1 The Central Nervous System as an Integrated Self-Organizing Process

1.1 Basic Principles of Self-Organizing Processes

The topos “self-organization” is used in connection with systems that can structure themselves “by themselves”, i.e. spontaneously and without control from the outside. Irreversibility is characteristic of self-organizing systems. Self-organization reveals a new form of creativity in matter.

Already Kant dealt with the idea of self-organization in this way: “One says far too little of nature and its capacity in organized products, if one calls this an analogue of art; because there one thinks of the artist (a rational being) apart from it. It rather organizes itself and in each species of its organized products, indeed after one and the same specimen in the whole, but nevertheless also with suitable deviations, which the self-preservation requires according to the circumstances”. [1] Given the limited depth of experience of science at the time, Kant declared the ability of matter to self-organize to be an “unexplored property.”

The term self-organization is defined by Ebeling and Feistel as follows: “By self-organization we understand processes that run far from equilibrium and lead to more complex structures of order through system-immanent driving forces”. [2] Modern theories of self-organization derive from many intellectual tributaries. Among them are cybernetics, which is connected with the name of Norbert Wiener, or information theory with Claude E. Shannon as its best-known representative. General systems theory, which is connected with the name of Bertalanffy, has contributed significantly to the development of the theory of self-organization. The theory of self-organization from a physical approach experienced a rapid development since the beginning of the 1970’s. Three works could be mentioned as starting points of this development:

P. Glansdorff, I. Prigogine: Thermodynamic Theory of Structure, Stability, and Fluctuations (1971), on the other hand the work “Synergetics” by Hermann Haken (1973) as well as “The Self-organization of Matter and the Evolution of Biological Macromolecules” by Manfred Eigen (1971). Prigogine had already been working on the problems of irreversible thermodynamics since the 1940s, and in 1971 he succeeded in transferring its formalism to disequilibrium processes and publishing this in the above-mentioned paper. In his studies on the thermodynamics of irreversible processes, Ilya Prigogine was able to show impressively that even under conditions far from equilibrium, systems can develop into stationary non-equilibrium states with an approximately linear behavior. However, in order to maintain this state, a continuous supply of energy is required. At a further distance from the equilibrium state, for example as a result of changes in the boundary conditions of the system, at some point such states are reached where irreversibility occurs. Self-organization requires not only a supercritical distance to equilibrium but also non-linear dynamics of the system, which are usually caused by feedback effects. Under the prevailing conditions of non-linearity, such states of instability are possible, which can sponta-

1 Kant, I. (1924): Kritik der Urteilskraft 65, B 293, 6th ed. ed. by K. Vorländer. Leipzig, p. 237.
2 Ebeling, W., Feistel, R. (1994): Chaos and cosmos. Spektrum Akademischer Verlag Heidelberg Berlin Oxford, p. 35.

neously lead to the formation of new spatial, temporal or spatio-temporal patterns and structures. Dissipative structures are manifestations of self-organization processes, which can take different forms in the individual layers of reality. In chemical systems; these can be rhythmical changes of the composition or concentration of the substances. These are coherent movements of billions of molecules. Non-linear feedback interactions between the system components are especially characteristic for all living systems, as we know it from the catalytic networks of enzymes and nucleotides. Similar patterns can be observed in the behavior of insect populations and even in the realm of human societies. The overwhelming majority of disease processes follow self-organizational dynamics characterized by feedback phenomena: the dynamic pattern formations in the domain of the major integrity-maintaining systems of humans, starting at the level of genes and extending to the immune system and other systems of the body, emerge from non-local self-organizational processes. We will show that the behavior of neural networks at all levels of the central nervous system also takes place on the basis of self-organizational processes, and it is reasonable to assume that the entire system of evolution takes place on the basis of such processes. The development of dissipative systems is characterized by different phases: In one phase, self-organizational systems evolve on the basis of deterministic or quasi-deterministic laws. Here, the mean values of the variables follow a causal development. In another phase, the system can enter a state of increasing fluctuations, so that the global behavior of the system undergoes an abrupt change. As a consequence, beyond the critical parameters, certain modes of fluctuation are amplified, which contain the seeds of new structures. The structures formed by self-organization are, as a rule, conditioned by boundary values as well as by internal factors. [3] Thus, biological systems form new forms at supercritical distance from the equilibrium state under supply of high-quality energy. Systems undergoing transitions to such states are consequently called self-organizing systems. Concepts such as sensitivity, instability, stochasticity and branching (bifurcation) are associated with the situations far from equilibrium.

Instability means that fluctuations can determine the global development of a system. Consequently, events can no longer be reduced to a regular, reproducible behavior. Rather, whether events become causally effective depends on the circumstances: One and the same event can be completely negligible if the system is stable and the same event can become essential for the behavior of the system if the system is on the way in direction towards a non-equilibrium state. Systems are then no longer describable in a controllable way. Thus, according to Prigogine, a narrative element enters physics. [4] At the so-called branching points, i.e. in the area of critical threshold values, the system behavior becomes increasingly unstable and can develop towards different stable modes of operation.

Fluctuations and abrupt changes in the course can be observed by the clinician in a variety of disease processes. Every clinician is familiar with these critical situations in which it is no longer possible to predict how a patient's condition will develop. At a branching point, which can be assumed to be the simplest, one state becomes unstable while two other possible stable states emerge symmetrically. At this point, the behavior of the system is no longer deterministic; rather, an insur-

3 Ebeling, W., Feistel, R. (1994): Chaos and cosmos. Spektrum Akademischer Verlag. Heidelberg Berlin Oxford, p. 41
4 Prigogine, I., Stengers, I. (1993): The paradox of time, p 93.

mountable probabilistic moment emerges in the branching situations. The probability of finding the system in one of the two states after a branching point is then 50:50. Furthermore, a system that is pushed away from the equilibrium state may pass through many zones of instability in which qualitative changes in its behavior may occur – for example, it may turn into chaotic behavior, i.e., its behavior is only partially coherent, its behavior is governed by far-reaching correlations, and it has become unpredictable. [5]Examples of self-organization processes can be found manifold in the fields of chemistry, physics, astronomy, and especially in living systems.

Self-organization is the elementary process of evolution, which can be understood as an unlimited sequence of self-organizing processes. In the sense of a self-organizing narrative, the processes on earth and in the cosmos are evolutionary processes which can only be understood in the context of their history, i.e. the whole chain of causative self-organizing processes. Processes of self-organization often develop from kinetic transitions which can occur with increasing deviation from equilibrium at certain critical parameter values. Here the science of synergetics has done valuable work.

1.2 Synergetic Aspects in the Organization of the Central Nervous System

Synergetics is a term proposed by Hermann Haken (1969,1977) to outline an interdisciplinary field of research that aims to understand how patterns form in open non-equilibrium states. [6] Living systems depend on a continuous influx of matter and/or energy. How can many individual parts of a system cooperate to evolve new spatiotemporal structures or processes? In this field tremendous advances have been made in how nature generates patterns in open physical, chemical, and biological systems. [7] The synergetic design principles of a theory of self-organization are also based on the concepts of instability and fluctuations and, moreover, on the concepts of order parameters and enslavement. Haken's paradigmatic starting model was the laser, which is used to demonstrate how the monochromatic laser light can be created by the coherent interaction of components, i.e. in this case electrons. [8]Normal white light from an incandescent lamp consists of a mixture of waves of different frequency and phase. In contrast, the entire energy of the electric field of a laser beam originates from a single monochromatic wave train. This self-organizing behavior of laser light does not result from regulatory influences from outside, but from cooperation of the components of the laser beam with each other.

A system can adopt several configurations or behavior patterns, also called modes. If the external boundary conditions change, such a system can enter a new mode. Quantities describing collective modes are called order parameters.

5 Prigogine,I, Stengers, I. (1993): The Paradox of Time, p. 97

6 Haken H. (1969): Lecture at the University of Stuttgart.
Haken H. (1975): Cooperative Phenomena in Systems Far from Thermal Equilibrium and in Non-Physical Systems. I: Reviews of Modern Physics 47, pp. 67-121.
Haken, H. (1977): Synergetics: An Introduction. Springer Verlag Berlin

7 Kelso J.A.S. (1997): New laws are to be expected in the organism: synergetics of brain and behavior. Spektrum Akademischer Verlag Heidelberg Berlin Oxford, pp. 157-183.

8 Haken, H. (1983): Synergetik. Eine Einführung, Berlin, Springer Verlag.

A similar approach underlies Manfred Eigen's theory of a cooperative network, which he has called a hypercycle.[9]

In order to understand the self-organized formation of patterns in complex systems, the mathematical tools of non-linear dynamics had to be developed beforehand. In physics, the transitions between different states of matter – solid, liquid, gas - are called phase transitions. When steam turns into ice this is an example of a transition from disorder to order. Non-linear processes that occur far from equilibrium are rich enough to allow biological self-organization. Biological systems, including the brain, exist near boundaries that separate regular from irregular behavior. Thus, they survive at the boundary of instability. As will be shown, the brain, as well as the central nervous system as a whole, is also an example of an active self-organizing system. One of the essential core points of synergetics is embodied in the concept of complexity: There is strong evidence for the assumption that biological systems operate multifunctionally i.e., several patterns are formed at the same time. That is, the same set of system components can self- organize for different functions or different components can self-organize for the same function. The processes that determine how a pattern is selected from myriads of possibilities are captured by the laws of self-organization. This determination takes place in the context of cooperation and competition. In this context, Herrman Haken formulated the principle of order parameters on the following bases: In the study of self-organization processes, usually only one time scala is the focus of interest. All faster processes are considered to be stationary or considered quasi-stationary and the corresponding dynamic variables are replaced by their stationary or mean values. These variables have been called "enslaved" modes by Haken. The much slower processes are taken as statistical external conditions and their variables are simply fixed and called control parameters. The really interesting variables are thus the order parameters, which in most cases are only a few variables, i.e., contain from 1-5. A one-dimensional system would therefore be a system with only one order parameter.

