CHAPTER 2

The Emergence of Temporal Structures in Complex Dynamical Systems

Klaus Mainzer*

Department of Philosophy and Theory of Science, Director of the Carl von Linde Academy, Technical University of Munich, Munich, Germany

Abstract: Dynamical systems in classical, relativistic and quantum physics are ruled by laws with time reversibility. *Complex dynamical systems* with time-irreversibility are known from thermodynamics, biological evolution, growth of organisms, brain research, aging of people, and historical processes in social sciences. Complex systems are systems that compromise many interacting parts with the ability to generate a new quality of macroscopic collective behavior the manifestations of which are the *spontaneous emergence of distinctive temporal, spatial or functional structures*. But, emergence means no mystery. Mathematically, the emergence of macroscopic features results from the nonlinear interactions of the elements in a complex system. Complex systems can also be simulated by computational systems. Thus, arrows of time and aging processes are not only subjective experiences or even contradictions to natural laws, but they can be explained by the nonlinear dynamics of complex systems. Human experiences and religious concepts of an arrow of time are considered in a modern scientific framework. Platonic ideas of eternity are at least understandable with respect to mathematical invariance and symmetry of physical laws. But Heraclit's world of change and dynamics can be mapped onto our daily real-life experiences of arrow of time.

Keywords: Symmetry of time, proper time, relativistic space-time, singularity, PCT-theorem, quantum cosmology, cosmic arrow of time, irreversibility in thermodynamics, evolutionary time, aging process, computational time, cellular automata, autopoiesis, self-organization, nonlinearity, eternity.

1. THE EMERGENCE OF TEMPORAL STRUCTURES IN CLASSICAL AND RELATIVISTIC DYNAMICS

According to Newton's laws of mechanics, a *dynamical system* is determined by a time-depending equation of motion. Newton distinguished *relative* and *absolute*

***Address correspondence to Klaus Mainzer:** Department of Philosophy and Theory of Science, Director of the Carl von Linde Academy, Technical University of Munich, Arcisstrasse 21, D-80333 Munich, Germany; Tel: +49 89 289 25360; Fax: +49 89 289 25362; E-mail: mainzer@cvl-a.tum.de

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time, assuming that all clocks of relative reference systems in the Universe could be synchronized to an absolute world-time of an absolute space. The *symmetry of time* is expressed by changing the sign of the *direction of motion* in an equation of motion. In *classical mechanics*, mechanical laws are preserved (invariant) with respect to all inertial systems moving uniformly relative to one another (Galilean invariance). A consequence of time symmetry is the conservation of energy in a dynamical system [1]. Newton's absolute space can actually be replaced by the class of inertial systems with Galilean invariance. But, according to the Galilean transformation of time, there is still Newton's distinguished absolute time in classical mechanics.

In 1905, Einstein assumed the *principle of special relativity* for all inertial systems satisfying the constancy *c* of the speed of the light ('Lorentz systems') and derived a common space-time of mechanics, electrodynamics, and optics. Their laws are invariant with respect to the Lorentz transformations. Time measurement becomes path-dependent, contrary to Newton's assumption of absolute time. Every inertial system has its *relative ('proper') time*. The situation is illustrated by the Twin paradox [2]. In a space-time system, twin brother A remains unaccelerated on his home planet, while twin brother B travels to a star with great speed. The traveling brother is still young upon his return, while the stay-at-home brother has become an old man. But, according to the *symmetry of time*, the twin brothers may also become younger. Thus, relativistic physics cannot explain the *aging of an organism* with direction of time. According to Einstein (1915), gravitational fields of masses and energies cause the *curvature of space-time*. Clocks are effected by gravitational fields: The gravitational red shift of a light beam in a gravitational field depends on its distance to the gravitational source and can be considered as dilatation of time. The effect is confirmed by atomic clocks.

