2 Autopoiesis and Self-Organization in Animate and Inanimate Systems

2.1 Remarks on the Evolution of the Universe from a Physical Perspective

The processes in the universe are governed by fundamental physical laws.

In the large dimensions of the universe, a high degree of order and uniformity becomes apparent. So, the composition and the movement of the star systems behave similarly everywhere and, as far as we know, the physical laws known to us are valid everywhere. The radiation of the universe is homogenously distributed and corresponds to about -270 degrees Celsius. As measurements with COBE or WMAP have shown, blackbody spectra are typical for this background radiation. We also know since Hubble that the universe is expanding. From this, the conclusion is drawn that the universe must have expanded from an initially small and extremely densely packed state. Such an initial event, referred to as the Big Bang, is thought to have occurred about 13.7 billion years ago. From the observations of the background radiation can be deduced that at the beginning of the universe, matter must have been distributed over space with high uniformity and it must have had the same density and the same temperature everywhere. The universe must have been, at its beginning, in a state of high temperature of estimated 10 billion degrees Celsius and extremely high density to cool down with increasing expansion. However, it has been found in the meantime that the mentioned background radiation is not exactly the same everywhere. Matter has clumped to solar systems, to galaxies, to clusters and superclusters of galaxies. One assumes that already at the beginning smallest existing irregularities in the distributions of the early matter have strengthened under the influence of the gravitation more and more. Today, it is also assumed that 13.7 billion years ago and shortly after the Big Bang the universe consisted of an ionized, opaque gas, which should have been distributed evenly, however not exactly evenly, over space. Approximately 380,000 years after the Big Bang, the universe had already cooled down to a few thousand degrees. Now atomic nuclei and electrons caught together in the initially still ionized gas. This had the consequence that the gas became transparent, and the radiation could penetrate the matter. This background radiation thus opens a view to the astronomers on a still early, i.e. 380,000 years old universe, which is supposed to expand from every point in all directions. Accordingly, the universe has no center because all past observations led to the result that the galaxies move away from all others. What expands thereby is space.[62] From this, the idea is derived that it is a universe without an edge and without a center. In this respect, the concept of a "Big Bang" should not lead to the erroneous idea that the initial expansion took place from a specific point. At that time, neither points in space existed, nor a space at all. The Big Bang is understood by cosmologists as a kind of space horizon. We will never be able to look behind this space horizon imagined in such a way. Much more, empirical findings suggest that we will never be able

62 Davies, P.: Der Kosmische Volltreffer. Campus Verlag Frankfurt a. M. New York (2008), p. 45.

to make observations beyond a limiting distance of about 13.7 billion light years. In the context of observing galaxies at a distance of about 13 billion light years, we can register light that has traveled a distance of an almost intangible 13 billion light years in the meantime. At the moment of such an observation, astronomers thus look at a galaxy in its state of 13 billion light years ago. In view of the enormous expansion of the universe that has taken place in the meantime, the distance of such a galaxy must thus be much greater. With the Hubble telescope, it became possible to observe galaxies at a distance of approx. 28 billion light-years.

Moreover, the space of the universe is not flat in the sense of three-dimensional Euclidean geometry, but it is curved due to the gravitational effects.

With the development of his general theory of relativity, which was published in 1915, gravitation became the determining force in modern cosmology. Einstein saw in it not only a force but rather he understood gravitation as a curvature of the geometry of space. In the presence of large masses, space experiences a distortion accordingly. This curvature of space, which was predicted theoretically at first, was proved on the occasion of a total solar eclipse in 1919 by Arthur Eddington, who calculated the curvature of the light beam of stars from small position differences, when the sun was exactly in the center of the field of view.[63] By the way, the strongest deflections of light rays are caused by black holes, because light cannot escape from them. The mass of the universe is estimated at 10^{50} tons. With these enormous masses, space experiences thus manifold curvatures or distortions. According to an Einsteinian idea, space could resemble the three-dimensional surface of a sphere, which is also called a hypersphere.

For a better understanding: The earth‘s sphere has a center, but not the earth‘s surface. Thus, the three-dimensional surface of such a hypersphere could also have no center. For reasons of principle, it would then not be possible to make any statements about the interior of such a hypersphere. So, there is no center in the universe, the expanding space is limited, but the universe has neither barriers nor borders. In this context, astronomers develop quite bizarre ideas that it could be possible, at least in theory, to look further and further into the depths of space with high-performance telescopes, and at a distant point in time, possibly after billions of years, we would then see ourselves again. However, this idea does not seem to be completely absurd, because what we see in the universe is always ourselves, if we take a closer look.

Although the space is formed locally by the galaxies and by galaxy clusters, it is supposed to be flat in its totality in the Euclidean sense according to some theories. The total mass of the universe is supposed to be zero because the positive mass energy of the matter is supposed to be canceled by the negative mass energy of the gravation field of the matter.[64]

One second after that event called Big Bang, the universe existed in the state of plasma with freely moving elementary particles, for example, protons, electrons, and neutrons. Some protons united in nuclear fusion processes with neutrons to helium nuclei, which are known to consist of two protons and two neutrons. Others formed deuterium nuclei.

63 Davies, P.: Der kosmische Volltreffer. Campus Verlag Frankfurt a. M. New York (2008), p. 59.
64 Davies, P.: Der kosmische Volltreffer. Campus Verlag Frankfurt a. M. New York (2008), p. 73.

Modern physics is able to experimentally reconstruct the events between a millionth of a second and a few minutes after the Big Bang. Thus, it is possible to deduce from the findings of nuclear physics that the processes of nuclear fusion came to a halt just a few minutes after the Big Bang after the temperature had dropped below 100 million degrees in the wake of rapid expansion and cooling.

The question about the origin of the Big Bang from an initial state to be called singularity still remains highly speculative, because in such an imaginary "point" the physical equations would go towards infinity. In such a case, therefore, the invariable validity of the physical laws can no longer be trusted. So, in this context, the question arises as to how far the range of validity of these laws could be extended at all. The equations for electromagnetism established by Maxwell are valid in the size range of atoms as well as in the range of galactic magnetic fields, which are 1032 times larger. Thus, these laws without any doubt have a universal validity. On the other hand, if the laws of quantum mechanics are applied to gravity, large deviations from the predictions of general relativity are to be expected, namely in the range of the Planck length of 10-33 cm. With this length, a fundamental length scale is reached, at which extrapolations in connection with gravitation are no longer possible. A further fundamental time unit is given with the Planck time of 10-43 seconds. In these almost infinitely small orders of magnitude, general relativity fails. From this it is to be deduced that the range of application of the general relativity should end in the proximity of the Big Bang from a period of less than 10-43 seconds. The discipline of the so-called quantum cosmology deals with quantum effects in the vicinity of the Big Bang singularity and with questions about a possible quantum state of the early and the present universe.

The arrangement of electrons in atoms determines the chemical properties of today's matter. From this, finally, the whole complexity of the material world emerges. And nevertheless and in spite of this immense complexity, the world of the material is essentially determined by two numbers that cannot be derived any further:

1. by the quotient of the mass of the proton and the mass of the electron with the value 1836,104 ... and
2. by the quotient of the square of the electric charge of an electron and the product of the speed of light and Planck's constant from the quantum theory. This quantity is called the fine structure constant. Its value 1/137.036 ... is determined by combining the measured values of the three constants.

However, science is still not able to explain the riddle of how these values could come up at all. If these values had been only slightly different, a completely different universe would have arisen. These constants are almost the elementary condition for the fact that life could develop at all in the universe.

Another comparison seems to be very remarkable: The strength of the gravitational force is determined by Newton's gravitational structure constant 5,9041183 x 10-39. This value is in comparison with the fine structure constant with 1/137,036 ... vanishingly small. These ratios mean that the electromagnetic forces between protons and electrons in the atom are incomparably stronger than gravity, which is therefore of no essential importance for the structure of atoms. The sizes of astronomical bodies are again determined by the values of the fine and gravitational structure constants. These conditions which are elementary for our existence depend on such constants, whose origin is completely unclear. Equally remarkable is the fact that between some combinations of these constants, quite unusual agreements turn out: For example, carbon, which is so important for life on Earth, is formed in the explosion of stars in a two-step process from helium nuclei called alpha particles, two of which combine under stellar conditions to form the element beryllium. From a physical point of view, this is a rather improbable process. In the wake of a so-called "carbon resonance", however, such an improbable process can occur far more frequently than would be expected. In this process, the energies of the particles involved and the thermal energy of a star add up to a value that is very slightly below the natural energy level of a carbon nucleus. Thus, a carbon resonance level is reached, which facilitates the carbon synthesis so important for life. Possibly even more remarkable is the fact that this carbon resonance level is very slightly above the total energy produced in this reaction. Every carbon nucleus in our body has thus originated from stellar matter. Moreover, another resonance level exists in that oxygen nucleus which would be produced in the next step of the chain reaction if a carbon nucleus could interact with another alpha particle. However, this resonance level is exactly above the total energy of alpha particles, carbon core, and stellar environment. This, in turn, has the consequence that the carbon is not completely destroyed in the course of the next resonant nuclear reaction. This is a very precise tuning of the resonance level, where the position of the resonance level depends in a complicated way on the numerical values of the physical constants. Coincidences of natural constants tuned to the most exact are therefore the precondition for the emergence of our universe and therefore of life. Moreover, our universe is to be called peculiar for the reason that it is in an ordered state which must be called improbable for reasons of thermodynamics. Moreover, observations with the Hubble telescope have shown that the universe expands in all directions at the same speed. This isotropy of the expansion of the universe is very striking because it raises the question of whether there could be cosmic processes that could be able to smooth possibly occurring inequalities in the expansion or also the question of whether the universe could have expanded isotropically already from the beginning.

Unresolved questions arise not least in connection with the concept of entropy: Since the entropy of the universe increases with time, the universe should have been in a state of high order and low entropy in its initial state. But the probability for this is quite conspicuously very small. Because it is rather reasonable to assume that a so-called Big Bang would have to have developed from a random initial state with greatest randomness, greatest chaos and minimal order. This apparent paradox has already been pointed out at the beginning. The entropy concept contains a summary of states according to the criterion of coarseness. According to the 2nd law of thermodynamics, the entropy must increase. Thus, it becomes possible, under precise knowledge of the present state of a system, to predict its most probable state in the future. Thus, it is possible to predict that a teacup on the floor will shatter into shards when it falls from the table. The shards on the floor denote a higher state of entropy than before. However, if we tried to make a prediction in the opposite direction, the probability would be vanishingly small that the cup was initially on the floor as a pile of shards and that the shards would have spontaneously coalesced into a cup afterward. We know that someone had put the cup on the table and that it had fallen on the floor for some reason. So, there is a chain of justifications for why the cup had been put on the table in the first place. This chain of justifications goes further and further back to states of lower entropy in the past, i.e. the further back in time one would go, the smaller the entropy. Thus, based on the second law with the increase of entropy, such a process would not be clarifiable. Roger Penrose points out in this connection that these questions could possibly be clarified only in the course of a theory of quantum gravity.[65] So, if the described natural constants would not exist in such an exact coordination, then no life would be possible, and no consciousness would have knowledge of this universe. The emergence and existence of the universe depend on an extremely exact fine-tuning of these physical constants whose origin we cannot explain. The last truth lies, as already Einstein suspected, unattainable for us on an asymptote: "However we select a complex (of phenomena) with the help of the criterion of simplicity, in no case the theoretical treatment will prove to be the right one forever. ... But I do not doubt that the day will come when also that description (the general theory of relativity) will have to give way to another one for reasons which we cannot suspect at present. I believe that this process of deepening the theory has no limits".[66]

Based on and probably under the overwhelming impression of these described riddles and findings equally the so-called "anthropic principle" was formulated, which should lead to the most violent controversies in the scientific community. In the bow wave of this principle, which can be called a hypothesis, a considerable number of publications were published, for example by Bernard Carr and Martin Rees[67] or John Barrow and Frank Tipler[68], Paul Davies[69] and a number of other authors. The "anthropic principle" was described in the 1980s as a "quasi-religious principle". [70]

From circles of theoretical physics, even the question was raised in the meantime whether the known laws of nature must be possibly not chiseled in stone and that their range of application could come into wobble in the proximity of an assumed Big Bang. Possibly they could be effective only within a range of moderate energy levels. Today, even the ideas of models of a multiverse instead of a single universe are discussed.[71]

Last but not least, the question is also raised whether perhaps in other regions of this universe of ours, completely different laws of nature could apply. All this is speculation, and with certainty it can only be said that we humans are in a region of the universe in which life is possible.