A prime example of spontaneous pattern formation is Rayleigh- Bénard instability. Here, a liquid is heated. All molecules in the liquid initially follow a random, i.e. disordered, motion. If the temperature difference between the surface and the lower surface of the liquid level is small, no visible motion of the liquid is visible on the macroscopic scale. At this stage, the heat between the particles is still distributed as microscopic movement. Nevertheless, there is also a small temperature gradient between top and bottom. The system is activated by a temperature gradient, which is called a control parameter in the language of synergetics. If this control parameter grows, instability develops and the fluid begins to move in roll-like patterns reminiscent of honeycombs: Billions of molecules are in a cooperative relationship and develop patterns in space and time. In synergetics, the amplitude of the rolling motion plays the role of an order parameter or collective variable: All parts of the fluid are no longer independent but are sucked into an ordered cooperative mode. Close to instability, the behavior of the macroscopic system is governed only by a few collective modes, i.e., the order parameters. They are the only variables to exhaustively describe evolving patterns. This compression of the degrees of freedom close to the critical points is called the enslavement principle, to which Haken has given a mathematical form for a large class of systems: New laws are to be expected in the

9 Eigen, M (1987): Steps to Life. Die frühe Evolution im Visier der Molekularbiologie, Piper München.

organism: synergetics of brain and behavior. [10] This temperature gradient is called a control parameter in the language of synergetics. This visible rolling movement is called convection in common parlance. The reason for convection is that the cooler liquid, being at the top of the vessel, is denser and tends to sink down, while the warmer and less dense liquid at the heated bottom of the vessel tends to rise. Other examples represent the formation of typical concentration patterns in chemical reactions, such as the Belousov-Zhabotinsky reaction, but also the onset of coherent laser light. What all these reactions have in common is that the formation of the patterns comes about as a result of the cooperative dynamics of the system – without any outside interference. These patterns are products of self-organization. The order parameter is established by the cooperation of the various system components, which in turn determines the behavior of the individual parts.

We will encounter the example of circular causality again at numerous points in the book. The result of the mentioned processes is an enormous compression of information. Circular causality is typical of non-linear processes far from thermodynamic equilibrium: information does not flow in one direction, for example from DNA to RNA and not vice versa, as was assumed earlier. Rather, the information flows back again and again. Self-organizing systems are also characterized by other properties such as fluctuation and symmetry breaking. The interplay between randomness (stochastic) and selection determines the patterns that are formed. Fluctuations continually test the stability of states and allow the system to discover new ones. An excellent brief concise and easy to understand overview of the importance of fluctuation can be found in the article by J.A.S. Kelso and H. Haken on "New Laws in Organism: Synergetics of Brain and Behavior". [11] In self-organizing systems, new patterns of ever-increasing complexity can form in this way. The system can be driven in such a way that it enters a turbulent state. The behavior of the systems can change discontinuously and abruptly when a control parameter exceeds a critical value. Non-equilibrium phase transitions may occur, or bifurcations may occur. Patterns that occur preferentially at nonequilibrium states are called attractors: Many independent trajectories with different initial conditions converge over time to a common attractor solution. The resulting pattern dynamics is non-linear. This reveals the rich complexity of behavior, including random, stochastic behavior or behavior analogous to deterministic chaos in the systems of life. These basic variations of patterns can be observed especially in the functions of neuronal networks, especially of the brain.

Today's complex world can thus only be understood as the result of a comprehensive fundamental process of self-organization. The evolution of living systems is not only an evolution on the basis of the laws of selection, selection, survival of the fittest, it is rather in its essence a self-organizing and thus creative process underlying all biological matter. Evolution is creative.

10 Spektrum Akademischer Verlag Heidelberg Berlin Oxford (1997) pp. 161-162). Haken, H. (1977): Synergetics: An Introduction. Springer Verlag, Berlin.

11 In: What is Life? The Future of Biology, J.A.S. (1997): New laws are at hand in the organism: synergetics of brain and behavior. Spektrum Akademischer Verlag Heidelberg Berlin Oxford, pp. 157-183. Haken, H. (1983): Synergetics. Eine Einführung, Berlin, Springer Verlag.

1.3 Chaos and Order in Self-Organizing Systems

Every chemical reaction, every pattern formed in the neuronal networks, every representation in the brain, every process in the course of a disease, indeed every newly formed piece of information marks a difference between the past and future. According to the second law of thermodynamics established by Clausius, all natural processes cause an increase of entropy. Every chemical reaction develops without influence from the outside towards a state of equilibrium and thus towards a state of uniformity, which leads to the disappearance of their occasions. For a long time, turbulence in liquids was considered a typical example of disorder and a crystal appeared as the epitome of order. According to chaos theory, in particular according to the work of I. Prigogine, a turbulent system is in fact an ordered system: In the state of turbulence, the motions of two molecules, between which there is a macroscopic distance, are correlated. In contrast, the atoms of a crystal oscillate incoherently around their equilibrium position: the crystal is disordered with respect to its excitation modes (its thermal motion)[12]. The construction of complex biomolecules is based on the destruction of other molecules by metabolism, with the coupled processes corresponding in sum to a positive entropy generation. Both order and disorder are components and products of correlated processes of development. Dissipative structures are those structures which can exist only as long as the system dissipates energy and generates entropy. According to Prigogine, the entropy change of any system can be divided into:

- Entropy production $_{diS}$ inside a system in the wake of the irreversible processes taking place there, and
- in the entropy flow $_{deS}$ across the boundaries of the system into the environment or out of it following formula:

$$dS = diS + deS$$

For reversible processes, dis = 0. For irreversible processes, $_{diS} > 0$.[13]

The difference between a closed and open system is that in a closed system no information is discarded. Thus, the behavior of the system is reversible and the phase volumes are preserved. In open systems, information is lost to the environment, the behavior of the system is not reversible, and the phase volume of the system may decrease. For living systems, it can thus be stated that the increasing entropy in these systems as a result of the irreversibly occurring processes is compensated again by an outward transfer to the environment.

Under the prevailing conditions of non-linearity, instabilities are possible, which may result in the spontaneous formation of new spatial, temporal or spatio-temporal patterns and structures.

An example from hydrodynamics for the spontaneous pattern formation in dissipative systems is the already above mentioned “Bénard instability”. The occurrence of collective flow dynamics is equivalent to a breaking of spatial symmetry: near equilibrium, the motion of the molecules was incoherent and random. When heat was added, the molecules assumed a coherent collective behavior. [14]

12 Prigogine, I., Stengers, I. (1993): The paradox of time S 80.
13 Prigogine I. (1969): Structure, Dissipation and Life. In: Theoretical Physics and Biology (Ed. M. Marois). North Holland, Amsterdam
14 Prigogine, I., Stengers, I. (1993): The paradox of time. Piper Verlag München Zürich, pp. 82-83.

1.4 Emergence as a Fundamental Property of Self-Organizing Systems

Both in the theory of self-organizing systems and in the cognitive sciences, the concept of emergence as a kind of middle ground between vitalism and mechanism is attracting interest.

In the natural sciences, this term is used to describe the behavior of complex systems with spontaneous pattern formation. In the cognitive sciences and in the philosophy of mind this term is used in the context of the impossibility to reduce mental processes to physical ones, i.e., processes which can be defined by the laws of nature. It is therefore not surprising that different conceptual varieties are mentioned in this context. Thus, a distinction is made between weak, synchronic and diachronic (structural) emergentism. Of these conceptual interpretations, weak emergentism is compatible with some reductionist positions. This form of weak emergentism provides a common ground for most sophisticated emergent theories. Diachronic emergentism mainly considers aspects of unpredictability and novelty, while synchronous emergentism mainly emphasizes the feature of irreducibility. The theses of weak emergentism are mainly based on the theses of a physical monism, the thesis of systemic properties and the thesis of synchronous determinacy. These theses are compatible with reductionist positions. In the thesis of physical monism, for example, conceptual assignments such as "res cogitans" or "Entelechy" are not included.

Living systems, including living beings with consciousness, consist of the same building blocks as inanimate objects. Emergent properties, dispositions or behaviors are instantiated in physical monism from physical components only. According to the thesis of systemic properties, the ability to fly or to move, for example, are to be described as such properties that emerge from the collective interaction of the system components and that are not primary components of the system itself. They thus reflect the system as a whole, whereas no part of this system has such a property. The thesis of synchronic determinacy specifies more the type of relationship that exists between the microstructure of a system and its emergent properties. This thesis aims at the fact that there can be no difference in systemic properties without there being at the same time differences in arrangement or properties of system components.[15] In nature, the occurrence of new emergent properties is by no means rare but can be found everywhere. The world is full of properties that occur at the system level rather than at the level of system components.