Relativistic cosmology assumes an expanding universe in cosmic time [3]. According to Hubble's law of expansion, no galaxy is distinguished. The *Cosmological Principle* demands that galaxies are distributed spatially homogeneous and isotropic ('maximally symmetric') at any time in the expanding universe. In geometry, homogeneous and isotropic spaces have constant (flat, negative or positive) curvature. In two dimensions, they correspond to a Euclidean plane with flat curvature and infinite content, a negatively curved saddle, or a positively curved surface of a sphere with finite content. With the assumption of the Cosmological Principle and Einstein's theory of gravitation, H.P. Robertson and H.G. Walker derived the three standard models of an expanding universe with open cosmic time in the case of a flat or negative curvature and final collapse and end of time in the case of positive curvature. F. Hoyle's *steady state universe* (1948) without global temporal development can be excluded by overwhelming empirical confirmations of an expanding universe. K. Gödel's *travelling in the past* on closed world-lines in an anisotropic ('rotating') universe (1949) is excluded by the high confirmation of isotropy in the microwave background radiation.

The beginning and end of time gets new impact by the theory of *Black Holes* and *cosmic singularities*. According to the theory of general relativity, a star of great mass will collapse after the consumption of its nuclear energy. During 1965-1970, R. Penrose and S.W. Hawking proved that the collapse of these stars is continued to a point of singularity with infinite density and gravity. Thus, the singularity of a Black Hole is an *absolute end of temporal development*. The Schwarzschild-radius determines the event horizon of a Black Hole. Because of the *symmetry of time*, there might be also, White Holes with expanding world lines and exploding matter and energy, starting in a point of singularity. This idea inspired Hawkins's theorem of cosmic origin (1970): Under the assumption of the theory of general relativity and the observable distribution of matter, the universe has an *initial temporal singularity* ('*Big Bang*'), even without the additional assumption of the Cosmological Principle. Time is initialized in that point [4].

From different philosophical points of view, theists or atheists have supported or criticized the idea of an initial point of time, because it seems to suggest a creation of the universe. The mathematical disadvantage is obvious: In singularities of zero extension and infinite densities and potentials, computations must fail. Thus, nothing can be said about the origin of time in relativistic cosmology.

2. THE EMERGENCE OF TEMPORAL STRUCTURES IN QUANTUM DYNAMICS

According to Bohr's correspondence principle, a dynamical system of quantum mechanics can be introduced by analogy to a dynamical system of classical

(Hamiltonian) mechanics. Classical vectors like position or momentum are replaced by operators satisfying a non-commutative (non-classical) relation depending on Planck's constant *h*. The dynamics of quantum states is completely determined by time-depending equations (*e.g.*, Schrödinger equation) with *reversibility of time*. The laws of classical physics are invariant with respect to the symmetry transformations of time reversal (T), parity inversion (P), and charge conjugation (C). According to the *PCT-theorem*, the laws of quantum mechanics are invariant with respect to the combination PCT [5]. Thus, in spite of P-violation by weak interaction, the PCT-theorem still holds in quantum field theories. But, it is an open question how the observed violations of PC-symmetry and T-symmetry (*e.g.*, decay of Kaons) can be explained.

An immediate consequence of the non-commutative relations in quantum mechanics is Heisenberg's principle of uncertainty which is satisfied by conjugated quantities such as time and energy: Pairs of virtual particles and antiparticles can spontaneously be generated during a tiny interval of time ('*Planck-time*'), interact and disappear, if the product of the temporal interval and the energy of particles is smaller than Planck's constant. Thus, the quantum vacuum as the lowest energetic state of a quantum system is only empty of real particles, but full of virtual particles ('quantum fluctuations') [6].