The modern sciences of becoming have shown that the second law of thermodynamics, which is based on the principle of the increase of entropy, does not at all forbid the spontaneous emergence of order structures. Thus, the second law is still valid. The contributions of Prigogine and other authors to non-equilibrium thermodynamics and dissipative systems allow, however, indications that a postulate of a

65 Penrose, R.: Das Große, das Kleine und der menschliche Geist. Spektrum Akademischer Verlag Heidelberg Berlin (1998), p. 11.
66 Quoted from: Barrow, J. D.: Theories of Everything. The search for the world formula. Rowohlt Verlag Reinbek bei Hamburg (1994), p. 122.
67 Carr, B., Rees, M.: The anthropic principle and the structure of the physical world. Nature 278 (1979), p. 605.
68 Barrow, J., Tipler, F.: The Anthropic Cosmological Principle. Oxford 1986.
69 Davis, P.: Der Plan Gottes. Frankfurt a. M. 1996.
70 Davis, P.: Der kosmische Volltreffer. Campus Verlag Frankfurt New York (2008), p. 10.
71 Susskind, L.: The Cosmological Landscape. String Theory and the Illusion of Intelligent Design. New York (2005), p. 138.

uniform dissolution of the universe into the heat death of a final general disorder of highest entropy derived from the second law must at least raise questions.

The evolution of the universe is driven from symmetry breaks. From these break lines, from such transitions, always new histories arise, so the history of the development of living systems and in these connections the history of living systems with a consciousness. This history in turn derives from the history of the organization of physical-chemical units. In the development of man, a transition to the development of culture took place, which emerged from the physical-chemical history and needs it as a carrier medium.

2.2 Introductory Considerations in Natural Philosophy on the Concept of Causality and the Emergence of Order between Determinism and Indeterminism

According to the Greek philosophical tradition, order was a fundamental property of matter and thus something given, always already present, which did not need to be questioned further. According to their view, matter could basically only exist in a certain state of order, whereas disorder characterized an initial state of the world, from which only secondarily the material order of the objects of the world emerged. In the Aristotelian concept of causality, the causa formae, in addition to the other three components of causality, the causa efficiens, the causa materialis, and the causa finalis, a connection between causality and the emergence of order was established, whereby the concrete form of order emerged from the different interaction of all four components: According to this, order arose in connection with a conception of purpose (causa finalis) or from the design of a form, the provision of materials and the beginning of the completion itself in the sense of effective trade.[72] The generating principle of order was thus anchored in the principle of causality. This principle was basically and from the beginning integrated into the explanatory principles of the world, because matter always already appeared in an ordered form and for these reasons did not need any further explanation. According to Aristotelian ideas, another "ideal" principle of form, namely the principle of entelechy, governs the way in which systemic wholes can emerge from their parts.

The similar principle of teleonomy comes to the fore in the consideration of the dynamic organizational structures of living beings: In living beings, the organs can only exist in their integration into a physical whole, and only in such an integration are they able to carry out their functions. According to an Aristotelian way of thinking an amputated hand would not be a hand anymore.[73] It is always a matter of two components so that life can form itself, namely on the one hand the matter, which is called "dynamis" by Aristotle, and on the other hand the form-forming principle of entelechy. More detailed ideas about basic organizing principles in connection with the dynamics of processes of living systems do not appear in Greek philosophy.

72 Küppers, G., Paslack, R.: Die natürlichen Ursachen von Chaos und Ordnung. In: Küppers, G.: Chaos und Ordnung. Formen von Selbstorganisation in Natur und Gesellschaft. Philipp Reclam Jr. Verlag Stuttgart (1996), p. 44-45.

73 Küppers, G., Paslack, R.: Die natürlichen Ursachen von Chaos und Ordnung. In: Küppers, G.: Chaos und Ordnung. Formen von Selbstorganisation in Natur und Gesellschaft. Philipp Reclam Jr. Verlag. Stuttgart (1996), pp. 44-45.

It was Immanuel Kant (1724-1804) who first applied the concept of "self-organization" to a fundamental capacity of nature to produce purposeful orders:

"In such a product of nature, each part, as it exists only through all the others, is also thought of as existing for the sake of the others and of the whole, i.e., as a tool (organ): which, however, is not enough [...]; but as an organ bringing forth the other parts (consequently each mutually to the other), the like of which cannot be a tool of art, but only of nature supplying all material for tools (even those of art): and only then and therefore will such a product, as an organized and self-organizing being, be able to be called a purpose of nature ...".[74] According to Kant, life emerges from the capacity, namely the capacity of a substance, "to determine itself to act ... from an inner principle".[75] Thus, an intrinsic capacity, an organizational principle given for reasons of expediency, is inherent to all living beings in order to be able to produce that richly structured organization of life processes in the first place. The existence of such an intrinsic purposefulness of living beings in the form of a reciprocal relationship between the whole of an organism and its parts seemed to Kant to be "an unexplored property of nature", because it cannot be derived from purely mechanical interactions of matter.[76]

From Kant early on the problematic relation between a causality and a possible finality was seen. This problem has continued into the current discussions surrounding self-organizational processes:

"To speak precisely, then, the organization of [organic] nature has nothing analogous with any causality that we know".[77]

It was explained above that the classical worldview was supported by laws of nature, which described a deterministic closed universe, in which future and past were defined equally.[78] This temporal equivalence found an analogous implementation in the strong causality principle, where equal or similar causes result in equal or similar effects. But this principle has no universal validity even in classical physics. For example, the strong causality law fails when considering causal interactions between more than two physical bodies.

As described in the next chapter, in these cases a strong dependence of the trajectories on the initial conditions appears: For example, the trajectories of coupled pendulums suddenly become unpredictable and move in chaotic curves. It has been shown in a large number of astronomical observations that chaotic motion patterns in the universe are not the exception to Newtonian mechanics, but rather can be observed ubiquitously. Typical examples for nonlinear chaotic patterns are for example the rings of Saturn. Meanwhile, we also know that the deterministic laws of Newtonian mechanics apply only to stable classical systems and stable quantum systems, and thus only to a limited class of physical systems. The idealized deterministic laws of mechanics have meanwhile been replaced in the consideration of natural processes by probabilistic irreducible laws, which dominate the behavior or events of an open, indeterministic universe.

74 Kant, I.: Kritik der Urteilskraft (1790), § 64, B 284.
75 Kant, I.: Kritik der praktischen Vernunft, Vorwort, A 16.
76 Küppers, G., Paslack R.: Die natürlichen Ursachen von Chaos und Ordnung. In: Küppers, G.: Chaos und Ordnung. Formen von Selbstorganisation in Natur und Gesellschaft. Philipp Reclam Jr. Verlag Stuttgart (1996), p. 52.
77 Kant, I.: Kritik der Urteilskraft, § 65.
78 Prigogine I., Stengers I.: Das Paradox der Zeit. Piper Verlag Munich Zurich (1993), p. 18.

2.3 Non-equilibrium States and the Computable Non-computable

The question of how order could arise without the presence of ordering forces with respect to a goal remained unanswered in classical physics. In the 19th century, chaos appeared for the first time in connection with the three-body problem, which was to occupy physicists and mathematicians intensively from then on: According to Newton's equations, the orbital curves of two masses moving freely in space, on which only gravity acts, can be calculated with arbitrary accuracy and over an arbitrarily long time. However, if a third body is added, the orbits can no longer be described exactly, the orbits can at best be calculated approximately with great computational effort. A so-called error catastrophe can occur: Every error in one part of the calculation, no matter how small, can have a maximum effect on further calculation steps, so that even the largest computer can no longer indicate at a certain point in time in which part of space one of the three bodies is located. The reason for such a behavior is that the trajectories of the three bodies have become sensitive to changes in the initial conditions. On the one hand, we are dealing with the movements of three mass bodies in space, whose individual trajectories are based on strict laws and calculability, and on the other hand, the same trajectories in mutual coupling states can suddenly and unpredictably change into a state of randomness, and thus into chaotic behavior.

Such a sensitive dependence on the initial states has meanwhile been described in numerous patterns, in the so-called "baker's map", which describes processes of repeated stretchings and foldings, mathematically called recursions or iterations.

Systems are called unstable if arbitrarily small deviations can lead to completely different processes.

The term "chaos" is used in everyday language to describe an unmanageable, ruleless state that does not seem to be based on any laws. The term chaos was first used by J.A. Yorke and T.-Y. Li in a paper entitled "Period 3 implies chaos" in 1975.[79]

In the state of chaos, which is scientifically called deterministic chaos, the principle "same cause, same effect" is still valid. However, this principle has no more general validity, because there is always the possibility that microscopic events can have effects on processes of the macro world. Here then the principle applies: Small causes can result in large effects.

Chaos leads to the introduction of an arrow of time into the fundamental description of dynamic systems, to which we also belong. Furthermore, the introduction of the concept of probability into classical dynamics is connected with the concept of chaos. However, the term probability in connection with the concept of chaos is by no means to be understood as a consequence or as a result of ignorance or deficient empirical experience. The term deterministic chaos has to do with the fact that chaotic systems do not further follow the strong principle of causality, but these states are clearly determined by mathematical equations.[80]

All systems which follow an irreducible probabilistic description can be called chaotic by definition. If we take a closer look, this is the case for most of the systems

79 Li, T.-Y., Yorke, J. A.: Period three implies chaos. In: American Mathematics Monthly 82 (1975), pp. 985- 992.

80 Martienssen, W.: Gesetz und Zufall in der Natur. In: Gerock, W., Haken, H. (Eds.): Ordnung und Chaos in der unbelebten und belebten Natur. Stuttgart (1989), pp. 77-99.

in our everyday world. Such systems cannot be described by a single trajectory, but only by bundles of trajectories.

An example of known chaotic systems is turbulence, which is omnipresent in our everyday world:

The phenomenon of turbulence in rushing streams or in the dramatic images of lava flows rushing down mountain slopes fascinated and stimulated the thinking of quite a number of great minds very early on, such as physicists like Helmholtz, Lord Kelvin, Lord Raleigh, and others in the 19th century. Leonardo da Vinci was also taken by the phenomenon of turbulence and in a whole number of drawings of fast-flowing water he tried to reproduce the patterns of vortices and their division into smaller and smaller vortex formations as close to nature as possible. Leonardo had intuitively recognized an important property in connection with the formation of turbulence, namely the manifold divisions of vortices and their branching on ever smaller scales, which seemed to continue into infinity: Larger vortex patterns divide into smaller and smaller ones, and these further and further into still smaller ones. Turbulence can occur anywhere in nature, for example in aviation, in fast-flowing streams and currents, and also in many places in the human organism: turbulence can occur in flowing blood at the branching points of arteries and veins, or at the valves of the vessels, especially at the heart valves. Such turbulence can be an expression of disease-specific artifacts if they become hemodynamically effective. This would be the case, for example, if the flowing column of blood in the vessels impinges on the edges of arteriosclerotic plaques and washes around them. Such conditions can become the secondary cause and starting point of severe thromboembolic complications. The Russian physicist Lev Landau, who was awarded the Nobel Prize in 1962, studied the phenomenon of turbulence intensively throughout his life and was able to observe that turbulence sets in gradually and that the flow conditions follow an increasingly complex structure with each step. According to his theory, turbulence arises from superposition states of simple flow modes.

In a uniform flowing fluid, i.e. a laminar flowing fluid, the physical parameters describing the flow dynamics are unchanged in time. Thus, the physical variables of the flow dynamics do not change. Mathematically, such uniform flow behavior can be represented by a single point in a phase space. In the mathematics of nonlinear chaotic systems, this is also referred to as a point attractor. The special features of the attractor representation will be discussed in more detail in the following chapters. Indeed, attractor models are particularly well suited for the description of chaotic and turbulent systems. To stay with the consideration of fluid dynamics: If such an initially still uniform flow behavior is successively disturbed and distorted by disturbances from outside, for example by large stones in a riverbed or in the human organism by arteriosclerotic plaques, stable vortices can initially form in these areas. At this stage, the flow behavior is still relatively regular, and the vortex patterns formed behave stably and do not change shape. Such flow behavior can be called a limit cycle or a limit cycle attractor: After a brief disturbance, the flow returns to the previous flow mode. This was a transition from a point attractor to a limit cycle attractor. This transition took place at a transition point from an originally still laminar, i.e. uniform, flow behavior to a more complex flow behavior in the form of a limit cycle.