In connection with the concept of emergence, the difficulty of solving the emergence of cognition and consciousness satisfactorily with the means of physics or neurobiology reveals itself.

Neurobiologists and philosophers repeatedly argue that neurobiological activity, the representation of sensory events in the brain and thus also consciousness are nothing else than the brain itself, that consciousness and brain are thus identical in nature. Thus, if not today, at least in the foreseeable future, consciousness can be completely described in physical parameters.

However, it is to be held against this that physics is not even able to deliver an answer to the question what matter and energy are in the actual sense. Physics only

15 Stephan, A. (2006): On the role of the concept of emergence in philosophy of mind and cognitive science. In: D. Sturma: Philosophy and Neuroscience. Suhrkamp Verlag Frankfurt a.M., pp. 147-149.

determines measuring methods and establishes theories on the basis of the connection of measuring results. Mathematics and physics are according to their approach gigantic syntactic buildings, because they treat their questions in an abstract space of sign evaluations. Mathematical formulas have their meaning, but this meaning can be traced back to sign mechanisms. The physical formula refers to the real world without being this world itself. By its very nature, it is a reduction in that it reduces the meaning of a measurement to a dimension for which numerical values are sufficient. [16] Physical theories thus contain information about nature in a certain way, because with it we are able to gain concrete statements about the outcome of an experiment. But there is no direct short circuit between nature and its theoretical description.

The theoretical description of natural phenomena in physics thus consists exclusively in the connection of measured quantities. Physics does not ask for the essence or even for the sense of realities. Physics does not know what mass and energy "really" are. Nevertheless, within the framework of scientific concepts, precise mathematical terms have been formulated with which selected properties and their behavior under observational conditions can be described.

Science is always limited to real definitions that specify the type of measurement and the units in which it is measured.

16 Zemnek: In Folberth, p. 25.

2 Attractors as Models for the Self-Organization Processes of Living Systems

2.1 Mathematical Basics

The term attractor is a profound concept that connects the mirror worlds of order and chaos in the processes of living systems.

The orbital curves within the scope of Newtonian physics follow continuous processes.

Dissipative systems are systems with a special kind of friction. A characteristic feature is the loss of energy: A pendulum swinging freely in the air shows dissipation due to friction at the air molecules and has to come to rest at some point if energy is not supplied from outside. With the models of attractors many self-organizing processes in the body and thus also in the area of the central nervous system can be represented at least in principle and under appropriate generalization. The mathematical framework of attractors is based on non-linear differential equations.

There is a non-linear relationship between the input Xn and the output Xn+1 of a biological process, i.e. the dynamic law xn+1 = f(Xn,C) is more complex than the simple proportionality Xn+1 = KXn. The quality of the solutions of this equation depends on the quantity C entered in each iterative process step. These processes strive towards three possible endings:

1. The final value X approaches a limit value which it reaches in the asymptotic, i.e., at infinity, which is the case for linear differential equations.
2. The process leads into a harmonic oscillation (pendulum motion, planetary orbit).
3. The process has an indeterminate outcome, which is thus unpredictable.

In physical and physiological reality, all three possibilities are present. Most occurring systems are mixed systems with partially chaotic solutions. [17]

Abrupt changes of direction are typical for non-linear dynamics, random movements and a high sensitivity of the systems to changes of the initial conditions. The dynamics of these complex systems is the content of chaos theory, which has become one of the most fruitful branches of modern natural sciences. Many scientific disciplines work within the scope of this chaos theory, dealing for example with weather observations, with the shock waves of supersonic airplanes, with the often-chaotic swings of the stock markets. The same applies to the chaotic rhythm of the heartbeat and the electrical brain activity, the fluctuations of blood pressure, the hormonal systems up to the large control and regulating circuits of the organism.

The almost infinite variability of patterns in flowing water has inspired artists throughout the ages. The genius Leonardo da Vinci also studied the flow properties of water intensively. He was able to create fascinating and lifelike sketches of turbulence and vortex formation. Turbulence is a typical property of chaos. The phenomena of turbulence are of great importance to many fields of science, from astronomy, aviation and meteorology to medicine. Moderate turbulences are physiologically detectable in the peripheral blood vessels or in the area of the heart valves in every

17 Cramer, F. (1993): Chaos und Ordnung. Insel-Verlag, p.185.

healthy person, strong and flow-relevant turbulences in the area of the heart valves, on the other hand, can be indicative of insufficient heart valves or of arteriosclerotic vasoconstrictions.

Stationary turbulence is also called attractors. The different states through which a dynamic system passes are modeled by so-called trajectories. The manifold modes of motion of the billions of water particles in a flowing stream can thus be represented on specific trajectories.

The motions of water particles in the catchment area of a turbulence follow trajectories on approximately circular trajectories around the center of this turbulence, i.e., they build up an attractor as a model of a relatively stable motion pattern in a flowing dynamical system.

In 1976, Otto E. Rössler made the discovery how chaos can be constructed in a time-continuous system in a simple elementary way. For this purpose, he succeeded in developing a simple mathematical formalism, which can also be understood by a layman, which is the basis of the model of his attractor:[18]

$$x' = -(y + z)$$

so:

$$x' = -(y + z)$$
$$y' = x + ay$$
$$z' = b + xz + xz - cz$$

The three coefficients a, b, c are constants that can be suitably chosen. The parameters a and b remain fixed, while c is varied:

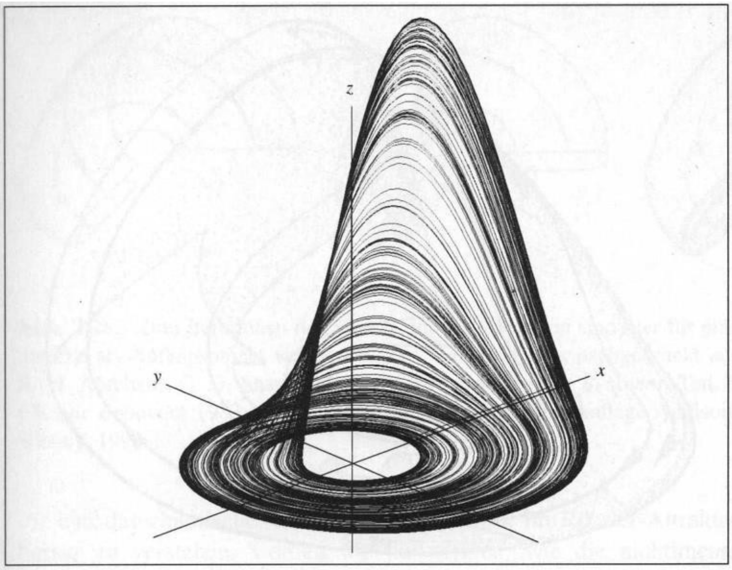
$$a = 0.2, b = 0.2$$

Thus, there are three variables in this system: x, y, z. The system can therefore be conceived as a system of laws of motion for a point with coordinates (x, x, z) in three-dimensional space. Given initial coordinates (x_0 , y_0 , z_0), the system defines a unique trajectory that is parametrized by time t and satisfies the equations at all times. If the coordinates of this trajectory at time t are denoted by x(t), y(t), z(t) this means:

$$x'(t) = -(y(t) + z(t))$$
$$y'(t) = x(t) + ay(t)\ z'(t) = b + x(t)z(t) - cz(t)$$

If this trajectory is plotted with the coordinates (x, y, z) in three-dimensional space, a visual impression of this Rössler attractor is obtained (see figure).

18 Rössler, O. E. (1976): An equation for continuous chaos, Phys. Lett. 57A, 379-398.



The trajectories on the attractor wind out of the origin and mostly run near the xy plane. If the distance of an orbit from the origin exceeds a critical value, the orbit curve leads out of the xy plane. After it has reached a maximum z-value it is bent again into that part of the attractor which winds around the origin near the xy plane: The closer the deflection is in the z-direction, the closer the trajectory comes back to the origin. This process is repeated again and again. [19]

Attractors as mathematical objects represent specific regions in a phase space towards which the trajectories of the system processes converge. They can be in the form of a point, or they can be in the form of periodic loops, for example. Periodic patterns are called limit cycles. Depending on their basic mathematical framework, they can model even much more complex entities, for example a geometric shape of the type of a torus. Attractors can also have fractal geometric properties, which are discussed below.

The long-term behavior of dissipative systems can thus settle down to comparatively "simple" motion patterns such as limit cycles.