Further on, according to Heisenberg's uncertainty principle, there are no time-depending orbits (trajectories) of quantum systems, depending on precise values of momentum and position like in classical physics. In order to determine the temporal development of a quantum system, R. Feynman suggested using the sum ('integral') of all its infinitely possible paths as probability functions. In *quantum cosmology*, the whole universe is considered a quantum system. Thus, Feynman's method of path integral can be applied to the whole universe. In this case, the quantum state (wave function) of the universe is the sum (integral) of all its possible temporal developments (curved space-times). In 1983, J. Hartle and Hawking suggested a class of curved space-times without singularities, in order to avoid the failure of relativistic laws in singularities and to make the cosmic dynamics completely computational [7]. Therefore, the real numbers of the time parameter in the corresponding path integral are replaced by imaginary numbers. Thus, in a Lorentz metrics $x^2 + y^2 + z^2 - t^2$ of space-time, the three coordinates *x*, *y*, and *z* of space can no longer be distinguished from the time parameter *t* by a minus sign, because $-t^2$ is replaced by $-(it)^2 = --t^2 = +t^2$ with imaginary number $i = \sqrt{-1}$. In that sense, the *early universe existed in a "timeless" (imaginary) state without beginning* until the *Big Bang* started its expansion [8].

According to Hawking's hypothesis of an *early universe without beginning*, Feynman's path integral allows different models of temporal expansion which are more or less probable – collapsing universes, critical universes, universes with fast (inflationary) expansion. They are all initiated by random quantum fluctuations in a quantum vacuum as ground state of a quantum system. The real time of a universe starts with its expansion. St. Augustine's famous question: "What did God do before the creation of our universe?" is now answered in the framework of quantum physics. In the beginning of the universe, there was a random quantum fluctuation of the quantum vacuum. In quantum physics, random events must not be determined by hidden causes without violating fundamental laws (EPR-experiment). Thus, in the beginning, God played dice to initiate our universe. If you don't believe in God, then, according to quantum cosmology, you must state: In the beginning, there was (quantum) *randomness*.

Hawking uses the (weak) Anthropic Principle to distinguish a universe like ours, enabling the evolution of galaxies, planets, and life, with an early inflation and later retarded expansion of flat curvature. From his hypothesis, R. Laflamme and G. Lyons [9] derived the forecast of tiny fluctuations of the microwave background radiation which was confirmed by the measurements of COBE in 1992. Thus, Hawking's hypothesis of an early universe without temporal beginning has been confirmed (until now), but not explained by an unified theory of quantum and relativistic physics which we still miss.

The temporal development of the universe can be explained by dynamics of phase transitions from an initial quantum state of high density to hot phase states of inflationary expansion and the generation of elementary particles, continued by the retarded expansion of galactic structures. Thus, the *emergence of cosmic structures* is made possible by phase transitions of the universe. Cosmic time is characterized by the development from a nearly uniform quantum state to more complex states of differing cosmic structures. In this way, we get a *cosmic arrow* *of time from simplicity to complexity*, which is characterized by a bifurcation scheme of global cosmic dynamics: An initial unified force has been separated step by step into the partial physical forces we can observe today in the universe: gravitation, strong, weak and electromagnetic interactions with their varieties of elementary particles [10].

If in the early universe gravitation and quantum physical forces are assumed to be unified, then we need a *unified theory of relativity and quantum mechanics* with new objects as common building blocks of the familiar elementary particles. The string theory [11] assumes tiny loops of 1-dimensional strings (10^{-35} m) with minimal oscillations generating the elementary particles. In a superstring theory, the unified early state corresponds to a transformation group of *supersymmetry*, which leaves the laws of the unified force invariant. During the cosmic expansion the early symmetry is broken into partial symmetries corresponding to different classes of particles and their interactions. Only three spatial dimensions of the more dimensional superstring theory are 'unfolded' and observable. Today, there are five 10-dimensional string theories and an 11-dimensional theory of supergravitation with common features ('dualities') and identical forecasts of the universe. They are assumed to be unifiable in the so-called M-theory. In this case, the *cosmic arrow of time* could be completely explained by phase transitions from simplicity to complexity. But we still must miss such a final explanation.