2.4 Order in Non-equilibrium States

For a long time, turbulence in liquids was regarded as a prime example of disorder, whereas a crystal appeared to be the epitome of order. In reality, however, the turbulent system is of far more complex order: for the atoms in a crystal oscillate incoherently only about their equilibrium position, whereas in a turbulent liquid, the motions of two molecules in a comparatively very large, i.e. at a macroscopic distance of several centimeters are in correlation with each other! Order on the physical level is of a different genesis than order on the level of living systems: Thus, the order in a crystal is based on an "ordering" activity, which physically corresponds to an entropy-generating process. For the area of living systems, on the other hand, a different principle applies because the build-up of complex biomolecules on the level of metabolic processes is based here on the destruction of other molecules.

The occurrence of collective motions in dissipative, i.e. energy-consuming, systems is also equivalent to a breaking of spatial symmetry: In the vicinity of equilibrium, fluids behave homogeneously, the motion of the molecules in this state is incoherent and is described by the laws of chance. In the non-equilibrium state, new properties of matter can appear, which clearly deviate from the properties in the equilibrium state: Thus, in the vicinity of a Bénard instability, the molecules enter into correlation with each other and now move in a collective compound. In Bénard instability, a thin layer of liquid is subjected to a temperature difference where the lower boundary is continuously heated while the upper layer is still at room temperature. If the temperature difference between top and bottom is small, i.e. if the temperature difference is still comparatively close to equilibrium, the heat transfer from bottom to top is approximately linear by the principles of heat conduction mediated by mechanical collisions between the molecules.

The lower and warmer layers are less dense than the cooler layers higher up in the wake of their thermal expansion. This results in a density gradient between the bottom and the top. Because this is an unstable density gradient, even comparatively small disturbances or turbulences in the lower layer cause these particles to rise upward in the Earth's gravitational field. In the process, the particles rise faster than the temperature equalization with the environment takes place. Thus, an internal imbalance has been created by external influence, which causes balancing processes. These balancing processes change the conditions of their origin, namely the imbalance.[81] With the imbalance, self-reinforcement processes are set in motion, whereby even small, i.e. microscopic, movements at the beginning can result in more and more macroscopic movements. On the other hand, small disturbances at the surface can cause liquid particles to be displaced downwards, i.e. into zones of lower density. In this environment, they are heavier and sink downward: Local microscopic fluctuations thus lead to macroscopic motions. These dynamics of fluid flows can be completely described by physical quantities, such as velocity, pressure and density as functions of place and time. In this context, the elementary forms of flow patterns are still to be considered.

81 Küppers, G.: Selbstorganisation: Selektion durch Schließung. In: Küppers, G.: Chaos and Ordnung. Formen der Selbstorganisation in Natur und Gesellschaft. Reclam Verlag Jr. Stuttgart (1996) p. 136.

In the macroscopically visible flow pattern of a fluid, all elementary phenomena of motion are integrated. Such elementary forms of motion are called modes. However, when the temperature difference in a column of liquid is increased beyond a critical value, not all modes will grow at the same rate: a critical mode, which has the highest growth rate for a given value of temperature difference, eventually imprints its shape on the resulting flow. The elementary flows are interconnected in a nonlinear way, and the emerged critical mode is also interconnected with all others, again limiting the processes of self-amplification: Self-organization has emerged. The patterns that emerge in this way are thoroughly dynamic, and they can only exist as long as the processes that support them are intact. These transitions from initially static fluid layers to complex flow patterns are driven by the equilibrium processes mentioned above, and they are vivid examples of the transition from chaos to order.

Thus, if the temperature difference between top and bottom exceeds a certain upper threshold, heat transport is mediated by convection at increasing distance from equilibrium. This produces the typical fluid vortices which divide the fluid into regular patterns resembling cells or honeycombs. In the state of convection, the interactions between the molecules are physically still the same, but the correlations between the molecules have changed drastically.[82]

Self-organization means establishment of order in the structure of existing orders. The emergence of order on the basis of order is bound to the differentiation of a self-ordering dynamic network or, in another conceptual representation, to the operational exclusion of a dynamic from a comprehensive operational context. Such exclusions are possible if processes can close themselves cyclically, because they are cause and effect at the same time, regardless of their own dynamics.[83] Accordingly, such systems are also called operationally closed systems. If systems generate the elements of their own networks in their network processes, they are also called autopoietic systems in a slightly different notation. Living systems are typical examples of self-organizing or autopoietic systems. Cell assemblies, for example, generate those molecular biological elements, i.e. nucleotides, proteins, lipoproteins, etc., of which they are composed and with which they organize themselves into networks. The products of causes are thus the causes of their own products. Cellular associations, in the definition elaborated above, are to be understood as operationally closed associations. In the dynamic patterns of self-organizational processes, moreover, the emergence of a multitude of different structures is possible, which are also called "eigenstates" and whose forms, in turn, depend on system-mineral processes.[84]

On the level of inorganics, i.e. on the level of chemistry and physics, non-equilibrium, non-linear reactions can lead to fixed correlations between molecules. These are long-range correlations, which are causal for the macroscopic patterns appearing in the form of honeycombs or rolls. Such long-range correlations are determined by kinetic constants and diffusion coefficients. In contrast, molecular interactions at the level of crystalline structures are characterized by correlations of only short range. In these static systems, the order is determined by the local properties of the

82 Prigogine, I., Stengers, I.: Das Paradox der Zeit. Piper Verlag Munich Zurich (1993), p. 83.

83 Küppers, G.: Selbstorganisation: Selektion durch Schließung. In: Küppers, G.: Chaos und Ordnung: Formen der Selbstorganisation in Natur und Gesellschaft. Philipp Reclam Jr. Verlag Stuttgart (1996), p. 141.

84 Küppers, G.: Selbstorganisation: Selektion durch Schließung. In: Küppers, G.: Chaos and Order. Forms of self-organization in nature and society. Philipp Reclam Jr. Verlag Stuttgart (1996), p. 144.

atoms establishing them. Their equilibrium states show only short correlations, the range of which is only about one Angstrom (10-8 cm).[85] Macroscopically, the parts, i.e. the atoms or molecules, behave incoherently at equilibrium, while far from equilibrium the correlations can extend over long, i.e. macroscopically relevant, distances. Thus, chaotic systems are based on complex intrinsic ordering principles, and in the enormous difference of the orders of magnitude between static and chaotic systems on the level of correlations the differences between equilibrium and disequilibrium become apparent.

We encounter chaotic systems on the level of physics and chemistry, and they become even more significant on the level of living systems, not least in medicine: Thus in the electrical derivation of the heart action, the electrophysiological activity of the brain, in many quasi-rhythmic processes of the metabolic systems up to the non-linear, chaotic courses of the various diseases, which, however, all follow an intrinsic subtle order.

2.5 General Remarks on the Theories of Self-Organization

The paradox "Carnot or Darwin" discussed in connection with the second law of thermodynamics[86] could be brought closer to a solution only when one began to study systems far from equilibrium in their behavior. In these systems, linear relationships between the general forces no longer exist, as was so successfully shown, above all, by Ilya Prigogine in his studies on the thermodynamics of irreversible processes.[87] In these studies, it could be proved that systems can evolve towards steady states even under conditions far from equilibrium. These systems can thus assume stationary non-equilibrium states, which then behave approximately linearly. To maintain such states far from equilibrium, an appropriate amount of energy must be supplied. If the distance from the equilibrium state increases, e.g. due to changes in the boundary conditions of the system, at a certain point in time such states can be assumed which are characterized by the occurrence of irreversible processes. Under the prevailing conditions of nonlinearity, instabilities are also possible, which can lead to the spontaneous formation of spatial, temporal, or spatio-temporal patterns and structures. An example of such pattern formations was discussed in connection with Bénard's instability. Biological systems are classic examples of nonlinear processes that can form new shapes at a supercritical distance from equilibrium. However, this is only possible under a continuous supply of high-quality energy.

Systems that have the ability to go through such states are generally called self-organizing or autopoietic systems. Examples of self-organization are ubiquitous in chemistry, as well as in physics and astronomy, and especially in living systems. The term self-organization was once defined by Ebeling as follows: "By self-organization, we understand an irreversible process, which leads to more complex structures of the whole system by the cooperative action of subsystems. With self-organization, an elementary process of evolution comes on the scene, because evolution can be

85 Prigogine, I., Stengers, I.: Das Paradox der Zeit. Piper Verlag Munich Zurich (1993), p. 84.
86 Caillois, R. (1973), La dissymétrie. In: Cohérences aventureuses. Paris, p. 198.
87 Prigogine, I. (1947): Étude thermodynamique des phénomènes irreversibles. Desoer, Paris et Liége. Prigogine, I. (1969): Structures, dissipation and life. In: Marois, M. (Ed.): Theoretical physics and biology. North Holland Publ. Compo., Amsterdam, London, p. 50.

understood as an unlimited sequence of processes of self-organization. The processes on earth as well as in the cosmos are usually evolutionary processes that can only be understood in the context of their history, i.e. in the context of the whole chain of the causing self-organization processes. Typical for the processes of self-organization are often sequences of kinetic transitions, which occur with increasing deviation from equilibrium at certain critical parameter values.[88]

According to Ebeling, the four most important methodological foundations of the theory of self-organization are:

1. The thermodynamics of irreversible processes. This theory describes the global and local balances of energy, entropy, momentum and quantities of matter.
2. The nonlinear dynamics of order parameters, which deals with the solution of nonlinear differential equations for the characteristic quantities of the processes.
3. Stochastic theory, which deals with macroscopic order parameters, but considers them as fluctuating quantities.
4. The statistical theory, which works with probability distributions for the microscopic state of the system.[89]

The basic thermodynamic condition for self-organization is, as mentioned, the export of entropy and the supply of high-quality energy. Only those processes that can free themselves from the entropy generated inside by the irreversible processes are capable of self-organization.

Moreover, a fundamental characteristic of these processes is that they cannot be fully understood from the physical identity of their components, even though they are physical attributes of matter. Many physical systems possess the property of spontaneously forming spatial or temporal patterns under certain conditions. They thus exhibit a certain degree of global cooperation.

A simple example of self-organization is the phase transition during the transition of a liquid into a solid or a gas, e.g. when water freezes to ice. Another example of self-organization in the inorganic domain is the phenomenon of superconductivity of metals near absolute zero. In this low-temperature range, substances can ever lose electrical resistance and they thus become superconducting. Electricity is known to result from the flow of electrons. Under temperatures near absolute zero, the flowing electrons go into a cooperative large-scale form of organization. They now behave as a single electron and move according to the form of a highly organized quantum wave pattern.

Bénard's instability has already been described as an example of spontaneously arising dissipative patterns in the inorganic realm, which can shape the thermal motions of a liquid into roll-like patterns. Such self-organizing structures in liquids can only form because energy is introduced into the system from outside in the form of thermal energy. Thermal energy supplied from the outside does not, as would be expected, lead to more violent movement of the liquid molecules and thus to greater disorder, but on the contrary to the spontaneous formation of high-order patterns.

A chemical example is the Belousov-Zhabotinsky reaction, which results from the oxidation of an organic acid (e.g. malonic acid) with potassium bromate in the

88 Ebeling, W.: Wir und die Natur: Chaos-Ordnung-Information. Urania Verlag Frankfurt a. M. (1989). p. 17.
89 Ebeling, W.: Wir und die Natur: Chaos-Ordnung-Information. Urania Verlag Frankfurt a. M. (1989), p 42-43.

presence of a catalyst. This reaction proceeds discontinuously, so that spatial or temporal patterns, for example in the form of spiral waves, occur. In these processes, initially homogeneous states are replaced by spatial pattern formations with a distinct long-range order. Such transitions from simple to more complex phases are again accompanied by symmetry breaking: For example, water drunk from a glass exhibits rotational symmetry. If the glass of water is placed in front of the window in winter, the water freezes. Ice crystals have formed, and the previous rotational symmetry has been lost. The reason for the symmetry breaking is that the crystal faces now have a preferred direction in space.