An example of a limit cycle from everyday reality would be the pendulum movements of a mechanical clockwork: If the pendulum approaches the highest point of its swing path, it slows down its speed more and more and comes to rest for a short time at this highest point. From this resting point, it then moves in the opposite direction, gaining speed again until it reaches the lowest point of its path at maximum speed. Afterwards it strives again with decreasing speed towards the highest point on the opposite side. In an ideal Newtonian world without friction losses, the pendulum could continue to swing for eternity. In physical reality, however, the pendulum moves back and forth between velocity extremes, with the velocity at the two points farthest from its center position approaching zero. This back and forth swinging of the pendulum can be represented under ideal conditions in vacuum as a complete circular form in a state space. If the pendulum is given an additional impulse by

19 Peitgen, H. O., Jürgens, H., Saupe, D. (1998'): Chaos. Building blocks of order. Rowohlt Verlag, pp. 250-252.

a strong push, it increases its velocity accordingly, thus the pendulum swings out further and the diameter of its circular form increases accordingly. Under realistic conditions, however, air resistance must also be taken into account. For example, the pendulum also swings against the air resistance and loses energy. With time, its deflections become smaller and smaller and its speed slows down. In such a real state space, the pendulum thus describes in the wake of these continuous energy losses a spiral motion inwards until the pendulum finally has to come to rest in a center point with an impulse and a deflection of zero. This center, towards which the pendulum moves, is called attractor by mathematicians. Attractors thus exert a kind of attraction on dynamic systems. In a mechanical clock exactly adjusted by the clockmaker, the pendulum receives a shock and thus an energy supply at regular intervals. This energy supply is exactly timed to the oscillation modes. That is, the clock does not slow down with time and does not need to be readjusted. The clock thus always indicates the exact time.

Boundary cycles can be seen in many areas of nature. Population studies of predators and prey provide an impressive example of such a limit cycle: The behavior between prey and predator also takes place in the manner of an oscillation mode between predator and prey, similar to a pendulum swing: from year to year, periodically once the carp and once the pike reach their highest population numbers. It is known from studies that the numbers of pike and carp always approach their original limit cycle. Even if a disease nearly wipes out the carp, the population will spiral back to its original limit cycle under improved conditions. Such systems are thus remarkably stable in their inherent dynamics.

Boundary cycles can also enter into mutual interactions. This results in higher dimensional attractor structures, for example torus attractors. Mathematics can deal with tori of arbitrary high dimension. Coupled motions of a pair of oscillators can be seen as a line wrapping around a torus. This shows that the surface of a torus is itself the attractor. If the periods or frequencies of the two coupled systems are in a simple relationship, for example, if the frequency of one system is twice the frequency of the other system, then the two turns around the torus system fit together exactly: The combined system is strictly periodic. However, the ratio of coupled oscillations can also be "irrational". This is the case with positive and negative feedbacks: while rational numbers, for example ½, ¼ etc. can be represented as a decimal fraction with a finite number of digits, or as a simple decimal fraction 1/3, irrational numbers can no longer be written down as fractions. In their representation as decimal numbers, an infinite number of digits occur without repeating patterns. The digits are arranged as if by chance. So if the ratio of the frequencies of coupled oscillations results in an irrational number, an imaginary point wanders around the torus and never meets itself again: The system can be called quasiperiodic.[20] There are infinitely many rational numbers, but mathematicians have shown that the number of irrational numbers is much larger. It seems to be the case that quasiperiodic systems dominate the universe and thus the processes of life. It is also known that most planetary orbits are quasi-periodic. "Gaps" have been found in Saturn's rings caused by non-linear interactions (positive feedbacks) by Saturn's inner satellites. These gaps correspond to simple ratios between the rotational periods of the rings and the moons that cause these perturbations. Detailed investigations

20 Bigss, J., Peat, F. D. (1993): The discovery of chaos. Dtv Taschenbuch München, pp. 55-56.

reveal that gaps again exist within these gaps, as if they were cascades of reflections of an object standing between two mirrors. Mathematically, this means that the torus of Saturn's rings is splitting into smaller and smaller tori. Some of these tori remain stable, but others do not. [21]

2.2 Chaos and Strange Attractors

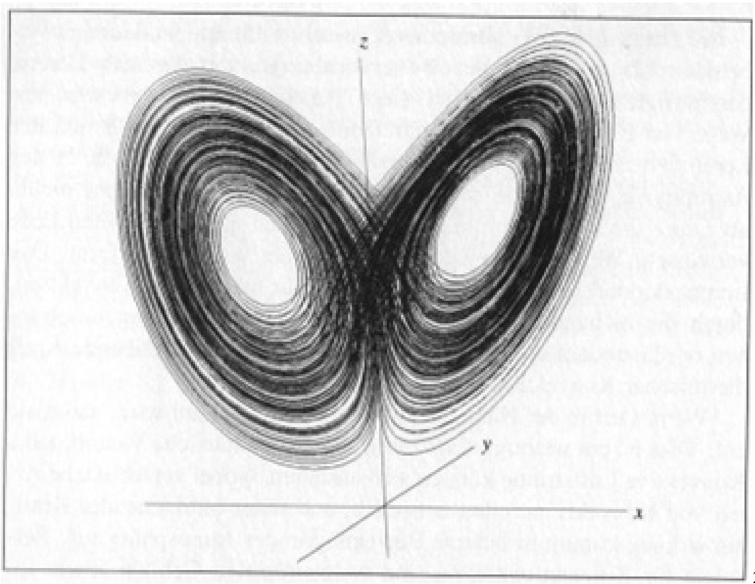
In non-linear feedback systems, and this is also and especially true for the systems of life, randomness and order are interwoven: The simple includes the complex and the complex in turn includes the simple. Regularity and chaos alternate on smaller and smaller scales, which is called "fractal". Chaos is a subtle form of order.
Turbulence is an example of strange attractors: In turbulence, the system has assumed many degrees of freedom. Turbulence can occur in many places in the organism and be relevant to disease. For example, turbulence in the cardiovascular system can lead to thromboembolic complications. In an increasingly turbulent flow, each flow element can serve as a trigger of coincidences for every other part. The flow generates the coincidences from its wholeness. The Liapunov number is a measure of how fast neighboring points, or how fast neighboring elements in a flow move away from each other, it thus gives a measure of how fast correlations in a system can be destroyed and how fast the effect of a disturbance can spread.
Strange attractors are characterized by a highly complex structure and they are characterized by chaotic properties.
Strange attractors are fractals as geometrical objects and as dynamical objects they are chaotic. The first strange attractor to become widely known in the natural sciences in 1962 is the Lorenz attractor. The geometrical model of this attractor was designed by John Guckenheimer and Philip Holmes. [22]
13 years before the establishment of the above-mentioned Rössler attractor, the meteorologist Edward N. Lorenz designed an attractor named after him and often presented in popular science literature, whose equations are similar to those of the Rössler attractor.[23]

$$x' = -\sigma x + \sigma y \quad y' = Rx - y - xz \quad z' = -Bz + xy$$

The numbers σ, B, and R are the physical parameters defined by Lorenz on

$$\sigma = 10, B = 3/8, R = 28$$

21 Briggs, J., Pea, D. (1993): The discovery of chaos. Dtv Verlag München, p. 61.
22 Guckenheimer, J., Holmes, P. (1983): Nonlinear Oscillations, Dynamical Systems, and Bifurcations of Vector Fields, Springer Verlag New York.
23 Lorenz, E. N. (1963): Deterministic nonperiodic flow, J. Atmos. Sci. 20, pp.130-141).



24

The figure shows the associated attractor, which, in contrast to the Rössler attractor, has two compartments in which the trajectories spiral outward.

The Lorenz model is a model for thermal convection that can now be considered classical: If air is heated near the earth's surface, the air rises and various types of convection cells can form, including the Bénard cells described above. In these hexagonal or cylindrical cells, the heated air rises in the center, cools down in higher air layers and sinks down again at the edge of the cells. In this way, turbulent movements can occur in the atmosphere if sufficient force is applied.

The reconstruction of chaotic attractors leads to algorithms that can be used to determine numerical quantities such as dimensions and Lyapunov exponent. Such numerical quantities serve as a measure of how chaotic and strange an attractor is. Mathematically, an attractor comprises a finite set of states through which a system can pass. In reality however, never exactly the same but always only similar states are passed through: Satellites never return exactly to their starting point on their orbit around the earth, but they always deviate from it by a more or less large amount. The orbital curves of satellites thus do not follow an exact circular path in an exact periodicity, they do not arrive exactly at their starting point after an orbit around the Earth, they rather approach it only with more or less large deviations. Such a behavior is called ergodicity.

If a quasi-periodic process were to lead to a quasi-periodic circular process, only one intersection point would be found, since all points of the process are located on this one and ideal circular line. In quasi-periodic processes, as for example in the orbit of a satellite around the earth, one gets a large amount of different intersections, in the extreme case, with an infinite number of quasi-periodic passes, also leading to an infinite amount of intersections. In case of quasiperiodic processes, a whole network of intersections would be represented, if one wanted to represent them in a

24 Peitgen, H. O. et al. (1998): Chaos Bausteine der Ordnung. Rowohlt Verlag, p. 263.

phase space. Such lattice networks, also called homoclinic tangles, are said to have once caused Poincare to say: "Things are so bizarre that I cannot bear to think about them any further".

In the non-linear feedback systems, randomness and order are interwoven, the simple includes the complex and the complex in turn includes the simple. Regularity and chaos alternate on progressively smaller scales, which is called "fractal". Chaos is a subtle form of order.

