol. 14, R 445 - R 446).

HARNAD, S. (1987), "Introduction". In *Categorical Perception*. Harnad, S. (ed.), Cambridge, Cambridge University Press.

HARTH, E. (1986) "Does the brain compute?', *Behavioral and Brain Science 9*, 98-99.

HAWKING, S. (1987), "The direction of time". *New Scientist*, July 9, 46-49.

JAHNSEN, H. & LLINÁS, R. (1984), "Ionic basis for electroresponsiveness". *Journn. Physiol.* (London) *349*, 227-47.

JAMMER, M. (1960), *The Philosophy of Quantum Mechanics*. New York, Wiley.

KANDEL, E.R. & SCHWARTZ, J.H. (eds.) (1985), *Principles of Neural Science*, 2nd ed., New York, Amsterdam, Oxford, Elsevier.

KLOPF, H. (1977), *Mental and Physical Phenomena; Toward a Unified Theory*. Air Force Avionics Laboratory, Wright-Patterson AFB, Ohio 45433, Part I & II, pp. 205. Unpublished draft of a manuscript.

LLINÁS, R. (1987), "'Mindness' as a functional state of the brain." In *Mindwaves*. Blakemore, C. & Greenfield, S. (eds.), Oxford, Blackwell.

LOCKER, A. (1981), "Metatheoretical presuppositions for autopoiesis". In *Autopoiesis*. Zeleny, M. (ed.), New York, Elsevier-North Holland; pp. 211-231.

LÖFGREN, L. (1983), "Autology of help; resolving problems of levels and boundaries". In *Problems of Levels and Boundaries*. Pedretti, A. & de Zeeuw, G. (eds.), London-Zürich, Princelet Editions.

MADLER, Ch. & PÖPPEL, E. (1987), "Auditory evoked potentials indicate loss of neuronal oscillations during general anaesthesia". *Naturwissenschaften 74*, 42-43.

MADORE, B.F. & FREEMAN, W.L. (1987), "Self-organizing structures". *Amer. Scientist 75*, 252-9.

MARGENAU, H. (1984), *The Miracle of Existence*. Woodbridge, Conn., Ox Bow Press.

NICOLIS, G. and BARAS, F. (1984), *Chemical Instabilities*. Dordrecht, Reidel.

NUMEZ, P. (1974), "The brain wave equation: a model for the EEG". Abstract, *Electroencephalography & Clinical Neurophysiology 37*, 426.

PARRINDER, P. (1981), *James Joyce*. Cambridge, University Press.

PRINGLE, J.W.S. (1976), "The mechanism of knowledge: limits of prediction". Paper presented at the 5th Intl. Conference on the Unity of Sciences, Washington, D.C., Hilton, November 26.

ROGERS, L. (1973), "EEG correlates of chanting". Presented at the *Transformations of Consciousness Conference* (sponsored by R. M. Bucke Memorial Society & McGill University) Montreal, October.

RÖSSLER, O.E. (1983), "The chaotic hierarchy". *Z. Naturforsch. 38 a*, 788-801.

SEJNOWSKI, T. J. & HINTON, G.E. (1985), "Parallel stochastic search in early vision". In *Vision, Brain and Cooperative Computation*. Arbib, M.A., & Hanson, A.R. (eds.), Cambridge, Mass., M.I.T. Press./Bradford Book.

SHAFFER, J.H., HILL, R.M. & FISCHER, R. (1973), "Psychophysics of Psilocybin and $^{9}$-tetrahydrocannabinol". *Agents and Actions* (Basel, Birkhäuser) *3*, 48-51; and In *Abstracts of 5th Intl. Congress on Pharmacology*, San Francisco, California, July 23-28, 1972, p. 209.

SKARDA, Ch. A. & FREEMAN, W.J. (1987), "How brains make chaos in order to make sense of the worlds". *Behav. and Brain Sciences 10*, 161-173.
STAROBINSKI, J. (1987), *Montaigne in Motion*. A Goldhammer (transl.), Chicago, University of Chicago Press.
STEVENS, J.C. & SAVIN, H.B. (1962). "On the form of learning curves". *Journ. Exptl. Analysis Behavior 5*, 15-28.
SZENTÁGOTHAI, J. (1987), In *Mindwaves*. Blakemore, C. & Greenfield, S. (eds.), Oxford, Blackwell.
URIBE, R.B. (1981), In *Autopoiesis*. Zeleny, M. (ed.), New York-Oxford, Elsevier-North Holland.
WEIZSÄCKER, C. F. von (1985), *Aufbau der Physik*. München, Hanser.
WELLS, H.G. (1947), *The Time Machine*. New York, Random House; reprinted in New York, Bantam, 1968.
WINFREE, A.T. (1987a), *When Time Breaks Down*. Princeton, N.J., Princeton University Press.
— (1987 b), *The Timing of Biological Clocks*. Scientific American Library, New York, Freeman.
ZABARA, J. (1972), "Foundation for a cybernetic model of psychobiology". *Kybernetes 1*, 165-168.
— (1973), "Autorhythmic structure of the brain". *Cybernetica 2*, 77-98.
ZHABOTINSKI, A.M. (1967), *Oscillations in Biological and Chemical Systems*. Nauka, K. (Ed.), Moscow, U.S.S.R. Academy of Science.

### Acknowledgments

**I am grateful to my friend, the late Erich Jantsch, University of California, Berkeley, for having provided me with Pringle's (1976) important and unpublished paper; to William L. Pensinger, Trumansburg, New York, through whose courtesy I obtained a copy of Harry Klopf's (1977) provocative and unpublished manuscript; and to my friend Priv. Doz. Dr. Werner Brönnimann, University of St. Gallen, for critically reading the entire manuscript.**