3. THE EMERGENCE OF TEMPORAL STRUCTURES IN THERMODYNAMICS

In physics, a direction of time was at first assumed in thermodynamical systems. According to R. Clausius, the change of the entropy S of a physical system during the time $\mathrm{d}t$ consists of the change $\mathrm{d_e}S$ of the entropy in the environment and the change $\mathrm{d_i}S$ of the intrinsic entropy in the system itself, *i.e.,* $\mathrm{d}S = \mathrm{d_e}S + \mathrm{d_i}S$. For isolated systems with $\mathrm{d_e}S = 0$, the *2nd law of thermodynamics* requires $\mathrm{d_i}S \geq 0$ with increasing entropy ($\mathrm{d_i}S > 0$) for *irreversible thermal processes* and $\mathrm{d_i}S = 0$ for *reversible processes* in the case of thermal equilibrium. According to L. Boltzmann, entropy S is a measure of the probable distribution of microstates of elements (*e.g.*, molecules of a gas) of a system, generating a macrostate (*e.g.*, temperature of a gas): $S = k_B \ln W$ with k_B Boltzmann's constant and W number of probable distributions of microstates, generating a macrostate. According to the 2^{nd} law, entropy is a measure of increasing disorder during the temporal development of isolated systems. The reversible process is extremely improbable. For Hawking, the cosmic arrow of the expanding universe from simplicity to complexity, from an initial uniform order to galactic diversity, is the true reason of the 2^{nd} law.

Nevertheless, as the 2^{nd} law is statistical and restricted to isolated systems, it allows the *emergence of order from disorder in complex dynamical systems* which are in energetic or material interaction with their environment (*e.g.*, convection rolls of Bénard-experiment, oscillating patterns of the Belousov-Zhabotinsky-Reaction, weather and climate dynamics) [12]. In general, the development of dissipative systems can be characterized by *pattern formation of attractors* (*e.g.*, fixed point attractor, oscillation, chaos) and *temporal bifurcation trees*. In a critical distance to a point of equilibrium, the thermodynamical branch of minimal production of energy ('linear thermodynamics') becomes instable and bifurcates spontaneously into new locally stable states of order ('symmetry breaking') [13]. Then, the nonlinear thermodynamics of nonequilibrium starts. If the system is driven further and further away from thermal equilibrium, a bifurcation tree with nodes of locally stable states of order is generated. Global *pattern formation and emergence* of complex dynamical systems can be *irreversible*, although the laws of locally interacting elements (*e.g.*, collision laws of molecules in a fluid) are *time-reversible*.

4. THE EMERGENCE OF TEMPORAL STRUCTURES IN EVOLUTIONARY DYNAMICS

The *emergence of life* is not so special in the universe. It is explained by the nonlinear dynamics of complex molecular systems. Catalytic hypercycles are prototypes of complex molecular systems with catalytic and autocatalytic feedback loops of nonlinearly interacting molecules. In a prebiotic evolution, self-assembling molecular systems become capable of self-replication, metabolism, and mutation in a given set of planetary conditions. It is still a challenge of biochemistry to find the molecular programs of generating life from 'dead' matter. *Darwin's evolution of species*, as far as it is known on Earth, can also be characterized by *phase transitions* and *temporal bifurcation trees*. Mutations are random fluctuations in the bifurcating nodes of the evolutionary tree, breaking the local stability of a species. Selections are the driving forces of branches, leading to further species with local stability. The distance of sequential species is determined by the number of genetic changes. *Evolutionary time* can be measured on different scaling, *e.g.*, by the distance of sequential species and the number of sequential generations of populations. Its *temporal direction* is given by the order of ancestors and descendants.

As conditions changed in the course of the Earth's history, *complex cellular organisms* have come into existence, while others have died out. Entire populations come to life, mature, and die, and in this they are like individual organisms. But while the sequence of generations surely represents the time arrow of life, many other distinct biological time rhythms are discernable. These rhythms are superimposed in *complex hierarchies of time scales*. Each hierarchical layer *emerges* from the previous ones by phase transions. They include the temporal rhythms of individual organisms, ranging from biochemical reaction times to heartbeats to jet lag, as well as the geological and cosmic rhythms of ecosystems.