Nature's complex systems maintain their blueprints and appearance in detail on smaller and smaller scales. The fractal branching patterns of the large arteries show almost the same complex appearance on smaller and smaller scales down to the capillaries. Fractals can be described as lines characterized by infinite detail, for example, by infinite lengths, by fractional number dimensions, and by self-similarity, and they can be generated by iteration. A typical example of such a fractal curve is the curve named after Guiseppe Peano, which has such a complex structure that it has surface character. This curve is characterized by such extreme irregularity when observed on smaller and smaller scales, so that its fractal dimension is approximately two. It forms so many turns that it reaches every point of a surface. And there is no overlapping anywhere. Another example for such a fractal is the so-called Koch curve, which shows strong similarities to a snowflake. This curve emerges from an iteration process in the course of which the same steps are repeated on smaller and smaller scales. A Mandelbrot set with the Julia sets surrounding and controlled by it emerges from a similar non-linear equation.

These known figures arise in feedback equations

$$Xn+1 = X2n + C$$

where C is a complex constant. The Mandelbrot set, which is also called appleman because of its shape, has fractal dimensions at its chaotic edges and at higher and higher resolution new and refined images of Julia sets appear.

From this, the connections of attractors and fractals become apparent: On a strange attractor those traces of system states come to the representation, which a system passes through in the phase space with the time.

2.3 Attractors and Fractals in the Organism

The vast majority of systems in our organism are dissipative self-organizational systems that establish and maintain their sources of order at the various levels by converging on smaller attractors in their phase spaces. The actual source of order existing in them emerges from the way dynamical trajectories converge on smaller attractors in the phase space of the system:

The entire integrative attractor of the brain builds up from the dynamic trajectors converging on smaller attractors:

It has been shown that the trajectories on complex attractors or strange attractors are characterized by an immensely high complexity. Strange attractors thus model fractal curves. Fractal curves and fractal objects are self-similar on increasingly smaller scales: for systems under the influence of a strange attractor, each individual form of motion represents a mirror image of the entire process. In the complex systems of life, including medicine, but especially in the realms of central nervous system systems, we are dealing with attractor formations constructed by a large number of variables. These attractors also interact with each other, and trajectories can jump from one attractor to another attractor. The dynamics of these systems is non-linear, partly continuous and thus differentiable, but partly jumpy and undifferentiable and often close to chaos and turbulence. We can recognize chaotic states as states of an implicit order, which can be found again and again in the geometric structure of complex attractor structures. The principle of self-similarity emerges from the iteration of the basic computational steps, where the result of one computational step appears as input in the next computational step. This explains the repetition of details on smaller and smaller scales. Self-similarity can be demonstrated at all levels of the world, and it appears at the cellular level, in the structure of organs, all the way to the distribution of galaxies in the universe: the detail reflects the whole, and the course of a trajectory on an attractor reflects the structural dynamics of the whole. The world of non- linear self-organizing processes is a world of wholeness. Fractals are on the one hand extraordinarily complex and yet simple. They are complex because of their infinite details and their unique mathematical properties. No fractal is completely the same as any other. And yet they are simple because they are created in a sequence of continuous iterations. This is one of the reasons why such complex systems cannot be analyzed completely. For these reasons of self-similarity and iteration, complex systems are ultimately also not completely analyzable, because they are not completely reducible to their parts. This is true for all self-organizing systems of the body and especially for the states of the brain. It can be said in advance that every sensory perception is stored by fractional trajectories on the attractors of neuronal activity and thus reflects the states of the systems as a whole. Each trajectory is stored on the detail of such attractors, which appears more and more subtle and nested up to infinity, at each enlargement step. A storage problem does not arise insofar because the storage capacity arises from the complex geometry of attractors and their fine structure appearing more and more complex in detail. Each detail reflects the whole and the whole acts back on the detail.

2.4 Disease and Self-Organizing Processes: An Introduction

High degrees of interconnections and interactions speak for high complexity. Complex non-linear systems, for example the systems of metabolism, take place in physiological states close to chaos. These are not commonly understood as chaotic states in the sense of almost complete disorder, but stable states of high sensitivity and flexibility: All systems of the organism, starting with the DNA via the cells and organs up to the central nervous system, must be able to react flexibly to the constantly changing conditions.

For example, the contractions of the heart do not follow the pattern of an exact periodic pendulum beat; rather, a completely uniform periodic heartbeat could provide evidence of heart disease. The complex branching of vascular trees in our body or the networks of coronary vessels are constructed by fractal geometric principles and the quasi-cyclic patterns of electrical activity of the heart can be represented by attractors. In the state of ventricular fibrillation, this attractor is out of its resting position and now strives towards chaos. An electric shock or the administration of certain drugs is supposed to shift this attractor, which is dislocated in its phase space, back to its initial position.

Diseases are characterized by disease-specific self-organization processes with abrupt phase transitions, discontinuity and frequent occurrence of fractals. Diseases are self-organization processes of their own kind within the integrated self-organization processes of the body. A number of diseases are characterized by typical courses. These are at least in principle mathematically representable by non-linear differential equations as a basis for attractor models. For attractors highlight visually and make visible that which transcends thought.

3 On the Concept of Information in the Context of Self-Organizing Systems of Life

The concept of information is originally derived from the Platonic-Aristotelian concept of eidos and can be found, among others, in the scholastic philosophy of Thomas Aquinas as a basic concept of the Aristotelian theory of abstraction. In modern philosophy, this concept was more and more shifted from the doctrine of being to the doctrine of knowledge, whereby the concept of eidos, structure was shifted from the structure of an object to the human subject[25] , whereby this concept was used to describe a mental (Descartes) or sensory-physiological process (Locke).

In the meantime, the concept of information has found a multi-layered interpretation in the various fields of physics, biology, linguistics, psychology and medicine and has risen to become a central metaphor of a multitude of interdisciplinary theories, for example information theory, communication theory, systems theory, cybernetics and semiotics. All these theories deal with the question of how information can be generated, represented, transmitted and processed. Accordingly, there is a great deal of confusion about what is actually meant by the term information. Norbert Wiener's seemingly tautological definition aims in this direction: "Information is information, neither matter nor energy". [26]

The concept of information is multifaceted and multi-layered with regard to the following aspects:

1. The amount of information as a measure of intelligence (Shannon).
2. Information as equivalent of control (stored program)
3. Information as gradient of possible knowledge (semantic information measure)
4. Information as a structure-determining element
5. Information as a measure of complexity
6. Information as a representation of real things (informational models, simulation). [27]

The relationship between entropy and information measure is qualitative and essential because it couples physics and information theory. The receipt of information about a system is paid for by the acquisition of entropy, i.e. an information flow is always accompanied by a proportional entropy flow. According to a relation formulated by Szilard-Brillouin, on the other hand, not every entropy transfer is associated with an information transfer.

This relation also states that the information transfer is always smaller than the entropy transfer. Because in the state of a thermodynamic equilibrium the entropy and thus the indeterminacy is maximal, information processes require non-equilibrium conditions. This observation emphasizes the importance of information in evolving nonequilibrium systems. From this point of view, information processing can be seen as a form of self-organization. [28]

Extraction of information therefore costs entropy, where 1 bit is at least $k_B \ln 2$. Recording and output of information are therefore connected with irreversible en-

25 Öser, E., in: Folberth, O. G., Hackl, C. (1986): Der Informationsbegriff in Technik und Wissenschaft, Oldenbourg Verlag, Munich, Vienna, p. 231.

26 Wiener in: Oeser, E.: Der Informationsbegriff in der Philosophie und Wissenschaftstheorie. In: Folberth, O. G., op. cit., p. 231.

27 Ganzhorn, K.: Information, Structures and Principles of Order. In: Folberth, O. G., op. cit., p. 106.

28 Ebeling, W., (1991): Chaos-Ordnung-Information. Verlag Harri Deutsch, Frankfurt a.M., p. 61.

tropy costs. Accordingly, an information system must be able to release entropy, e.g. in the form of heat or radiation. [29]

Ebeling and Feistel make a strict distinction between bound and free information. [30] This distinction is fundamental also for some statements in this book in connection with neuronal and mental activity. Bounded information is present in every physical system and its universal quantitative measure is the entropy of the state under consideration. This information is native, in a sense veiled. It represents itself and is an immediate material property of the system under consideration. Free information is always part of a relation between two systems, the sender and receiver. It corresponds to a binary relation between two systems. Because it is a relation, it is not a direct system property. It is essentially something else than a normal physical object. It has a purpose, it has a certain independence from the carrier and it is bound to the existence of at least two systems which extract it from bound information, exchange it, store it, process it in order to transform it back into bound information, for example for the purpose of creating a program or a construction plan. The concrete binding to the material carrier is not relevant for the content of the information. Free information is an abstract or even a mental one.[31] Purpose is a term which has a meaning only for living beings. Understood in this way, free information would have no existence outside of living beings. Feistel [32] could show that a measure for information is the probability of occurrence of a message. Shannon developed an operational definition of the information of a message as sequence of binary possibilities. This binary code, consisting of counting bits, denotes the most effective method of handling information. However, it does not solve the semantics and related effectiveness problem. None of these problems can be solved by merely counting bits. The mere counting of bits is therefore relatively far down in the hierarchy of problems in connection with the interpretation of the concept of information. The mere collection of information is also useless. One can only speak of information if it has an observable influence. For this reason, the physicists Gell-Mann and Jim Hartle tried to use the concept of information, which is derived from quantum physics to formalize the familiar concept of the observer. [33] They called their concept IGUS (Information Gathering and Utilizing System). [34]

By comparing Shannon's information quantity with Boltzmann's definition of entropy, he succeeded for the first time in bridging the gap between a physical and an information quantity: the smaller the entropy, the greater the amount of information describing a system state.