Because symmetries are generally broken at low temperatures and because the universe cools down from a very hot initial state, the history of the universe can also be understood as a sequence of such symmetry breaking.

Self-organization can thus occur in systems far from equilibrium at all stages of nature, and in all cases, self-organization leads to a more complete spatial, temporal, or spatiotemporal form. An important property of self-organizing systems is, above all, that they are open to their environment. The new emerges spontaneously and is theoretically explainable, but not exactly predictable in detail. Self-organizational systems are creative systems at all levels of nature.

2.6 Attractors as Mathematical Models of Processes of Self-Organization

In nature, the simple and the complex coexist without being linked hierarchically. In the models of attractors, such connections of the simple and the complex are vividly represented:

Even a seemingly simple movement of a pendulum under the real conditions of friction losses can hide a whole world of complexity.[90] Under the conditions of classical mechanics an ideal pendulum, i.e. a pendulum without friction losses, continues its oscillations indefinitely. However, such an ideal pendulum motion does not correspond to reality. On the other hand, a real pendulum comes to a standstill in its equilibrium position due to friction losses at some point in time, if no energy is supplied from outside. This temporal process of an increasing reduction of the pendulum swing until the equilibrium position can be modeled mathematically in the form of an attractor. The term "attractor" comes from Latin ("attrahere") and means something attracting. Attractors are representatives of the changing system states in a phase space. By the term of a phase space, the total number of possible states of a system is understood. Within such a phase space, attractors then denote special "areas" which are characterized by a special attraction force. Thus, an attractor is understood to be a state or behavior toward which the evolution of a dissipative system is heading.... The concept of an attractor can be clarified even better if a space is introduced, which has as many dimensions as variables are needed to describe the temporal development of a system. These variables could be, for example, the coordinates of a pendulum or the temperature changes of a gas. Each state

90 Prigogine, I., Stengers, I.: Das Paradox der Zeit (1993), p. 99.

of a self-organizing system can thus be characterized by a certain set of numbers in a phase space. However, the description is always of limited accuracy, since the numbers used contain only a finite number of digits.[91] Therefore, a state of the system is not defined by a point in space, but by a small area whose extent depends on the length of the sequence of digits. All points in this area thus denote the "same" system. Nevertheless, these points belong to trajectories on which the state changes of the system in the course of time are encoded.

The equilibrium state of a dissipative system, for example, the rest state of a pendulum, can be represented by a point in this space and thus corresponds to a "point-like" attractor. Similar observations apply to the quasi-steady states of dissipative systems near thermodynamic equilibrium, which obey the minimum entropy production theorem. In the above cases, the evolution of a system, regardless of its initial state, can be represented by a trajectory under the given boundary conditions.

It is self-explanatory that not every energy-consuming system in our everyday reality leads to a single endpoint. Such a case is rather to be considered as the exception. In reality, a variety of dissipative systems are known that do not evolve towards a single point, but rather generate specific dynamic patterns. An example of this would be the "chemical clocks", where the dissipative system does not drive a point state but evolves towards a stable periodic behavior. The so-called Beluosov-Zhabotinsiki reaction was mentioned as an example of this. In the graphical representation of more complex attractor patterns, it may turn out that one does not get points or a straight line, but two-dimensional surfaces or bodies. A so-called chaotic attractor consists of a set of states, in principle infinite in size, which are passed through in the course of time, never being exactly the same states. They are always only similar states which are passed through in non-periodic time intervals. For example, the chaotic attractor "weather" shows always recurring weather states, but they are never exactly the same.

A characteristic feature of complex chaotic attractors is their fractal structures and fractal dimensions. The dimension of an attractor is not an integer as in classical geometric objects, for example, a line, a surface, or a three-dimensional body. Rather, the set of traversed states builds a chaotic attractor in phase space whose dimensions are fractal, with lines exhibiting surface character and surfaces approximating three-dimensional objects. The fractal dimension can also be used as a measure of order of deterministic chaos, however, an attractor is by no means uniquely determined by its dimension.

The notion of fractal dimension is also closely related to the notion of self-similarity: arbitrarily small sections of an attractor resemble structures on larger scales. Thus, in the finite domain of phase space, where deterministic chaos takes place, the same laws apply to large and small scales. Moreover, attractors are stable structures because the principles of dynamics and stability are integrated in them in equal measure. This makes the typical behavior of such systems understandable, which can be temporarily forced out of their rest position by an external disturbance, but then return to their original range in phase space, but only if the external disturbance was not too great. Thus, these are on the one hand stable and on the other hand complex structures with fractal dimensioned forms and very complex temporal behavior. Consequently, attractors of this type also define behaviors that can neither be

91 Prigogine, I., Stengers, I.: Das Paradox der Zeit (1993), p. 107.

predicted nor reproduced. Such complex attractors are related to extreme weather caprioles and last but not least they could be related to physiological and pathophysiological processes in our organism. With high probability, complex attractor patterns also occur in connection with the neuronal processes of the central nervous system.

The states through which a dissipative or a self-organizing system passes in the course of time are stored on trajectories. In the ordered regime of such a dynamical system, neighboring states show a tendency to converge and often merge into the same trajectory before reaching the common attractor. However, at the edge of phase transitions and thus near the chaotic regime, neighboring states usually show neither convergence nor divergence. These phase transitions mark the complex regime. In these transition phases, the mean convergence of trajectories approaches zero. As a consequence, originally neighboring trajectories now show a tendency to diverge: Originally neighboring initial states now diverge and each initial state follows its own trajectory. This is one of the reasons for the so-called "sensitivity to initial conditions".[92]

The following statement is also of importance for the understanding of these systems:

It is the system states of self-organizing systems that essentially determine the courses of the individual trajectories. Thus, system states passed through in the past have an effect on the current course and the current behavior of the system. Therefore, a time integration takes place in the sense that the future behavior of the system is determined by the integration of past and present states: The current in each case is inferred from the past and is at the same time an option for the future. Thus, these systems show an impregnation that can be described as holistic.

2.7 The Complex and the Indetermined in the Context of Self-Organization

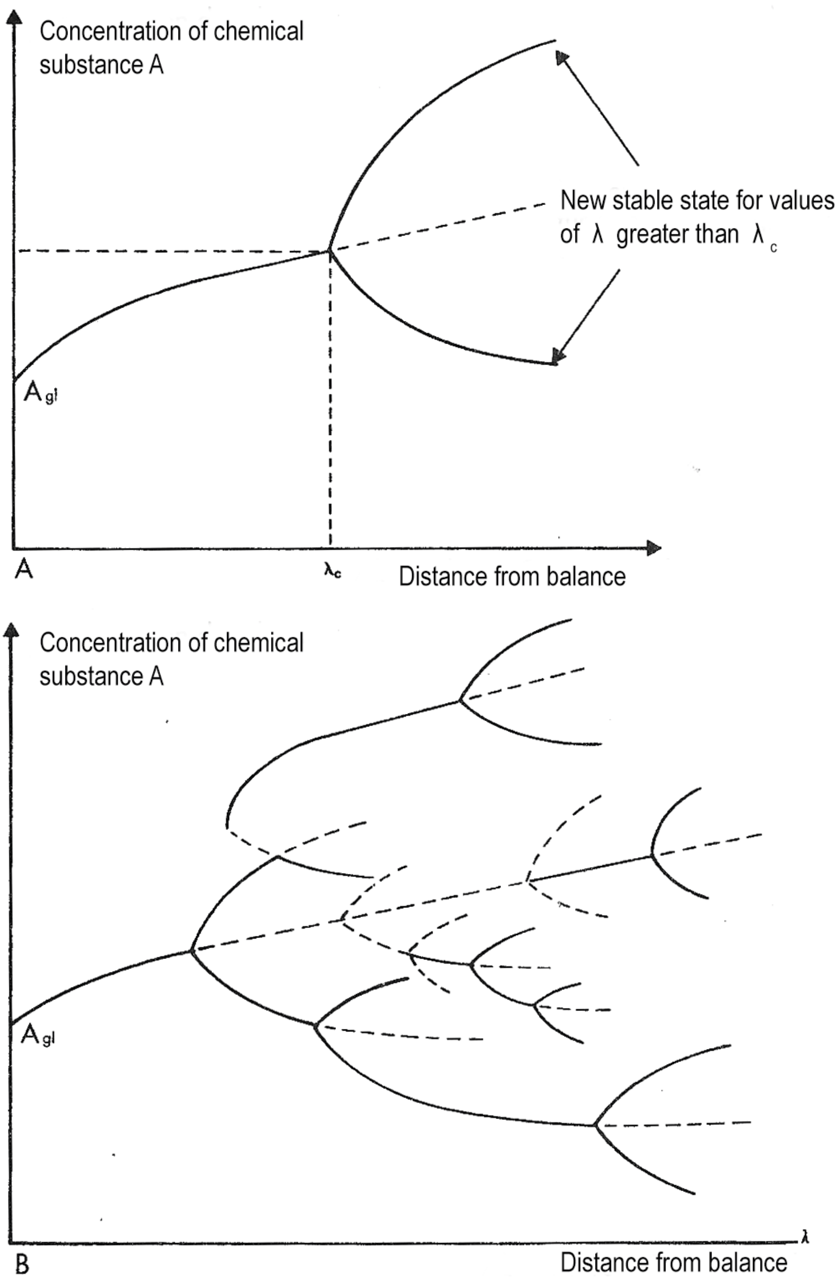
Transitions of attractors into higher and higher dimensions, for example into 4, 5, 6 or even more dimensions, have been proposed on various occasions. As far as I can see, no experimental evidence for the existence of such high-dimensional attractors has been found so far. The physicist David Ruelle, who worked intensively on chaotic flow behavior, could prove that in convection flow the smooth laminar flow changes from a point attractor into a limit cycle attractor. This should be followed by the transition of the limit cycle into the surface of a so-called torus attractor. Now it could be conjectured that in the next step, a transition of the system from the two-dimensional surface of a torus attractor to the three-dimensional surface of a torus embedded in the four-dimensional space could take place. Probably, however, such high-dimensional transitions do not take place according to Ruelle's findings: Rather, the torus could move toward a stage characterized by fractional dimensions. This is to express that the surface of the torus could now be between the dimensions of a plane and the three-dimensional dimension of a solid body. Interestingly, this assumption of Ruelle was confirmed by an experiment carried out by Harry Swinney and Jerry Gollub of the University in Austin/Texas: They investigated the

92 Kauffman, S. A.: "What is life? – Was Schrödinger right? In Murphy, M. P.; O'Neill (eds.) What is Life? The future of biology. Spektrum Akademischer Verlag Heidelberg Berlin Oxford (1997), p. 126.

flow behavior of a fluid between two cylinders, where only the inner cylinder rotated, while the outer cylinder was fixed. The idea is to generate specific patterns of fluid dynamics in which the different fluid elements can move at different speeds. As expected, an approximately uniform flow behavior could be observed with slow cylinder rotation. When the cylinder rotated faster, an initial instability occurred: the flow behavior changed abruptly, with spontaneous patterns appearing that were reminiscent of the twisted components of a rope. Under further acceleration of the cylinder rotations, a second instability phase occurred, which was characterized by new and even more complex internal rotations. In this phase, even two different cyclic oscillation modes presented themselves. With still greater acceleration these regular movement patterns decayed again into random oscillation patterns which built up an attractor of fractional dimensionality.[93] Uncommonly remarkable about this experiment is the realization that under an ever-faster cylinder rotation and the associated distance from thermodynamic equilibrium, on the one hand, the entropy production must increase very rapidly, but that even in these areas of high entropy production an orderly flow behavior could nevertheless be observed. The experiment shows in an impressive way the spontaneous emergence of more and more complex patterns. Such a spontaneous emergence of patterns is consequently called autopoiesis or self-organization, they are processes of almost universal importance.

In their development, self-organizing systems can take a multitude of possible development paths, which can be graphically represented in so-called bifurcation diagrams.