Complex systems that consist of many interacting elements, such as gases and liquids, or organisms and populations, may exhibit separate temporal developments in each of their numerous component systems. The complete state of a complex system is therefore determined by statistical distribution functions of many individual states. It has been proposed by B. Misra, I. Prigogine *et al.* that time can be defined as an operator describing changes in the complete states of complex systems. This *time operator* would then represent the average *age* of the different system components, each in its distinct stage of development [14]. For example, a 50-year-old person could have the heart of a 40-year-old one, but, as a smoker, the lungs of a 90-year-old one. Organs, arteries, bones, and muscles are in distinct states, each according to its particular condition and genetic predisposition. The time operator is thus intended to indicate the *irreversible aging of a complex system*, its *inner* or *intrinsic time*, not the *external and reversible clock time*. In short: we distinguish the irreversible *operator time* of complex dissipative systems and the reversible *parameter time*. Operator time refers to the *spontaneous emergence of distinctive temporal, spatial or functional structures in complex systems* [15].

The *human brain* may also be regarded as a complex system in which many neurons and different regions of the brain interact chemically and constitute collective cell assemblies by synchronously firing states. The *emergence of mental states* is explained by the neural correlates of firing cell assemblies. Our individual experiences of "*duration*" and "*aging*" are related to the operator time of complex-system states in the brain, depending on different sensory stimuli, emotional states, memories, and physiological processes. Hence, our *subjective awareness* of time does not contradict to the laws of science, but is explained by the dynamics of a complex system. Our intimate subjectively experienced flow of time was described in many examples of literature and poetry. The neurobiological knowledge of brain dynamics does not turn us into a Shakespeare or a Mozart. In this sense, natural sciences and humanities are complementary.

In econophysics, the theory of complex systems is also applied to the *temporal dynamics of socio-economic systems*. A city, for example, is a complex residential region in which different districts and buildings have distinct traditions and histories. Again, its development is explained by the *emergence of distinctive temporal, spatial or functional structures in complex systems*. New York, Brasilia, and Rome are the result of distinct temporal development processes. The time operator of a city refers literally to the average age of many distinct stages and styles of development. Institutions, states, and cultures are characterized by growth and aging processes with typical operator time. Today, there is the dramatic problem of *aging societies* in highly developed countries (*e.g.*, Japan, Germany). From the point of view of complex dynamical systems, the discussions of age is not just metaphorical, but can be explained in terms of structural dynamics [16].

5. THE EMERGENCE OF TEMPORAL STRUCTURES IN COMPUTATIONAL AND INFORMATION DYNAMICS

Modern technical societies depend sensitively on the capacities of computers and information networks. *Computational time* is a measure of the time needed to solve a problem by a computer. As a measure of a problem's complexity, one focuses on the running time and data storage requirements of an algorithm and their dependence on the length of the input. The theory of computational complexity deals with the classification of problems into complexity classes depending on running time and input length. It is suspected that extremely shorter computational times are possible with quantum computers operating with quantum dynamics. Nevertheless, classical computers as well as quantum computers are based on the concept of *time reversibility*: The laws of nature under which they operate permit, in principle, their computing processes (other than the act of measurement and reading out in the case of quantum computers) to run backward in time.

The question arises whether it might also be possible to use computers simulating *time-irreversible processes* that are well known from biological evolution and the self-organization of the brain [17]. The emergence of cellular patterns was simulated for the first time in the 1950s by von Neumann's *cellular automata*. Computer experiments show the *emergence of patterns* that are familiar as the attractors of complex dynamic systems [18]. There are oscillating patterns of reversible automata and irreversible developments from initial states to final patterns. For example, in the case of a fixed point attractor, all developments of a cellular automaton develop to the equilibrium state of a fixed pattern which does not change in the future. As these developments are independent of their initial states, they cannot be reconstructed from the final equilibrium state.