In the colloquial sense, information represents a kind of factual knowledge. Messages and information are often used colloquially as synonyms, although both terms are to be strictly separated in computer science. The message rather carries the information or represents it. However, it is not the information. A piece of information together with its representation is called an object or datum. Representations are concrete phenomena of the physical world, while information is funda-

29 Ebeling, W. op. cit., p. 64.
30 Ebeling, W., Feistel, R. (1994): Chaos and cosmos. Spektrum Akad. Verlag, Heidelberg/Berlin/Oxford, p. 55.
31 Ebeling, W., Feistel, R., (1994): Chaos and Cosmos, p. 56.
32 Feistel, R. (1990): Ritualization and the self-organization of information. In: Self-Organization, Yearbook of Complexity (U. Niedersen, ed.) Duncker &Humblot Verlag, Berlin.
33 Baeyer von, H. Ch. (2005): Das informative Universum, Beck-Verlag, München, p. 48.
34 Gell-Mann, M. (1994): The Quark and the Jaguar. From the simple to the complex - the search for a new explanation of the world. Piper Verlag, p. 232.

mentally abstract ideas. Interpretation bridges the gap between these two worlds. Information requires a representation, otherwise it can neither be communicated, nor stored, nor processed. Conversely, any representation without associated information is meaningless.[35,36]

The concept of information is an abstract, not a spatio-temporal concept, which cannot be described with the fundamental parameters of mass and energy of physics. The concept of form is also contained in the concept of information. Aristotle expressed in his theory of perception the opinion that the forms of an object are pre-existent in our mind:

"It is not the stone that is in the soul, but its form". [37] Shape can be expressed in mathematical terms. Alan Turing, for example, worked for a very long time on a mathematical theory of shape and form. [38] Form expresses relationship. However, information is not the same as form alone, because the word "informare", i.e. to shape, additionally contains a dynamic component in the sense that information includes the transfer of form from one medium to another. In this view, connections with the human exchange of information, i.e. communication, become apparent.

According to C. von Weizsäcker, the concept of information brings the two opposite poles of matter, namely form and consciousness, back into play. According to v. Weizsäcker, information is to be called the measure of the quantity of form. Information is defined by the probability of the occurrence of an event according to the equation I = log2 W. Accordingly, the more improbable an event is, the more information it brings. But according to v. Weizsäcker it would be quite wrong to conclude from this that information is exclusively a content of consciousness, because probability is something subjective, namely a conjecture. According to v. Weizsäcker, every conceived concept is something subjective and thus also the concept of matter or of a thing. Every concept is immediately "objective", as far as it is "true". In this sense, according to v. Weizsäcker also the concept of probability is an objective true concept, as far as it is possible to verify probability judgments empirically. [39]

According to von Weizsäcker, the information of an event can also be defined as the number of completely undecided simple alternatives which are decided by the occurrence of the event. As a quantitative measure of the amount of form of an object, v. Weizsäcker proposes the number of simple alternatives that would have to be decided in order to describe its form. In this sense, according to v. Weizsäcker, information indeed measures form. But the fact that information is subject-related in its essence is derived by v. Weizsäcker in this way: „But it (information) cannot be defined at the same time ... without reference to a consciousness, in the sense in which this is not true of every concept. Auch der objektive Wahrscheinlichkeitsbegriff ist nämlich subjektbezogen ..."[40].

35 Pepper, P. (1992): Grundlagen der Informatik. Oldenbourg Verlag, 2nd ed. 1.1.
36 Kolmogorov, A. N. (1941): Interpolation and extrapolation of stationary random sequences. Bulletin de Academie des Sciences URRS, Serie Math. 5, pp 3-11.
37 Baeyer v., H. Ch. (2005): The informative universe. C.H. Beck Verlag, 2005, p. 35.
38 Hodges, A., Turing, A. (1989): Enigma. Verlag Kammerer & Unverzagt, p. 567.
39 Weizsäcker, v., C. F.: Die Einheit der Natur. Dtv Wissenschaft (1995), p. 347.
40 Weizsäcker, v., C. F.: Die Einheit der Natur. Dtv Wissenschaft (1995), S. 348.

The terms "information" and "probability" must be understood both subjectively and objectively, because it is their conceptual sense to "quantify knowledge" and "knowledge is always knowledge that someone has of something "[41].

According to Carl Friedrich v. Weizsäcker, A. Zeilinger and other modern natural scientists, information is the original substance of the universe. Information is the answer to questions we ask. The meaning of the "bit" lies in the characterization of statements, whether they are true or false.

In technical usage, information refers to symbols with which a message is transmitted, regardless of what they stand for. According to v. Weizsäcker, information is "form". Its meaning is derived from the Latin word "informare" and means "to form", "to shape in the mind", "to imagine" and from there "information" means a "notion", a "concept ", a "likeness". Information is thus something like the bringing of form into matter or also of matter into form. [42] According to Aristotle, the form is the sum of all essential properties of a thing. The whole universe and the reality built up from atoms and radiation around us and also in ourselves is built up from the simplest and not further decomposable symbols from a sequence of zeros and ones. Symbols are the carriers, their substrate again is the information.

And yet, even from such an approach, a bridge to physics is possible: For information always refers to something surprising, more or less unpredictable. The real, surprising information of a source is the unpredictable part of the information, and thus the disorder and entropy. In this sense, information would be identical with entropy. Information would refer, for example, to the surprise content of a string. Its syntactic measure is then entropy. Shannon adopted the concept of entropy from physics very deliberately, naming Boltzmann's H-theorem. The formula mechanism is practically identical for both authors, only the physical entropy has a dimension. So, this would be the bridging to physics. [43]

Thus, information has several deep structures: the structure of a sequence of digits and characters, a mathematical notation as well as an assignment of meaning. Information is not a dimension like mass and energy. It has a dynamic character and is dependent on processing procedures which are outside of it. It is assigned a semantics from outside. It has a transcendent dimension. Information is unmeasurable according to previous understanding. Information is information insofar as it causes something, as it corresponds to a difference that makes a difference. [44] Carl Friedrich v. Weizsäcker even hinted at moving this concept of information into the transcendent and not into empirical consciousness.

41 Weizsäcker, v., C. F.: Die Einheit der Natur. Dtv Wissenschaft (1995), p. 348.

42 Weizsäcker, v., C. F.: Die Einheit der Natur. Dtv Wissenschaft (1995), p. 348.

43 Zemanek, H. (1986): Information and engineering science. In: O.G. Folberth, C. Hackl: Der Informationsbegriff in Technik und Wissenschaft. R. Oldenbourg Verlag, München, Wien, pp 24.

44 Bateson, G. (1985): Steps to an Ecology of Mind. New York: Ballantine Books (1972). German edition: Ökologie des Geistes. Frankfurt Suhrkamp.

Nevertheless, information as a part and presupposition of cognition is always also a part of the real world, because information is bound to a material carrier. In its basic interpretation the concept of information refers both to the structure of an object of cognition and at the same time to the subject of cognition. For the inner structure (eidos) is what one can recognize of an object and what one can pass on as conceptual cognition. [45] This means that the inner structure of an object is potential information for a subject of cognition and that, accordingly, there cannot be information without an observer, without a cognizing subject by definition. Today's natural science, on the other hand, teaches us that the static structural concept, the unchanging eidos, of an object as a solid, persisting substance, does not exist. In the modern view objects are considered dynamically as temporally lasting states. According to this view, only the occurrence of an event can be regarded as information, whereby the more improbable its occurrence, the greater the information content. Information thus arises from decisions between the alternatives of possible states. This information is new and it is objective because it is new with respect to the previous state [46] , whereby it is to be indifferent whether this event is observed or not. Information thus arises only where structures change or where structures are in flux. Thus, in the concept of information, a change, structure difference and a fundamental dynamic component are always contained.

In the equilibrium state of an isolated system, no more information is generated.

As a consequence of the second law of thermodynamics, the system remains in a kind of heat death. The situation is different in open systems with dynamic stability: Here the system is in constant energy and information exchange with the environment. By integrating dissipative hierarchies, a functionally ordered autonomy of high information density can build up in such energy-flowing systems. Evolution as a whole, with its progression from lower to higher levels, corresponds to a process of universal condensation of information, which is caused by the appearance of more and more complex systems with more and more variability of their elements. At the level of inorganic structures, information generation occurs as a consequence of interaction processes between molecules or as a consequence of more or less random interactions of simultaneous events within the framework of synergetic laws. At these levels, too, simple evaluation processes of potentially emerging information take place, for example, with respect to molecular complementarity between the binding sites of molecules and the resulting improvement of the energetic states. At the levels of organic systems, on the other hand, the evaluation of information is becoming more and more important. Here, it is less about the quantitative enlargement of information spaces than about the qualitative improvement of structures and functions and thus the enlargement of the informational diversity through evaluation processes. Complex structured organisms with a central nervous system have the ability to span new kinds of information spaces, which build up models of the outside world inside them in order to distinguish themselves from the outside world. Possibly these models, which are different for every human being, denote what is to be understood by some scientists and philosophers in connection with the concept of the individual. Whether these mental information spaces could actu-

45 Öser, E., in: Folberth, O. G., Hackl, C. (1986): Der Informationsbegriff in Technik und Wissenschaft, Oldenbourg Verlag, Munich, Vienna, p. 234.