93 Briggs, J., Peat, D.: Die Entdeckung des Chaos. Deutscher Taschenbuch Verlag Munich (1993), p. 71-72.



Bifurcation diagram

With such bifurcation diagrams, the temporal behavior of such systems can be represented with increasing distance from the thermodynamic equilibrium. In the figure, as an example, the concentration of a chemical substance is plotted on the vertical axis and the distance from thermodynamic equilibrium λc is plotted on the horizontal axis. Under constant external supply of the chemical substance and with moderately increasing λc, a state of equilibrium between substance supply and substance consumption is initially reached. Here, λ is still in the ordered linear range of the reaction, the so-called thermodynamic range. In this range, the reaction is still at the stage of minimal entropy production: in other words, the reaction is in a stable steady-state. Beyond a critical distance of λc, which is characterized as a bifurcation point, the thermodynamic branch, which has been stable until now, abruptly becomes unstable and the system suddenly offers two new possibilities of stable concentrations at each λ. The new states taken after a bifurcation process can exhibit a high degree of order in which trillions of molecules are in coordination with each other in space and time. The system states may also have a wide range of possible directions with a large number of neighboring stable local states that the further behavior of such a dynamical system becomes unpredictable. Such states are then called deterministic chaos.

Beyond such critical points, self-organization can thus occur spontaneously, i.e., in a nonlinear form. The spontaneous occurrence of color changes, which is called a chemical clock, or the occurrence of colored patterns in a test tube, would be typical examples of the spontaneous emergence of self-organization on a chemical basis. Put simply, these systems have a "choice" between two possible new states, but the definitive chemical reaction takes only one of several possible paths. However, no prediction is possible as to which of the various possible paths the reaction will actually take. There is thus a maximum degree of uncertainty in these points, which is referred to as Hopf instability. The further such nonlinear reactions take place in the distance from the equilibrium state, the higher the number of possible reaction paths or local states. Thus, a manifold of possible pathways is available to the system. When considering these processes, it is also important to note that not every possible path can be taken. Because these systems have their own history in the form of previously passed paths and previous changes of direction at the corresponding Hopf points. Which way the system actually takes through the space of a multiplicity of possible ways is therefore also a consequence of directional decisions made in the past at the respective bifurcation points. The states, which a system passes through in the course of time, can be represented as trajectories. The course of a trajectory thus depends on decisions made in the past. The paths of the trajectories thus encode the system states that have been passed through. To this must be added the thought that each self-organizing system does not exist on its own, but is itself integrated into an environment, i.e., into the network of further, over-forming, systems, just as in a river the smaller eddies and turbulences are integrated into the range of larger turbulences. In an analogous way, one can also speak of the superposition states of the catchment areas of attractors. This leads to the realization that the information about passed system states is not lost, rather it is stored on the trajectories of attractors, which in turn are integrated into whole landscapes of attractors.

Consequently, every living being can be understood as a complex and, moreover, unique system in the systems of structured attractors, whose information is intrinsically embedded in the contexts of attractor landscapes of living systems and is thus, in principle, preserved.

- As long as life exists, information about every living being is in principle preserved. Every life leaves indelible traces in the world.
- For humans, their acts of consciousness are species-specific. Thus, it can be assumed that the myriads of individual acts of consciousness of each individual remain stored in the landscapes of the attractors of living systems. Possibly even each of the thoughts is coded somewhere in the world.
- The physical and organic matter of the individual dies, its informatory contexts persist across the ages.

The uniqueness of the path of a trajectory through the multiplicity of possible trajectories in phase space or the system states passed through in the course of time are, in summary, consequences of decisions in the area of the critical points of a system or its bifurcation points. Typical and fundamental for the processes of self-organization is the fact that the respective actual states are related to the initial states via feedback loops. Thus, the newly created states from a multitude of possible alternatives always carry a kind of "memory" of previous decisions or of previously passed states.

Feedback means the transmission of information about the current result of a process back to the starting point. The current result of a process is modulatingly transmitted back to the output. By means of such loops, self-organizing systems are able to regulate the processes running within them in an inhibitory or stimulating way and to adjust them to the current demand.

By means of such loops, the past is always present in the present.

Thus, it becomes understandable that order in connection with self-organization arises on the basis of an already existing order. In this sense, the principle "order out of order", so-called by E. Schrödinger, is realized. Or also: Order in order is bound to the differentiation of an autonomic, self-ordering process network, which is then called a system.[94]

Self-organizing systems and networks emerge through the operational exclusion of a specific dynamic from a more comprehensive operational context, just as vortices, and turbulences differentiate themselves out of the flowing current, and this with the continued formation of new vortices. In this way, in a slightly different formulation, new operationally closed systems are created. However, these newly emerging systems, for example, the turbulence and vortices in a river, are not completely new in the sense that they are built up by a completely new set of physical variables. Rather, it is the case that these newly emerging systems always carry with them variables from those systems from which they have separated: Also, from such an intellectual approach the "new" systems always carry with them the traces of the past of those system states from which they originally emerged.

Using the example of biological systems, it is easy to understand that in their developmental dynamics, the past is always present, for example in the form of genes, on which the history of the individuals and, moreover, the history of the species as a whole is encoded. It is also true for living beings that they can be understood as operationally closed systems on the basis of pre-existing variables. They are operationally closed systems in context with overarching, broader, operational contexts.

94 Küppers, G.: Selbstorganisation: Selektion durch Schließung. In: Küppers, G.: Chaos and Order. Philipp Reclam jun. Stuttgart (1996), p. 141.

In the field of ecology, fluctuations of different animal populations in changing environmental conditions are now very well-studied examples of such self-organization processes in the context of broader system contexts.

2.8 On the Notion of Autopoiesis

In close semantic proximity to the concept of self-organization is the concept of autopoiesis. The basic mechanism of autopoiesis was described by Maturana and Varela in this way: “The maintenance of autopoiesis and the maintenance of adaptation are necessary conditions for the existence of living beings; the ontogenetic structural change of a living being in its milieu will always be a structural drift which is in accordance with the drift of the milieu. This drifting will appear to an observer in the course of the history of interactions of the living being as “selected” by the milieu”.[95]

According to Luhmann, in a somewhat different approach, the term autopoiesis is to be used in such a way that any sense-making can be possible exclusively from the internal view of these systems.[96]

Jongebloed establishes the following four criteria for autopoietic systems:

1. Living systems consist of elements and a relation between the elements. Elements and relations are interactively constitutive for each other.
2. Autopoietic systems delimit themselves from their environment. This boundary always remains changeable without losing its function.
3. Autopoietic systems are operationally closed, but “nevertheless or just because of that they are in a material and energetic exchange relationship with their environment”.
4. Besides the aspects of self-production and self-preservation, autopoietic systems are self-referential. “The feature of self-referentiality is constitutive for autopoietic systems, although not every self-referential system has to be an autopoietic system at the same time”.[97]

However, this is not yet a sufficiently precise statement about the way in which these autopoietic systems are organized. Luhmann also refers to autopoiesis as “systems that are formed via basal self-reference and have their system unity therein”.[98]

With respect to social systems, the autopoiesis theory is to a certain extent based on the expectation that this theory should accomplish something “which has irreconcilably fallen apart since matter and idea have come into contact with each other: namely, to capture society as it is and as it is not, but could be, in a concept that is its name”.[99]

95 Maturana, H., Varela, H. F.: Autopoietic systems: a determination of living organization. In: Maturana, H.: Recognizing: The organization and embodiment of reality. Selected works on biological epistemology. Viehweg-Verlag Braunschweig and Wiesbaden (1982), p. 170ff.

96 Spieß, R.: Bildung von Singularitäten. Draft of a theory of complementary systemicity. Inaugural dissertation. Books on Demand GmbH (2007), p.76.

97 Jongebloed, H. C.: Aktuelles Stichwort: “Autopoiese”. In: Kölner Zeitschrift für Wirtschaft und Pädagogik 2 (1987), pp. 75-80.

98 Luhmann, N.: Soziale Systeme. Grundriss einer allgemeinen Theorie. 7th ed. Suhrkamp Verlag Frankfurt a.M. (1999), p. 602.

99 Pfütze, H.: Weit entfernt vom Gleichgewicht. In: Fischer, H. R. (ed.): Autopoiesis. A theory in the focus of criticism. Auer Verlag Heidelberg (1991), p. 227.

Such an expectation, however, is not fulfilled by the concept of autopoiesis. On the contrary, it is rather correct to state that the autopoiesis concept should be understood as a strong reduction form to characterize the living. Life is, and here Friedrich Cramer is to be agreed with, "a system property, and the system is destroyed by decomposition".[100]

Autopoiesis as a self-creating entity bears the following characteristics according to Maturana and Varela:

1. As a composite entity, its organization as a closed network of production processes of constituents, which in turn constitute this very network of production processes through their interactions and which determine its extension by defining its boundaries in their sphere of existence.

2. A living system is an autopoietic system whose components are molecules. Or in other words, living systems are molecular autopoietic systems and exist as such in the space of molecules as closed networks of molecular production processes that generate their own boundaries.[101]

Autopoietic systems thus constitute themselves via the definition of their boundaries and qua "generation" of their components as a unit in a space which they determine and in which they exist.[102] Maturana specified the autopoiesis theory even further as follows: "An autopoietic machine is therefore a homeostatic (or better a relation-static) system that keeps its own organization (i.e., the relational network defining it) constant as the fundamental variable".[103]

In the meantime, a multitude of attempts to establish the autopoiesis or self-organization theory as universal basic theories exist, which not only want to describe the processes on the physical, and biological level but also the processes in the field of neuronal and cognitive processes and beyond that still on the level of sociological processes. Regarding these thoughts, Varela once expressed himself as follows:

"To put it straight – it is rather that biology is the basis of physics than vice versa"[104]

In distinction to self-organization, autopoiesis could rather be understood as a system-keeping process, whereas the term self-organization rather refers to an emergent, organization-constituting, moment.

Moreover, Maturana once referred to his theory as a deterministic theory:

"Living systems are deterministic systems, they are structure-specific einheiten". [105]

100 Cramer, F.: Chaos und Ordnung. The complex structure of the living. DVA Verlag Stuttgart (1988), p. 28.

101 Maturana, H. R.: Biologie der Realität. Suhrkamp Verlag Frankfurt a.M. (1998). Varela, F.: Autopoiesis, structural coupling and therapy. In: Fritz B. (Ed.): Living Systems, Reality Constructions in Systemic Therapy. Springer Verlag Berlin Heidelberg New York (1988), pp. 108-120.

102 Spieß, R.: Bildung von Singularitäten. Draft of a theory of complementary systemicity. Inaugural dissertation. Books on Demand GmbH (2007), p. 82.

103 Maturana, H.: Erkennen: The organization and embodiment of reality. Braunschweig Wiesbaden (1982), p. 185.

104 Kakuska, R. (ed.): Other Realities. Munich (1984), p. 103. citation after: Heuser, M.-L.: Wissenschaft und Metaphysik. Reflections on a General Theory of Self-Organization. In: Krohn, W., Küppers, G. (eds.): Self-organization. Aspects of a scientific revolution. Vieweg Verlag Braunschweig Wiesbaden (1990), p. 57.

105 Maturana H.: Kognition. In: Schmidt, S. J. (ed.): The Discourse of Radical Constructivism. Suhrkamp Verlag Frankfurt a. M: (1987), pp. 89-119.

De facto, this excludes a free choice for these systems. Only for the observer from the outside, it would appear that something new, creative would emerge. Therefore, again Maturana: "Therefore every ontological assertion of an objective indeterminism based on scientific analysis is false".[106]

The view of these authors can be agreed with, because the criterion of emergence, the emergence of the new, a teleonomy and the ability to generate semantic information are characteristic for self-organization. Self-organizational systems have a choice, i.e., from the unstable bifurcation points to take new directions of their system development. Self-organizational processes, strictly speaking, unite both determinism, randomness and indeterminism in their dynamics. They unite closedness and openness and this not as pairs of opposites, but as mutual conditional relations.

2.9 Singularity in Self-Organizing Systems

The general conditions of a system's behavior can, generally speaking, be formally described by parameters. Changes in the system behavior correspond to a transformation of system parameters. The temporal evolution of systems is described in physics by differential equations. However, the natural sciences are always confronted with serious problems when function values at singular points become infinitely large, indeterminate, or both. At such a point, science is confronted with a singularity.