Further on, there are cellular automata *without long-term predictions* of their time-depending pattern formation. These are cellular automata with the property of universal computability. *Universal computation* is a remarkable concept of *computational complexity* which dates back to Alan Turing's universal machine. A universal Turing machine can by definition simulate any Turing machine. According to the Church-Turing thesis, any algorithm or effective procedure can be realized by a Turing machine. Now Turing's famous Halting problem comes in. Following his proof, there is no algorithm which can decide for an arbitrary computer program and initial condition if it will stop or not in the long run. Consequently, for a system with universal computation (in the sense of a universal Turing machine), we cannot predict if it will stop in the long run or not. Assume that we were able to do that. Then, in the case of a universal Turing machine, we could also decide whether any Turing machine (which can be simulated by the universal machine) would stop or not. That is obviously a contradiction to Turing's result of the Halting problem. Thus, systems with universal computation are unpredictable. Unpredictability is obviously a high degree of complexity. It is absolutely amazing that systems with simple rules of behavior like cellular automata which can be understood by any child lead to complex dynamics which is no longer predictable.

There are at least some few cellular automata which definitely are Universal Turing machines. It demonstrates a striking *analogy of natural and computational processes* that even with simple initial conditions and locally reversible rules many dynamical systems can produce globally complex processes which cannot be predicted in the long run.

The paradigms of parallelism and connectivity are of current interest to engineers engaged in the design of *neurocomputers* and *neural networks*. They also work with simple rules of neural weighting simulating local connectivity of neurons in living brains. Patterns of neural self-assemblies are correlated with cognitive states. With simple local rules neural networks can produce complex behavior, again. In principle, it cannot be excluded that this approach will result in a technically feasible neural self-organization leading to systems with consciousness, and specifically with time awareness. Thus, computational systems (*e.g.*, robots) with spontaneously emerging features are possible.

In a technical co-evolution, *global communication networks* of mankind have *emerged* with similarity to self-organizing neural networks of the brain. Data traffic of the Internet is constructed by data packets with source and destination addresses. Local nodes of the net ('routers') determine the local path of each packet by using weighting tables with cost metrics for neighboring routers. There is no central supervisor, but there are only local rules of connectivity which can be compared to self-assembling neural nets. Buffering, sending, and resending activities of routers can cause high densities of data traffic spreading over the net with patterns of oscillation, congestion, and even chaos. Thus, again, simple local rules generate the *emergence of complex patterns of global behavior*.

Global information networks store millions of human information traces. They are *information memories* of human history, reflecting the *aging process of mankind as a complex dynamical system*. What is the future of mankind and its information systems in the universe? Cosmic evolution can also be considered as the aging process of a complex dynamical system. If we are living in a flat universe according to recent measurements, then relativistic cosmology forecasts an infinite expansion into the void with increasing dilution of energy and decay in Black Holes. Does it mean the decay of all information storages and memories of the past, including mankind, an *aging universe* with 'Cosmic Alzheimer'? Or may we believe in the fractal system of a bifurcating multiverse with the birth and recreation of new expanding universes? As far as we know there is a *cosmic arrow of time* in our universe, but it is still open where it is pointing at. With that question, we pass the boundary from science to religion. From a philosophical point of view, science is still following the traces of pre-Socratic philosophers starting in Greece in the 5^{th} century B.C.: Is the world in an irreversible change without beginning and ending in the sense of Heraclitus or is, according to Parmenides, only being real and change an illusion.

6. THE EMERGENCE OF TEMPORAL STRUCTURES FROM A PHILOSOPHICAL AND THEOLOGICAL POINT OF VIEW

The concept of spontaneous emergence of distinctive temporal, spatial or functional structures has an old philosophical tradition. In Aristotelian physics emergence means a teleological process transforming structureless matter into form. The growth of a plant or an organism from a seed or egg to its mature or adult form is a typical Aristotelian example of emergence. In the scholastic philosophy of the middle ages, the transformation from structureless matter to complete forms was called an actualization of potentiality. In modern times Kant criticized the ontological and teleological approach of Aristotelian tradition, because, following Newtonian mechanics, nature can only be explained by causal forces and not by goals and functions. Nevertheless, Kant recognized that classical mechanics failed in explaining the emergence of life. Thus, in his *Critique of Judgment*, he accepted teleological models as metaphoric interpretations of life, but not as physical explanations. For the first time, emergence of structure was described by a kind of "*self-organization*" (*autopoiesis*). But Kant proclaimed in a famous quotation: "The Newton of a blade of grass must still be found".