46 Öhler, in: Folberth, O. G., Hackl, C. (1986): Der Informationsbegriff in Technik und Wissenschaft, Oldenbourg Verlag, Munich, Vienna, p. 236.

ally be carrier-invariant, i.e. could be detached from the matter of the brain, is hotly disputed. Here, it is view against view: the brain is the mind or views that say that the conscious subject of cognition has no direct experience of the material carrier of information, i.e. the neuronal states of the brain. [47]

Information always has a mysterious subjective meaning. Thus, a series of numbers 1459265... has no meaning for most people as a random sequence of numbers. For the mathematician, on the other hand, it is a sequence of digits of the number pi after the decimal point. From this, it becomes recognizable how difficult a generally valid definition of the concept of information must be.

3.1 Semantic Aspect of Information

Semantics in an absolute sense cannot exist, but it is always relative in relation to a semantic reference frame. Such a frame of reference can be given at the molecular level, for example, in the relationship between a hormone and its specific receptor. Binding of a hormone to its specific receptor can only occur if both reaction partners have matching domains. If there is an alternating effect between the two partners, an information-carrying signal is generated. Thus, not every hormone matches every receptor type. One could therefore say that a specific receptor type provides the frame of reference for interactions with specific hormones.

Genetic information does not contain absolute semantics either, but only relative semantics, which is related to the current requirements of metabolism or body states in general. The example of human language shows particularly clearly that words have a definite meaning only in specific linguistic contexts. Thus, the German word “Bank” can be understood as a piece of furniture to sit on or an institute that manages money. Semantics is thus assigned to an information only after an appropriate evaluation.

In modern biology, the question of the semantic aspect of information arises with particular emphasis, i.e., whether at all and to what extent aspects of meaning and significance could be objectified on an empirical basis.

The emergence of biological order and regularity as characteristic features of living systems are information-driven. The problem of the emergence of biological information is parallel to the problem of the emergence of life. It is obvious that the tremendously complex network of metabolic cycles in the cell is information controlled. Every complicated process requires a plan. Thus, the complex interplay of metabolic and regulatory processes is also based on a plan that has been defined down to the last detail. [48] The plan for the complex life processes is encoded in the genetic information, the task of which consists in self-preservation, self-reproduction and the transmission of genetic information.

The information encoded in the sequence of letters in DNA can easily be translated into the language of information theory: nucleic acids are built up from four basic building blocks. Thus, in a binary code system, one would need two code units each to encode one letter, for example:

47 Öser, E., in: Folberth, O. G., Hackl, C. (1986): Der Informationsbegriff in Technik und Wissenschaft, Oldenbourg Verlag, Munich, Vienna, p. 239.

48 Watson. In: Folberth, O. G., Hackl, C. (1986): Der Informationsbegriff in Technik und Wissenschaft, Oldenbourg Verlag, Munich, Vienna, p. 1982.

$$A = 00, T = 11, G = 01, C = 10, \text{etc.}$$

The question of the origin of biological information is equivalent to the question of the origin of these sequences on the DNA, which correspond to a specific selection from an immense abundance of alternative sequences.

A theory of the origin of life has to include a theory of the origin of semantic information for the reasons mentioned above. From information-theoretical considerations a coincidence hypothesis in connection with the semantic information of living systems is not provable. On the other hand, the so-called vitalism hypothesis of a given plan is at least not refutable. The empirical basic sciences in their traditional form exclude phenomena of semantics from their intended field of application. This was once expressed in a rather drastic way by M. Polanyi: "All objects conveying information are irreducible to the terms of physics and chemistry "[49]

Beyond these genetic specifications, the processes of self-organization play an essential role, whose informational output in turn has a controlling and modifying effect on the genetic information.

The question about the semantics of information implicitly also contains the question whether exclusively under the laws of physics and chemistry the biological macromolecules can arise spontaneously from their basic building blocks and develop self-organizationally into animate systems. We know from prebiotic chemistry that the abundance of available results does not provide any evidence that proteins and nucleic acids could not form spontaneously. Thus, the abiotic synthesis of amino acids and nucleotides belongs to the standard repertoire of prebiotic chemistry [50]. On the other hand, the question whether a primordial soup enriched with nucleic acids is a necessary as well as a sufficient prerequisite for the formation of living systems has not yet been answered conclusively. Can biological macromolecules self-organize into living systems. For the spontaneous formation of a simple bacterial blueprint with approx. 4 million nucleotides, the number of sequence alternatives was estimated to be an unimaginable $10^{2.4}$ million. According to this, the expectation probability for the random emergence of a bacterial blueprint would be so low that not even the size of the universe with an estimated total mass of the universe, expressed in mass units of the hydrogen atom of 10^{78} would be sufficient to make random synthesis probable. [51]

The aforementioned statistical problems, which arise in connection with the emergence of biological and especially semantic information, could be interpreted as an indication that the structures of living systems are essentially irreducible structures, the complete explanation of which transcends physics and chemistry, at least in their present form. [52] Pointing in this direction, others, including Polany, also expressed themselves. [53]

49 Polanyi, M.: Life transcending physics and chemistry. Chemical Engineering News (1967), pp. 45, 56. Küppers, B. O.: Molecular self-organization and the emergence of biological information. In: Folberth, O. G., Hackl, C., op. cit., pp. 181-203.
Küppers, B. O.: Molecular Self-Organization and the Emergence of Biological Information. In: Folberth, O. G., Hackl, C., op. cit., p. 193.

50 Miller, S. L., Orgel, L. E: (1974): The Origins of Life on Earth. New Jersey: Prentice-Hall.

51 Küppers, B. O.: Molecular Self-Organization and the Emergence of Biological Information. In: Folberth, O. G., Hackl, C., op. cit., p. 187.

52 Küppers, B. O.: Molecular Self-Organization and the Emergence of Biological Information. In: Folberth, O. G., Hackl, C., op. cit., p. 193.

53 Polanyi, M. (1967): Life is transcendending physics and chemistry. Chemical and Engineering News 45, 56.

3.2 On the Concept of Biological Information

Biological systems are completely information-driven and are characterized by a high degree of order and regularity.

Evolution is an infinite chain of processes of self-organization, in which new information is continuously generated and evaluated. Following the image of Hegel, the evolutionary dynamic is made up of endless chains of self-organization. According to Ebeling and Feistel, each of these cycles passes through the following stages:

1. A relatively stable evolutionary state becomes unstable due to changes in internal or external conditions.
2. This instability triggers a process of self-organization that generates new structures.
3. As a result, a new relatively stable evolutionary state emerges, which in turn can lead to a new cycle. [54]

The dynamics of the individual cycles of self-organization essentially follows nonlinear differential equations. The transitions between the cycles occur in the form of bifurcations and show rough analogies to the phase transitions of thermodynamics. Thus, thermodynamic systems in the vicinity of phase transitions show extensive spatial correlations, structures on many scales, special smoke spectra, strong fluctuations and long relaxation times. In self-organizing processes, a critical instability is present in the transition region between cycles, which Bak and Chen termed self-organizing criticality. [55] While Newtonian or Hamiltonian mechanics were not able to resolve the contradiction between reversibility and irreversibility, the processes of self-organization are characterized by the principle of instability to variations in initial conditions. The concept of instability refers to the fact that in the dynamics of systems neighboring trajectories diverge: Two initially closely neighboring trajectories then run further and further apart as the process progresses. The concept of divergence of trajectories or instability is connected with another concept, namely with Kolmogorov entropy via the concept of entropy. Small uncertainties in the knowledge of the initial conditions lead, already after a short time to an extensive ignorance of the actual state of a system. For unstable regions of the phase space the deviation of two originally closely neighboring trajectories grows exponentially with time. Such systems are called chaotic. The so-called Lyapunov exponent denotes the quantitative measure of the divergence. This exponent is in turn closely related to the Kolmogorov entropy, which describes the sum of the positive Lyapunov exponents. [56] A final valid solution of the entropy problem and, connected with it, of the information problem is still pending. However, Ebeling considers the inclusion of cosmological aspects in this problem to be indispensable. Much could indicate that the cause of the macroscopic directionality of processes is based on the principles of instability and the divergence of microscopic movements, i.e. on microscopic chaos, and that it is these principles which underlie the cosmological arrow of time from chaos to ever more complex order structures. [57]

54 Ebeling, W., Feistel, R. (1994): Chaos and cosmos. Spektrum Akad. Verlag Heidelberg/Bern/Oxford, p. 211.
55 Bak, P., Chen, K. (1991): Self-organizational criticality. Spectrum of Science March.
56 Ebeling, W., Feistel, R. (1994): Chaos and cosmos. Spektrum Akademischer Verlag, Heidelberg Berlin Oxford, p. 198.
57 Prigogine, I., Stengers, I. (1993): The paradox of time. Time, chaos and quanta. Piper-Verlag, Heidelberg-Munich.