The term "singularity" is usually associated with the physicist Maxwell. However, already sometime before him, namely by J.P. De Gua De Malves, the term singularity was mentioned in 1740 as a singular or strange point in a curve without a continuous derivative or as an irregular, non-homomorphic point.[107]

Maxwell dealt intensively throughout his life with the problems connected with the concepts of causality and singularity.[108]

It can be called a central insight of Maxwell, in that he recognized that causality can be broken through the singularity. However, this did not mean to him at all that there is no causality.[109] Concerning causality, Maxwell first of all agreed with the view that the same initial conditions must always be followed by the same results. However, already at that time, he came to the conclusion that such a statement could have only little value in a real world in which the same initial conditions could never be exactly repeated: Precisely because the initial conditions would never exactly recur and because instabilities were always possible in the systems of nature, it could also not always be assumed that the same initial conditions would also produce the same events or results. Rather, there would always be a possibility that the smallest

106 Maturana, H.: Erkennen: The Organization and Embodiment of „Wirklichkeit". Braunschweig Wiesbaden (1982), p. 270. In contrast, H. Haken and I. Prigogine emphasize the fundamental importance of indeterminism in the bifurcation points of self-organizational systems. Haken, H.: Synergetics. An Introduction. Springer Verlag Berlin Heidelberg New York. 1977. Prigogine, I., Stengers, I.: Dialogue with Nature. New ways of scientific thinking. Munich Zurich (1981), p. 25.

107 Holzkämpfer, H.: Management von Singularitäten und Chaos. Springer Fachmedien Wiesbaden GmbH (1996), p. 79.

108 Maxwell, J. C.: Does the Progress of Physical Science tend to give any Advantage to the Opinion of Necessity (or Determination) over that of the Contingency of Events and the Freedom of the Will? In: Champbell, L./Garnett, W.: The Life of Clerk Maxwell. London, (1882).

109 Maxwell, J. C.: Substance and Motion. Braunschweig (1881), p. 14f. Poincaré, H.: Science and Method. Leipzig-Berlin (1914), p. 56.

differences could lead to very large and extraordinary deviations. He attributed such instabilities to singularities.

In the field of cosmology, an example of a singularity would be the Big Bang theory in the form of an initial singularity. In physics, causal processes are described in the form of differential equations, whose solutions can occasionally meet singularities. At such points, the theory then predicts effects that threaten to burst the formalism, because they can be either undetermined or unlimited in size. Singular points, however, can also signal certain critical states of a system, in which sudden reversals from one system state to another can take place. Meanwhile, it has been found that in the phase transitions of physical systems, certain correlations of critical equilibrium or non-equilibrium phases with the occurrence of singular points can play an important role.

Last but not least, singularities play a role in quantum theory, which has led to the revision of theories that were hitherto considered to be absolutely valid.[110] Singular points and states represent in this way something unique, both in the theories of physics as well as in the life sciences. Singularities might play an eminently important role especially in medicine and here in the course of diseases. Such singular conditions, which can cause abrupt changes in the course of diseases, have not yet been sufficiently considered, let alone understood, in medicine. In general, it must be stated that there are limits to a precise conceptual interpretation of what is to be understood by the uniqueness of a singularity.[111] The term singularity is currently quite misunderstood. Some authors speak in such contexts, for example, of singularity as a "carrier and expression of complementary systemicity". The term singularity is said to denote a "place" where complementary systemicity would quasi materialize.[112] The purpose or "meaning" of such a complementary systemicity could possibly be assumed to be that it could enable a kind of second-order observation on the basis of which statements about functional interrelations could be extracted – this in the sense that it could enable insights from the environment into functionally differentiated systems: An autopoietic or a self-organizing system, respectively, could thus not select its connection operations from basically infinite referral possibilities, rather the development of these systems is limited, restricted and quasi triggered by three essential specifications, namely:

1. By the kind of operation, which is carried out at a certain point in time.
2. By influences from the environment or from neighboring or superordinate systems and
3. by aspects of purpose.[113]

Following this train of thought, the referential possibilities and thus also the developmental strands or the trajectories of these systems are in principle to be

110 Mainzer, K.: Singulär; Singularität. In: Ritter, J., Gründer, K.: Historisches Wörterbuch der Philosophie. Vol. 9, op. cit. (1992), (p. 804 ff.

111 Spieß, R.: Bildung von Singularitäten. Draft of a theory of complementary systemicity. Inaugural dissertation. Books on Demand GmbH (2007), p. 39.

112 Spieß, R.: Bildung von Singularitäten. Draft of a Theory of Complementary Systemicity. Inaugural Dissertation. Books on Demand GmbH (2007), p. 40.

113 Spieß, R.: Formation of singularities. Draft of a Theory of Complementary Systemicity. Inaugural dissertation. Books on Demand GmbH (2007), p. 48.

classified as limited in their possibilities of variation. In this context, however, the question is raised whether the mentioned three points could also be fully applicable to humans. Especially for the systems of cognition, consciousness, and psyche, the mentioned guidelines cannot be valid, because on this level an appropriate behavior for the maintenance of the system is not always present. On the contrary, it is easy to see that it is just these systems that can generate behavior that is anything but expedient with regard to the environment, that seems downright nonsensical and can even be pathological with regard to the preservation of the system.

The systems of cognition, consciousness, and emotion are not precisely calculable, they are even characterized by partly contradictory and complementary behavior.

Such a complementary and also contradictory behavior can definitely be seen as such a behavior that shows typical characteristics of the chaotic. Such systems, therefore, call for an overarching theory or for so far unknown principles of cognition in which these contradictions can be resolved. However, the currently available principles of cognition unambiguously point to the limits of an analytical approach and complete causal derivability. The principle of complementarity in connection with a systemic approach could therefore be understood in the future as a principle of cognition on a higher meta-level. Possibly, the concept of singularity could then also be better understood.

Singularities can be understood according to another – and in my opinion – interesting approach also as elements between cause and effect, i.e., as contextually connecting elements between cause and effect.[114]

Such extraordinary, namely singular, events can therefore only be dealt with in the context of a dynamic view. Singularities are connected with a discontinuous nonlinear system behavior and for these reasons, they often elude an analytical methodical approach.

Singularity describes, according to another definition, only the "specific, only the individual case as unique".[115] Thus, a quite practicable and, as it seems to me, handy, definition is presented.

It must be emphasized again that singularities in the context of nonlinear and discontinuous system behavior cannot be investigated with exclusively analytical methods. Using the example of nonlinear chaotic systems, it was shown that despite a completely deterministic description of the system behavior, even the smallest changes in the initial conditions can lead to completely unexpected effects which cannot be calculated in individual cases. Such nonlinear systems with internal activating or inhibiting feedback loops can generate extraordinary structures of fractal patterns of the highest mathematical beauty. The singular and the chaotic unfold from a common root. Both the chaotic and the singular also bear the hallmarks of the irreversible. Thus, it is also impossible for systems that have undergone a singular event to return to the same initial state as they were in the beginning. For the same reason, repetitions of a certain singular state cannot be possible.[116]

114 Holzkämpfer H.: Management von Singularitäten und Chaos. Springer Fachmedien Wiesbaden GmbH (1996), p. 6.
115 Breckling, B.: Singularität und Reproduzierbarkeit in der Modellierung ökologischer Systeme. Diss. Bremen. (1990).
116 Staudinger, H.: Singularity. Sitzungsbericht der Wissenschaftlichen Gesellschaft an der Johann-Wolfgang-Goethe-Universität Frankfurt a. M., Vol. 21. no. 3. Stuttgart (1985). Niedersen, U.: The concept of "singular determination". In: Niedersen, U. (ed.): Complexity-Time-Method IV: Growth, Pattern, Determination. Halle (Saale) (1990), p. 73.

The term singularity also has a quantitative and qualitative component, whereby the qualitative component again depends on an observer and thus refers to something subjective: For singular situations that are quite extraordinary for one person may seem rather normal for another. In this context, Poincaré stated: "But what is very small to one person may be very large to another, and what seems very involved to one person may seem very simple to another".[117] Poincaré geometrized the problems of nonlinear differential equations by focusing on solution curves rather than solution functions. He examined the global behavior of solution curves and not the local behavior of solution functions.

The behavior of processes on a more global level of observation is again represented in the patterns of attractors.

As described, the bifurcations in the behavior of nonlinear self-organizational systems are to be regarded as strange, as special states. This is because in the vicinity of these bifurcation points, the system behavior changes not only in quantitative but also in qualitative terms. Bifurcation points can thus be regarded as examples of singularities in the domain of dynamical systems.[118] This is because, starting from a bifurcation point, a system development can take not only two but almost any number of courses – and this with only a small change of the parameters. Closely connected to the concept of bifurcation is the concept of a "catastrophe" in a mathematical sense.[119] A catastrophe designated as such is referred to as a bifurcation at a "dangerous boundary".[120] The "catastrophe theory" founded by R. Thom as a branch of analytical mathematics is therefore intensively concerned with the nature of singularities.[121] Catastrophe theory is particularly interested in the transitions of dynamic systems in special phases, namely when these transitions take place very quickly.

Singular events are above all also related to the structure of the time of events, which Luhmann had pointed out: Namely, each event, by its appearance, separates time into past and future. Each event must therefore lead to a modification of time. In this sense, time is change, because if nothing changes, there is no time.[122] The temporality of time and change correspond to each other. Singular events thus mark salient points in the structure of time in this context.

Moreover, change is not only a sequence of events. In order to be able to prove change at all, a structure is necessary in which the events unfold. It is this structure which links the events in time, and which thus corresponds to a possibility space for events. In such a possibility space, on the other hand, the principal freedom of an event is limited. Thus, an event cannot take place in every conceivable form, because its structure is shaped by events that have already taken place in the past. This makes the repetition of events possible in a structure shaped by past events.[123] The structure of time thus receives an imprint by events of the past. Transferred to the human being this means: Every human life takes place in the structure of its own

117 Poincaré, H.: Wissenschaft und Methode. Leipzig Berlin (1914), p. 73.
118 Prigogine, I., Strengers, I.: Dialogue with Nature – New Ways of Scientific Thinking. 6th ed. Munich (1990), p. 166. Kolk, W. R., Lerman, R. A.: Nonlinear System Dynamics. New York (1992), p. 145.
119 Holzkämpfer, H., op. cit., p. 88.
120 Thompson, J. D., Stewart, H. B.: Nonlinear Dynamics and Chaos-Geometrical Methods for Engineers and Scientists. Chichester (1986), p. 262.
121 Thom, R.: What is Catastrophe Theory about? In: Haken, H.: Synergetics: A Workshop. Berlin Heidelberg New York (1977), pp. 5-11.
122 Luhmann, N.: Systeme. Social systems – outline of a general theory. Frankfurt a. M. (1991), p. 390.
123 Luhmann, N.: Systems. Social systems – outline of a general theory. Frankfurt a. M. (1991), p. 390.

time. The structure of this own time is again shaped by past events. On the other hand, the structure of this time is to be understood as a space of possibility for future events and it allows only a selection of certain events, it is quasi a filter for even possible events in the future. Each event appears as a singular event, which is relativized by repetition. Singular events, on the other hand, do not repeat themselves beyond a certain limit. It was not until the 20th century that the realization that instabilities and singularities play a very fundamental role in the understanding of the world gradually prevailed.

The role of singularities in the processes of nature could not be precisely grasped in the natural sciences so far, because, as Prigogine stated, there was a lack of scientific knowledge and mathematical procedures.[124] He called singularities the discontinuous changes of state at the critical points of a system, for which an extreme sensitivity is characteristic: A critical point with an extreme sensitivity appears for example at a cone standing on its tip. In this condition, even the smallest symmetry error can cause the cone to fall over.

From a synergetic approach, two types of phase transitions can be physically distinguished in connection with the formation of structures and orders, namely continuous and discontinuous transitions. In both cases, the order structure changes at a singular point from one state of matter to another. In the case of discontinuous transitions, an order parameter changes slowly at first, depending on external influencing variables, which are also referred to as control parameters. At a certain point, a sudden behavior occurs. This abrupt change in behavior is associated with an equally abrupt change in the symmetry of the system. Such abrupt transitions in connection with symmetry changes occur, for example, in the transition from water to ice at 0° degrees. In this context, the control parameter would be the temperature and the order parameter would be the density difference.

It must be surprising that completely different systems in the vicinity of such critical points show similar and quite comparable behavior. In this context, therefore, one spoke of a "universality hypothesis".

Behind the at first very unwieldy term of singularity, there seems to appear a basic pattern of behavior, a basic constitution of being of the natural processes, which raises all the more questions the closer it is looked at. With the concept of singularity, even the hitherto irreconcilable opposition between substance and movement could possibly be resolved, as Luhmann suspects.[125]

Thus, discontinuity, as well as continuity, can be seen as a possibly crucial building block of the world.