In the early 19th century, the ideas of self-organization (*autopoiesis*) were revisited during the German period of romantic literature and romantic natural philosophy. Inspired by the new ideas of electromagnetism, Schelling (1775-1854) explained emergence and self-organization by cyclic causality of opposite forces. In the tradition of scholasticism, he distinguished producing and emerging processes in nature (*natura naturans*) and the generated products of objects and organisms (*natura naturata*). *Emergence* and *self-organization* refer to *natura naturans*, but the *emerged products* of nature to *natura naturata*. Although Schelling's natural philosophy influenced famous physicists of his days (*e.g.*, H.C. Oerstedt, J.W. Ritter), he was also attacked by mathematicians and mathematical physicists, because "*emergence*" and "*self-organization*" seemed to be only idealistic speculations which could be neither experimentally analyzed nor mathematically formalized in those days.

In modern systems theory, the scientific situation has completely changed. *Emergence* and *self-organization* can be mathematized by nonlinear dynamics of complex systems [19]. Schelling's cyclic causality is made precise by mathematical nonlinearity. There are stochastic differential equations (*e.g.*, master equation) modeling phase transitions of complex systems. Phase transitions refer to steps of emergence. *Complexity* has become an interdisciplinary (or "transdisciplinary") topic cutting across all traditional disciplines of the natural and life sciences, engineering, economics, medicine, neuroscience, social and computer science. Kant's "*Newton of a blade of grass*" is found: Models of such systems can be successfully mapped onto quite diverse real-life situations like the climate, the coherent emission of light from lasers, chemical reaction-diffusion systems, biological cellular networks, the dynamics of stock markets and of the internet, earthquake statistics and prediction, freeway traffic, the human brain, or the formation of opinions in social systems, to name just some of successful applications. Although their scope and methodologies overlap somewhat, one can distinguish the following main concepts and tools of nonlinear systems theory: self-organization, emergence, nonlinear dynamics, synergetics, turbulence, dynamical systems, catastrophes, instabilities, stochastic processes, chaos, graphs and networks, cellular automata, adaptive systems, genetic algorithms and computational intelligence.

The *emergence of temporal structures* is explained by phase transitions of complex systems. Structures, organisms, and organizations have their own proper time and scaling. Thus, every individual being has its proper life time. Their time-depending trajectories are connected in a complex network of evolution and human history. Time is not only external clock-time, but a complex network of internal systems dynamics cutting across all layers of being (operator time). The individual time of a human being is embedded in the history of mankind which is part of cosmic time. In *theology*, birth, growth and death are the fundamental experiences of extential human time which are distinguished from God's eternity. *Eternity* is often defined as absence of time or a timeless state. But, according to Hawking's model of an initial universe without beginning, a timeless state can be mathematized by a path integral.

Timelessness is not sufficient to characterize eternity. From a theological point of view, eternity does not mean a physical state, but is related to the sense of human life. Is our individual life only a statistical trajectory in a probabilistic distribution of mankind evolving according to the stochastic laws of nonlinear dynamics? In the Jewish-Christian tradition, each unknown man in past and future is not forgotten or unimportant but personally loved and accepted. Eternity means that each human life is embedded in a *sense beyond the finite time of an individual life.* In the old Latin translation of Psalm 30,16 the *eternal sense of life* is described by a simple, but wonderful picture: "*In manibus tuis tempora mea*" (My times are in your hands). These simple words express more than all abstract formulations of theological and philosophical eschatologies. Obviously, they cannot be derived from mathematical theories, but need another source of *emergence* which we call *revelation*.

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The author(s) confirm that this chapter content has no conflict of interest.

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Edited by

Argyris Nicolaidis

Faculty of Science
Aristotle University of Thessaloniki
Thessaloniki
Greece

&

Wolfgang Achtner

Institute of Protestant Theology
Justus Liebig University
Giessen
Germany

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