In the field of living systems, evolution does not proceed continuously for the reasons mentioned above [58] , but in cyclic processes with erratic phase transitions, from which the respective new emerges. The dynamics of the processes is based on processes of self-reproduction in connection with mutation and selection. Mutation corresponds to a faulty self-reproduction and is therefore essentially to be understood as a stochastic phenomenon. Evolution thus progresses via interplay between chance and necessity. In the process of the expression of self-reproduction of polynucleotide chains under the catalytic influence of polypeptides, methods were developed for the coding of information in the primary sequence and for the transmission of this coded information. With this discovery, science has come a long way towards answering the question of how biological information is generated. From a modern point of view, information processing in biological systems can be understood as a particularly highly developed form of self- organization. [59] The term "self-organization" can be defined in this context as a process, which structures the behavior of a system without external intervention, i.e. without control from outside, or gives it a function, whereby the term function shall have the higher meaning compared to structure. [60] The historical development of the term self-organization is linked to the names of outstanding scientists, for example Boltzmann, Ostwald, Poncare, Andronov, Schrödinger, Bertalanffy, V. Foerster, Turing, Prigogine, Eigen, Haken.

The processes of self-organization can be considered from different levels, whereby entropy as a general measure of order plays an important, albeit different, role on all levels. While this term was originally defined by Clausius and Planck only for macroscopic systems, it was extended to non-equilibrium states by Boltzmann, Meixner and Prigogine, among others, and was finally transferred to information-bearing systems by Shannon, Szilard, Hartley and Brillouin. The relationship between entropy and information measure is qualitative and essential because it couples physics and information theory. These relations will be presented in more detail later in the study of the brain-mind problem.

The introduction of the concept of probability in quantum mechanics runs parallel to the replacement of the trajectory model by the statistical bundle in the field of mechanics. The statistical bundles in connection with the dynamics of complex self-organizing systems show the property to be able to smear over all possible states in the temporal progress. A reversible description of natural phenomena is then no longer possible: formulated mathematically, the group of reversible motions merges into the semigroup of irreversible dynamics. [61] However, chaos and limited predictability are by no means mutually exclusive. The above-mentioned synergetics of complex systems allows, for example, to describe the system behavior on a higher level with the help of a small number of order parameters and by means of reduced information. [62]

58 Singer, W. (2002): The observer in the brain. Suhrkamp Verlag Frankfurt a.M., p. 60.

59 Eigen, M. (1971): The Selforganization of Matter and the Evolution of Biological Macromolecules. Natural Science 58, p. 465 .
Ebeling, W., Feistel, R. (1982/1986): Physics of Self-Organization and Evolution. Berlin Akad. Verlag.
Wolkenstein, M. W. (1990): Entropy and information. Berlin/Frankfurt/M Akademie-Verlag/Verlag H. Deutsch.
Nicolis, G., Prigogine, I. (1991): Chaos and Information Processing. Singapore (World Scientific).

60 Ebeling, W., Feistel, R. (1994): Chaos and cosmos. Spektrum Akad. Verlag Heidelberg Berlin Oxford, p. 210.

61 Petrosky, T., Prigogine, I. (1993): Poincaré Resonances and the Limits of Trajectory Dynamics. Proc. Natl. Acad. Sci. USA 90, 9393.

62 Haken, H. (1988): Information and self-organization. Springer Verlag, Berlin/Heidelberg/New York.

Feistel could show that there is a phase transition from bound to free information in evolution. [63] This phase transition was called ritualization or symbolization. Free information as a relation or as a relationship between two systems is therefore always symbolic information. This is because it presupposes that sender and receiver can generate and understand these symbols. We will return to this central metaphor of free information at various points. For the content of the information, it is unimportant of which kind these symbols are, as long as sender and receiver understand the same thing by the same symbol. While bound information represents the physical state of a system and is inseparable from it, free information shows an invariance against the physical nature of the data carriers. According to the second law of thermodynamics, closed systems strive towards a state of thermodynamic equilibrium with a maximum entropy. No more information can be extracted from this state. It is always the difference between said maximum value of entropy and the current value that is relevant for the bound information. This difference corresponds to the potentially bound information, which is also called Klimontovich entropy reduction. Free information can be stored on a material medium or even on a local attractor of a dissipative process. From this fundamental invarance of free information against the physical nature of the data carrier it is to be inferred that this form of information is withdrawn from the action or the scope of those laws from which the structure of its origin is withdrawn. [64] Ebeling and Feistel agree with this important insight that the conceptual inner layers of free information cannot be described, at least not completely, within the framework of the currently known physical laws. In our opinion this insight has a fundamental importance for the modern scientific world view and especially for the discussion of the brain-mind problem. In the physical measuring process, free information is extracted from bound information. Free information thus always represents only partial aspects of an object. It can be stored and transported subsequently to the bound information, or it can be linked with free information of other origin according to the rules of mathematics and logic: Libraries with infinite amounts of bound information have been created in this way. With the growth of free information, means of data decompression, abstraction and concept formation come more and more to the fore: these processes can then be called ritualization processes on a higher level. [65] While on the physical levels of dissipative processes in the area of phase transitions ritualization or symbolization processes appear, on the level of living systems it is a matter of symbolization processes on a higher level, because on these levels structures of symbols as new symbols erode the stock of signs but reduce the amount of text in the wake of data compression. A central feature of biological evolution is thus the importance of free information, while the complexity of cosmic evolution is reflected in the bound information of the states passed through. [66]

In biological evolution, processes of optimization and evaluation of information are becoming increasingly important. Already Clausius had the idea that entropy is a measure for the worthlessness of information. The selection processes of evolution described by Darwin are based on the selection of species that are positively valued

63 Feistel, R. (1990): Ritualization and the self-organization of information. In: Self-Organization, Yearbook of Complexity (U. Niedersen, ed.) Duncker & Humblot Verlag Berlin.

64 Ebeling, W., Feistel, R. (1994): Chaos und Kosmos, op.cit., p. 57.

65 Ebeling, W., Feistel, R. (1994): Chaos und Kosmos, op.cit., p. 60.

66 Ebeling, W., Feistel, R. (1994): Chaos und Kosmos, op.cit., p. 60

in the competitive process. The concept of value also plays a central role in modern information theory. [67] Values, which are assigned to elements of a system, express holistic properties of the system and are not to be understood as properties of the isolated elements. Values are of crucial importance for the structure and dynamics of evolutionary systems by determining the relation of the elements to each other. Fundamental in this context are again competition and selection. [68] However, these values cannot be derived and calculated from the phenotypic properties of the organisms; values are rather such magnitudes that cannot be derived from the variables of the systems. These are therefore emergent properties. Values express the essence of biological, economic or social interactions and relations with respect to the dynamics of the overall system. According to Ebeling, values are abstract non-physical properties of species in a dynamic context. [69]

Thus, free information and value systems play an essential role in the evolution of living organisms. The maintenance of homeostasis is a fundamental prerequisite for the efficient control of the complex systems of living organisms, this is equally true for the amoeba and the human being. In this context, value systems, reward and punishment systems, play a role in an extended sense. The concept of value is directly connected with the concept of entropy in thermodynamics and in analogy with the concept of information in information science. In the context of the concept of value for physical entropy, the second law of thermodynamics is to be interpreted in such a way that isolated systems spontaneously strive for the devaluation of the energy contained in the body. There, the amount of entropy present in a physical body is a measure of the worthlessness of its energy. The larger the entropy is, the more worthless is its energy. Thus, evaluation and optimization play an important role in the evolution of living beings also from this mental approach. Selection is selection of positively valued species. As already described, values are abstract physical properties of species in a dynamic context. Values express holistic properties of a system. [70] In biological systems, specific chemical transmitters represent values in the reward and punishment systems, including for example the dopamine, norepinephrine, serotonin, oxytocin or vasopressin and others. values are located in a direct relationship with survival. Thus, the best possible condition of the organs and tissues within the homeostasis ranges, adapted to the environment and working physiologically without repercussions, seems to be a driving force for the biological evaluations and value systems. The constant representation of chemical parameters in the brain also makes it possible to constantly balance actual and target states within the framework of homeostasis and to carry out appropriate differential corrections. Processes that ensure optimal life control are considered particularly valuable. These relationships also apply to the human cognitive and emotional systems. [71] Optimal areas find their expression in the conscious mind as pleasant feelings; dangerous areas express themselves in painful feelings. [72] Accordingly, defining aspects of our feelings are the conscious perception of our bodily states evaluated as positive, which are modified by emotions.

67 Haken, H. (1998): Information and Selforganization, op. cit. Wolkenstein, M. W. (1990): Entropy and Information, op. cit.
68 Ebeling, W., Feistel, R. (1994): Chaos und Kosmos, op.cit., p. 66.
69 Ebeling, W., Feistel, R. (1994): Chaos und Kosmos, op.cit., p. 66.
70 Ebeling, W., Feistel, R. (1994): Chaos und Kosmos, op.cit., p. 66.
71 Montague, R. (2006): Why Choose This Book? How Do We Make Decisions? Penguin, London.
72 Damasio, A. (2010): Selbst ist der Mensch. Siedler Verlag, Munich, p. 67.