In biology and medicine, spontaneously arising mutations on DNA could be taken as examples of so-called productive singularities, which give the carrier an advantage or a disadvantage. Thus, a single degenerated cell can mean death for the affected person.

Diseases can be understood as manifestations or consequences of basic instabilities and singularities. Diseases are also unavoidable consequences of the complexity of living systems.

124 Prigogine, I., Stengers, I.: Dialog mit der Natur – Neue Wege naturwissenschaftlichen Denkens. 6th ed. Munich (1990), p. 80.

125 Luhmann, N.: Zweckbegriff und Systemrationalität: über die Funktion von Zwecken in sozialen Systemen. 5th ed., Frankfurt a. M. (1991), p. 8.

Possibly even the origin of man himself, i.e., the hominization, can be understood as a consequence of such a singular event.

Carl Friedrich von Weizsäcker, on the other hand, consciously avoided the recourse to the term singularity: He was rather of the opinion that this term in the strictly mathematical sense would represent an infinite function value, which occurs, for example, in connection with the initial singularity or in connection with black holes.[126]

In physical systems, the appearance of singularities in the mathematic formalism can provide indirect indications of the validity or the weakness, i.e. inconsistencies of physical theories. This is one of the reasons why the so-called Big Bang theory is by no means undisputed in the physical or cosmological community.

For the field of history of science, Thomas Kuhn dealt with its crises and anomalies in an essay about the structure of scientific revolutions. He was able to show by means of many examples how scientific paradigms had got into a crisis by the emergence of anomalies and how out of such crises in the wake of scientific revolutions the transition into new paradigms can take place.[127]

From what has been said it becomes clear that singularities are not only analytically to be examined quantities or terms. The consideration of singularity always includes an integrative point of view. Otherwise, their partly revolutionary effects on the whole system could not be perceived. On the other hand, if a system is only viewed holistically, it is impossible to recognize and analyze details and effects on local levels and on relatively small scales. This leads to the conclusion that only the interaction of analytical and holistic views can be promising.

2.10 Chaos and Hidden Order

Concepts of order or disorder are always related to a rule.

Quite a number of attempts have been made to establish universal notions of order that could be applicable to all systems and processes and especially to evolution as a whole. Mostly, the proposals in this direction amount to linking the notion of order with the notion of complexity. Accordingly, the greater the degree of complexity of a structure, the more highly ordered it would be. From an information-theoretic point of view, the more text is needed to describe a system, the more complex it is. Thus, the concept of complexity is also linked to the concept of information. Using the example of so-called "genetic information", the statement could be made that DNA carries the information about the blueprint of an individual and is thus representative of its complexity and thus also of the level of order of an individual. However, it is not the amount of information that determines the complexity of an individual.

If we refer to Shannon's information measure in this context, it says that the measure of information essentially corresponds to the length of a text: A text twice as long would therefore also have to have twice the information contents. Thus, a page of a mathematical textbook would have the same informa-

126 Holzkämpfer, H., op. cit., p. 75.
127 Kuhn, T. S.: Die Struktur wissenschaftlicher Revolutionen. 12th ed. Frankfurt a. M. (1993), pp. 49 u. S. 65ff.

tion measure as a page with more or less randomly thrown-together letters. Analogous statements are also valid for the attempt to establish relations between the complexity of an organism with the number of genes or the number of nucleotides. Such a relationship does not exist. It is rather the case that at present a universal measure of order or complexity is not yet available.[128] With the number π≈ 3.141592653589793238, it can be shown that the digits 0-9 are randomly distributed in this number. Thus, the sequence of digits cannot be distinguished from a sequence of coincidences. Nevertheless, Archimedes could already show that every single digit behind the decimal point can be calculated. This is a very obvious regularity of the calculation scheme because the digits are generated according to a rule and inserted according to a stringent order. Nevertheless, for a person who has no knowledge in connection with the number π, there is no possibility to find out how the sequence of digits was created. Analogous considerations apply to the irrational number √2.

These examples show that from the phenomenology of a process, it is usually not obviously recognizable, whether this satisfies a regularity or not.[129]

Already Maxwell had recognized, as shown above, a deep relationship between singularity and complexity: According to his insight, a higher complexity was connected with the increase of singularities. At this point, the deterministic axiom loses its validity that equal causes also result in equal effects. Maxwell wrote: " ... it is to be expected that in phenomena of higher complexity, there will be a far greater number of singularities, near which the axiom about like causes producing like effects ceases to be true".[130]

With this, Maxwell defined the principal limits of causal knowledge. Analogous statements apply to the term chaos discussed above, which is associated in everyday language with an unmanageable, unregulated state, which apparently is not based on any regularities.

Chaos is formulated exactly because the scientist assumes regularities behind every state. Because according to the classical view of natural science, all natural processes and all observable states are determined by natural laws, which do not allow any gap. Nothing happens without a reason. Everything that happens is determined, i.e., causally caused within the framework of the valid laws of nature. This deterministic paradigm, valid for centuries, definitely did not allow a conception of chaos. What was called chaotic had to be based on an incomplete state of knowledge or on insufficient prediction and calculation capacity. A number of natural scientists opposed this view with the concept of objective randomness, among them above all Werner Heisenberg, who had come to the realization that processes in the quantum field can take place without a cause, i.e., objectively randomly. On the other hand, the definition of a state as chaotic does not mean that such a highly disordered state cannot come about in a lawful way. For example, the mixing of balls in a lottery

128 An der Heiden, U.: Chaos und Ordnung, Zufall und Notwendigkeit. In: Küppers, G.: Chaos und Ordnung. Forms of self-organization in nature and society. Philipp Reclam Jr. Ltd. Stuttgart (1996), p. 103.

129 An der Heiden, U.: Chaos und Ordnung, Zufall und Notwendigkeit. In: Küppers, G.: Chaos and Order. Forms of self-organization in nature and society. Philipp Reclam Jr. Ltd. Stuttgart (1996), p. 105-106.

130 Maxwell, J. C.: Does the Progress of Physical Science tend to give any Advantage to the Opinion of Necessity (or Determination) over that of the Contingency of Events and the Freedom of the Will? In: Campbell, L./Garnett, W.: The Life of Clerk Maxwell. London. (1882), p .443.

drum to a completely disordered state happens completely within the framework of physical laws.

One reason for the occurrence of chaos is that nonlinear self-organizing systems can drift into the vicinity of instability again and again. The rejection, i.e., repeated returns to the vicinity of an unstable state, does not occur by external influence but is ensured by the systems themselves.[131] The mentioned principles of instability and rejection thus refer to a very subtle order, i.e., to regularity and regularity in connection with deterministic chaos. Thus, subtle order structures are hidden in this state which are fundamental for the peculiar mathematical elegance of these states. The concept of chaos also has negative connotations because in phases of increasing instability unambiguous predictions concerning the system behavior are impossible due to the exponential divergence of trajectories. This can be deduced from the property of "sensitivity" to the initial conditions. But chaos is not only related to this sensitivity to initial conditions, resonance phenomena can also lead to chaos. Chaos also leads to changes in the structure of time because it leads to the introduction of the arrow of time into the basic dynamical description of systems. It has already been pointed out that the second law of thermodynamics by no means prohibits the spontaneous occurrence of order. On the contrary, this insight represents one of the key points of Prigogine's work, for which he received the Nobel Prize in Chemistry in 1977 because of his pioneering findings in the field of non-equilibrium thermodynamics. Chaos generates order and complexity from superposition processes of the simple, as Nicolis and Prigogine once put it:

"The ideas that prevailed until about 1960 led to a rather discouraging picture of the occurrence of turbulence. ... Turbulence was imagined as an effect of the dynamics of an infinite number of coupled modes, each belonging to a certain frequency".[132]

The already described phenomenon of turbulence as a known chaotic structure can arise when all elements of a movement interact or are interrelated. The disintegration of the ordered into the chaotic, which is understood as unholy and unfortunate, surprisingly reveals the existence of deep inner coherences, namely of coherences with regard to the systems as a whole. Underlying the chaos is the holistic.

According to its scientific orientation, so-called chaos research is a science of emergence, a science of processes, a science that deals with how order arises from disorder and vice versa. This was connected with a departure from a scientific program that had been fundamental for centuries and which, starting from Newton, Galilei, Descartes, and others, was oriented towards the investigation of fundamental principles of order behind natural processes. With the development of a science focused on the study of chaotic processes, the classical viewpoint was reversed, as a search began for structures and patterns of disorder behind the facade of seemingly orderly processes and behind the strict regularity of mechanical laws. Originally, order, the irregular, and the chaotic were considered to be categorically exclusive terms. However, we have learned that the reality surrounding us is built up by complex systems whose dynamics cannot be sufficiently described by the laws of classical mechanics. On all levels of our reality, we are confronted with chaos, whereas in

131 An der Heiden, U.: Chaos and Order, Chance and Necessity, op. cit., p. 114.
132 Nicolis, G., Prigogine, I.: Die Erforschung des Komplexen. München, 1987.

chaos there are always islands of regularity, subtle order and high complexity.

With chaos research, a science of becoming, a science of the establishment of complex systems with a multitude of variables has emerged. The mathematical foundations of this science are based on the principles of nonlinearity. Chaos research shows again and again that the complex is hidden behind the apparently simple. Chaotic systems are predictably unpredictable. In the chaotic, a depth opens up which must seem endless and unexplainable.

2.11 Islands of the Irregular in the Structure of Time

Time is a fundamental dimension of our existence. Strictly speaking, modern natural science only begins with the inclusion of time in the theoretical scheme of Newtonian and Galilean physics. The prototype of a universal law of nature is Newton's law, according to which acceleration is proportional to force. This law has two basic characteristics: First, it is a deterministic law, which states that accurate knowledge of the initial state allows accurate predictions about future behavior. Second, it is a time-reversible law. Thus, this law formed one of the crucial foundations of classical mechanics. The paradox of the concept of time has already been pointed out above. Because time shows no direction in the fundamental time-symmetrical laws of physics and this on the level of classical dynamics as well as on the level of relativity theory and quantum mechanics. Thus, the difference between past and future did not play any role in the theories of natural science for a long time; rather, still, in the 19th century, the laws of dynamics were considered as the ideal of an objective knowledge. And yet, in all phenomena of our living world – whether on the physical or biological and especially on the sociological-cultural level – future and past have fundamentally different meanings. The science of the investigation of chaotic conditions, which emerged in the 20th century, brought about the resolution of the time paradox. For chaos leads to the introduction of the arrow of time into the fundamental dynamical description of systems. Moreover, this was connected with the introduction of the concept of probability into classical dynamics, which until then had been a prototype of a deterministic scientific paradigm. In this context, we had also established that chaotic systems are believably unpredictable. Chaotic systems emerge from the non-linearity of their development laws and from the interaction of a multitude of variables, so precise statements about their temporal development are not possible. Order and deterministic chaos have the same origin: they are dissipative dynamical quantities described by nonlinear differential equations. This is the case for most systems of the everyday world surrounding us.

The irregularity of the processes in nature is therefore the regularity. Not the near-reversible, but the irregular creates the new and the unique. In the garb of the irregular, a creative moment shines. Irregular chaotic systems cannot be described by a single trajectory, but only by bundles of trajectories.

In the areas of the bifurcation points of nonlinear systems the irregular, the incalculable, and additionally a fundamental momentum in the structure of time unfolds, namely the momentum of the potential in an indissolubly condensed form: For the "places" where the bifurcation events take place are indeed places of highest uncertainty and instability and yet these places reflect in an indissolubly condensed form the specific history of the development of the system as a whole. Thus, it is the states of highest uncertainty and indeterminacy with regard to possible changes of direction of a system from which the potential and creativity of these systems can be tapped. Bifurcation events can thus be understood as nodes in the time structure of self-organizational processes.

Thus, irregularity and potentiality are to be understood as complementary quantities in the structure of time:

At the beginning of its lifetime, a newborn child faces an incalculable variety of potentially highly different life courses. After 50/60/70 or 80 years it has gone its unique way of life through the phase space of its manifold possibilities. Every life, even the life of a housefly, is to be called unique in the wake of its unique bifurcation events and to be evaluated and respected accordingly. For this reason, it is to be agreed with Henri Bergson in his insight that time is a "medium of renewal".[133] Those renewals, as they were called by Bergson, take their new beginning again and again in the unique bifurcation events in connection with the mentioned Hopf instability. Time is therefore the medium that lets the new emerge from the knot points of the irregular. Irregularities are thus to be understood as visual forms of a progressively renewing time.

2.12 The Concept of Information as Relation and Primordial Substance in the Center of Self-Organizing Processes

If one thinks of the world as a whole, i.e., as an externally closed system, then the second law of thermodynamics has fundamental validity for such a system. It has been pointed out in various contexts that, by analogy with the second law, the entropy of the system must increase. In a slightly different approach, it can be said that with the increase of entropy in a world system considered as closed, the number of possible microstates must increase. With it, however, also the information grows, which would be necessary to elucidate the microstate of a given microstate.[134] The concept of entropy was taken over by the information theorist Shannon from physics, naming Boltzmann's H-theorem, and he also kept the letter H for entropy. There is a close and almost identical connection between Shannon's concept of information and entropy because here entropy can be understood as a measure for that information which is needed to clarify the microstate of a given macrostate. According to C.F. von Weizsäcker, information is furthermore equal to the number of primal alternatives entering into it: "The information of an event can also be defined as the number of completely undecided simple alternatives which are decided by the occurrence of an event".[135] According to the postulate of last objects, according to von Weizsäcker, all objects and states of the world are built up from primal alternatives, so-called Ur`s, where a primal means a decision on the most elementary basis with an in-

133 Coveny, R., Highfield, R.: Anti-Chaos. Rowohlt Taschenbuch-Verlag, Reinbek bei Hamburg (1994), p. 278.
134 Schweitzer, F.: Selbstorganisation und Information. In: Complexity and Self-Organization - "Chaos" in Natural and Cultural Sciences. (Eds.) Krapp, H., Wägenbauer, Th.), Wilhelm Fink Verlag Munich (1997), p. 99-129.
135 Weizsäcker von, C. F.: Die Einheit der Natur, München: dtv (1974), p. 269.

formation gain of 1 bit. All objects consist of the last objects with n=2. Therefore, the information about a situation or an object is equal to the number of primal alternatives entering it. In the continuation of the thought, also mass is to be equated with information: Because the rest mass of a particle corresponds to the "number of the primordial alternatives necessary for the construction of the resting particle, thus exactly the information invested in the particle". This definition of information corresponds to the concept of a "structural information". Every state that exists can further be understood as a decision tree of questions that are decided or answered.

In this way, evolution as a whole can be understood as a universal process in which decisions are constantly made between primordial alternatives and thus new information is generated.

Because the entropy increases according to the second law, the number of alternatives, which have to be decided, must also increase in the course of the evolutionary processes. Thus, in the course of evolution, the number of questions which have to be decided in order to clarify a given microstate must also increase. In this way, it becomes understandable that information must always be potential information or virtual information and this according to the principle: "Positive entropy is potential (or virtual) information".[136]

Potential information thus spans a space that must constantly grow with the increasing number of decidable alternatives. Therefore, this space represents what is possible, while what is factually decided marks, in each case, a point in this space. The expansion of space, seen in this way, is paralleled by the expansion of potential or virtual information.

On the other hand, the structural information is connected with the existing physical structure of an object at a certain time and place. Structural information thus captures the information content as it is encoded on a material basis, and it represents the structural determinacy of a state.

According to Ebeling and Feistel, the concept of structural information is closely related to the concept of "bound information".[137] One possibility to represent structural information is strings or symbolic sequences, which can generally be called book staves.[138] With a string analysis, however, only the syntactic aspect of information is captured, i.e., exclusively structural links within the strings, and this is independent of their meaning.

Concepts of "semantic information" are essentially based on decomposing statements into logical elementary sentences, each of which can be judged as "true" or "false".[139] In contrast, the concept of "pragmatic information" operates with the notions of "firstness", "novelty", or "confirmation". Pragmatic information is also un-

136 Weizsäcker von, C. F.: Die Einheit der Natur, op. cit., p. 167 or as von Weizsäcker states elsewhere: „Evolution is growth of potential information". (Weizsäcker von, C. F., op. cit., p. 174.

137 Ebeling, W., Feistel, R.: Chaos und Kosmos. Principles of evolution. Heidelberg: Spektrum Akademischer Verlag (1994), p. 55/219 ff.

138 Schweitzer, F.: Strukturelle, funktionale und pragmatische Information zur Kontextabhängigkeit und Evolution der Information. In: Fenzl, N., Hofkirchner, W., Stockinger, G. (eds.) Information and Self-Organization. Approaching a unified theory of information, Studien-Verlag Innsbruck-Wien (1998), p. 341-364.

139 Carnap, R., Bar-Hillei, Y.: On the Outline of a Theory of Semantic Information (1952). Bar-Hillei, Y.: Semantic Information and its Measures. In: Bar-Hillei, Y.: Language and Information, Reading, Mass. (1964), p. 221-274.

derstood as a measure of the effect of the information on the receiver. It is minimal or zero if the information is already fully known, i.e., if it is redundant (first time zero, confirmation 100 percent). Consequently, Shannon's information entropy would be maximum if the first time is 100 percent, while it is minimum in the other limit case.

Fuchs-Kittowski attempts a subdivision and graduation of physical systems in connection with the concept of information in the following way:

1. Disorganized systems: systems without information. Concerning physical and chemical systems.
2. Functional systems: organized systems. Existence of information. Concerning macromolecules. For these functional systems, interpretations of the syntactic structure, for example of DNA, by proteins are typical.
3. Action systems: This type of system is self-organizing, generating information and values.

According to this approach, the nervous system activates programs and reaction modes, which evaluate the incoming signals from the environment and assigns a meaning to them. The evaluated information is subsequently transformed into meaningful behavior.[140]

Based on this, even an evolutionary-specific conception of information in the context of the evolutionary direction toward ever higher complexity could be derived in the following way:

On the basis of the theory of self-organization, it could be deduced that on all stages and levels of the processes of evolution, different forms of causality coexist: One cause can result in a multitude of often very different effects at this evolutionary level. Emergent properties in connection with these processes are not completely reducible to the stages and levels passed through before. However, emergent properties are in feedback with the systems, organizations, or levels from which they emerged.

On the level of physical and chemical systems, on the other hand, one could not yet speak of information, because these systems are not self-organizing, but only self-reconstructing systems. In his opinion, in physical systems information is only present as a potency, because it is not yet realized. However, one can only speak of information in the real sense when syntax (content), semantics (structure, form) and pragmatics (function, effect) are present.

According to the author, information proves itself only on the level of living systems as the result of the following conditional relationship of form, content and effect:

1. Information is not reducible to its syntax.
2. Information is not a substance, but a relation, a triad of form (syntax), content (semantics), and effect (pragmatics).
3. Information arises internally in a process of mapping (mapping of external effects

140 Fuchs-Kittowski, Ch., Hofkirchner, W.: A Unified Concept of Information for a Unified Information Science. In: Floyd, Ch., Fuchs, Ch., Hofkirchner, W. (Eds.): Steps to the Information Society. Festschrift on the 65th birthday of Klaus Fuchs-Kittowski. Frankfurt et al, Peter Lang ISBN 3-63f- 37642-1 (2002), pp. 241-281.

on internal syntax structures), of interpretation (meaning, formation of semantics), and of evaluation (through behavior pragmatics can manifest itself).

Semantics of information are not stored syntactically completely. This means that the information in the DNA is stored only syntactically; a significant part of the information comes into being only through interpretation (semantics) and evaluation (pragmatics).[141]

The term information can also be understood as an exclusively relational term because information serves the transmission of meaning, it is, therefore, communication, otherwise, it is not information. Information that nobody shares would not be information for this reason.[142]

Early approaches to a fundamental theory of information were made by, among others, E.C. Cherry.[143] According to Leon Brillouin, one of the main authors of the Information Theory, the notion of "negentropy" has an important place in information theory.[144] As described, life has the ability to transform disorder into order, i.e., entropy into "negentropy". This concept of negentropy was introduced by E. Schrödinger as a form of order of physical systems. From the point of view of information theory, the term negentropy is derived from the surprising part of a piece of information: After all, the real information of a source is the unpredictable part of the information. This part of the information can be equated with entropy. Once a string of information is established, it thus represents an established order and can now be understood as a form of negentropy, which, however, is always threatened by entropy, i.e., disorder.[145] The comparison between Shannon's information with Boltzmann's definition of entropy provides in a remarkable way a connection between a physical quantity and an informational quantity: For the larger the quantity of information to describe a system state, the smaller its entropy. On this basis, the amount of information can be understood as the probability of occurrence of a message. However, the question of the measure of information is raised here only from the point of view of the statistical measure of information transport. Thus, in Shannon's information, the understanding of the information, and its semantic references do not play a role, but exclusively its unambiguous coding does. By the way, the Shannon quantitative measure of information does not play an essential role in quantum mechanics anymore. On this level, the Shannon logarithm function cannot be transferred to qubits without serious problems because the properties and the information of a quantum system are not precisely determined before a measurement has taken place. On the contrary, on this level, the possible results are not fixed at all before a measurement. Zeilinger and Brukner pointed out this problem and established a new

141 Fuchs-Kittowski K., Heinrich, L., Rolf, A.: Information arises in organizations: in creative enterprises. Scientific-theoretical and methodological consequences for business informatics. In: Becker, J., König, W., Schütte, R., Wendt, O., Zelewski, St. (Eds.): Wirtschaftsinformatik und Wissenschaftstheorie: Bestandsaufnahme und Perspektiven. Betriebswirtschaftlicher Verlag Wiesbaden (1999), p. 330-361), Fuchs-Kittowski, K.: Information, self-organization and evolution - information emergence - a new category for the theory of biology. Paper of a lecture at the 7th International Congress of the International Society for Semiotics (IASS/AIS) "Sign Processes in Complex Systems" on 04/10/1999, Dresden.

142 Capuro, R.: Zur Genealogie der Information, Abstract of the lecture at the 125th WE-Heraeus-Seminar "Der Informationsbegriff aus interdisziplinärer Sicht", Cottbus, 1-4 March 1994.

143 Cherry, C.: A History of Information Theory. Proc. IEE 98, Part III (1946), S. 383-393.

144 Brillouin, L.: Maxwell's Demon Can Not Operate. J. Appl. Physics 22 (1951), pp. 334-343. Brillouin, L.: Science and Information Theory. Acad. Press New York (1953), p. 320 pp.

145 Zemanek, H.: Information und Ingenieurwissenschaft. In: Folberth, O. G., Hackl, C. (Eds.): The Concept of Information in Technology and Science. R. Oldenbourg Verlag Munich Vienna (1986), p. 23.

measurement rule by defining a new information measure, which they called "total" information.[146] This measure is not determined logarithmically and assigns to each elementary system the information content of 1 bit: One elementary system thus carries one bit of information. Two elementary systems thus have the information content of 2 bits, and so on.

Following Bohr, physics does not describe the world itself, i.e., how it is, rather it describes what we can say about it. Moreover, we cannot comprehend the objective world of objects and forces without considering the role of the mysterious mediator function of information. We do not see or measure an atom and have never seen a chair, we only receive sensory impressions via our sense organs or measurement data from our observation instruments. According to Bohr, our brain develops a kind of idea of a chair, which again would correspond to "form" in Aristotelian thinking. Physicists perform measurements on an atom and encode the measurement results in a mathematical formalism. The basis of quantum mechanics is thus not matter, but information. According to Wheeler, information is an answer to a question. According to Zeilinger, information can be equated with the concept of a proposition and the simplest propositions are yes-no-questions whose answer corresponds to one bit of information. According to von Weizäcker, the original matter of the world is the information, or better spoken, is the alternative which is decided to the information.

According to this representation, information is neither matter nor spirit, but as coding material and as meaning ideal/spiritual. Only a combination of both makes information according to this. Derived from this, the following can be concluded:

In the concept of information, the unity of matter and spirit, of being and meaning takes place.

According to this approach, information is to be understood as "dynamis" in its intrinsic dynamic between potentiality and facticity. With this dynamic, it organizes the forces of nature into form.

Thus, with and in the concept of information, a fundamental moving momentum of evolution comes to fruition, namely spirit.

146 Zeilinger, A.: Ein Grundlagenprinzip für die Quantenmechanik. Foundation of Physics. Vol. 2, No. 4 (1999), p. 631.