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Chaos

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The term “chaos” has scientific relevance particularly in antiquity and in modern chaos theory. Whereas in ancient mythology and philosophy it was supposed to answer the question of the origin of the well-ordered cosmos within the framework of cosmogonies and cosmologies, the meaning of “chaos” changed significantly in modernity. In scientific and mathematical theories in particular, chaos is no longer understood as a complete disorder, but as the unpredictability of processes. This unpredictability does not mean, however, that chaotic events do not take place within the framework of the basic categories of causality and determination, but that the slightest change in the initial data leads to unpredictable changes in the further course of the process – which is why one can speak of deterministic chaos.

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“Chaos” is one of those scientifically significant terms that have found their way into everyday language. There, “chaos” is usually understood in a general sense as disorder or confusion. As is often the case, there is a loose semantic connection to the scientific use of the term, but the differences between the everyday and the technical meaning are clearly discernible. The most important scientific epochs for chaos are antiquity and modernity. Accordingly, the focus in the following is on these epochs in order to present the content of the term “chaos” against the background of everyday understanding. While in ancient mythology and philosophy chaos is understood in contrast to the cosmic order, the modern understanding of chaos, in the sense of chaos theory, is situated explicitly within the framework of the “natural order”, i.e. causal and deterministic explanatory approaches.

1. Antiquity: out of chaos arises cosmos

In the cosmogony of Greek mythology, the term “chaos” plays a decisive role, especially for Hesiod (circa 700 BC). There it can be understood as an antagonist of the term “cosmos”, which means an ordered and beautiful world as a whole. In Hesiod’s *Theogony* chaos marks the beginning of the creation of the world; it is followed by Gaia (earth) and Eros (desiring love) and subsequently by the other gods and the entire cosmos (Hesiod: Theogony, verses 116–153). Here chaos is often interpreted as a “yawning abyss”, as that which was there before heaven and earth and everything upon it, in it and in between. In etymological terms, chaos is associated with the verb *chaskein* (yawning, gaping) and the adjective *chaunos* (gaping apart; spongy, porous, loose) (on the difficult semantics of “chaos” see Börtzler 1930: 254 et passim; Frisk 1970: 1073). “Chaos” bears similarities, for example, to the “Ginnungagap” of Nordic myth and the “Tohuwabohu” of Jewish mythology, each of which attempts to capture the originally indeterminable and ineffable source of the cosmos in a verbal and pictorial way. The “Ginnungagap” appears in the third verse of the first song of the *Edda*, the Völuspá: “It was prehistoric times when Ymir lived; there was neither sand nor sea nor cool waves nor earth nor sky above, only the primordial chasm [gap var ginnunga] existed, but nowhere grass” (Simek 2008: 67f.). The Hebrew “Tohuwabohu” also occurs at the very beginning of Bible, in the second sentence of the first book of Moses: “In the beginning God created the heaven and the earth. And the earth was without form and void [tohu wa-bohu]” (Gen 1.1–2, quoted from The Holy Bible).

Martin Buber (1954: 9) translated this as "vagary and confusion" ("Irrsal und Wirrsal"). An emotional tone to all these notions, "an idea of terror and fright" (Jammer 1954: 7), is probably not coincidental.

Following mythology (for the role of chaos in other myths see Paslack 1996a), a discussion develops in ancient philosophy that no longer directly resorts to the term "chaos" but takes up the problem of the primordial cause of the cosmos and addresses it in terms of the philosophy of nature. The first station in this process, which is often (albeit simplistically) described as the transition from myth to logos, is pre-Socratic thought, in which divergent thinkers and theories compete to answer the question of the primordial cause and in doing so introduce new, philosophically significant and powerful concepts which, although not phonetically related, do show a semantic relationship to "chaos". An important example of this is the term *archê*, which is highly variable in meaning. In most attempts at a translation the triad "principle", "beginning", "reign" is mentioned. With the term *archê* the pre-Socratics pose the question of what principle underlies everything that exists; formulated differently, it is the question of what is the beginning of everything and therefore "rules" over everything else. Their answers to this question differ.

The so-called "substance thinkers" define *archê* as one or more of the four elements fire, water, earth and air that were later canonized by Empedocles (circa 495–circa 435 BC). Anaximander (circa 610–circa 547 BC) achieved a higher level of abstraction by naming "the indeterminate" (*apeiron*) as a principle. The atomists, in their very modern-looking theory, assume that there is only empty space and indivisible (atomic) parts of which everything that exists is composed. (On the pre-Socratics see Rapp 2007 and on the *apeiron* in particular see Solmsen 1949).

In Plato's (328/327–348/347 BC) *Timaeus*, the main work of Platonic cosmology, "chaos" finds its equivalent in the Greek expression *chôra*, which is interpreted, for instance, as "shapeless space (*chôra*) in which material traces (*ichnê*) of the elements are in disordered motion (Tim. 53a–b)" (Mesch 2017: 220). That the Platonic *chôra*, however, is not a variation of the atomistic interpretation of the origin of the world, is made clear by Plato through the words of Timaeus: he describes his inquiry as the attempt "to illuminate in words a kind that is difficult and vague" (Timaeus 49a/Plato 1997: 1251); the most appropriate definition of the chôra is therefore "a *receptacle* of all becoming – its wetnurse, as it were" (ibid.). (For the connection between Hesiod and Plato see especially Pender 2010 and Sedley 2010.) Only through the demiurge, the world-maker, whose creative act is orientated to the eternal being of the (platonic) forms, does the cosmos, which is always in the process of becoming, emerge. Here *chôra* represents a third, situated between the eternal as model and the developing as copy, and which in other interpretations features as "disordered material", forming the material but indeterminate basis of world creation. (In this respect, a disputed line of connection to the Aristotelian concept of *prima materia* is established, see Strobach 2011: 294.)

In the context of his investigation of the concept of space in physics, Aristotle (384–322 BC) concretizes and problematizes the interpretation of Hesiod's chaos as "void" or "place without anything in it" (Physics IV 1 208b27–209a2; cf. Jammer 1954: 5–24). Aristotle understands chaos as something that exists independently of bodies and without which no perceptible bodies can exist. "Chaos" is thus brought within the framework of an explicitly physical investigation. It has now outgrown the mythological understanding to a great extent and, in Aristotle's work, serves above all to challenge the atomists who assert the existence of empty space. For Aristotle the assumption of empty space contradicts certain principles of his physical theory (e.g. the assumption of "natural movements" of the "physical elements", namely fire, water, earth and air, upwards or downwards) as well as his basic teleological view of nature. But he also develops – now with a strongly metaphysical focus – concepts that can be understood as answers to the pre-Socratic question of the origin of everything: noteworthy here is the concept of *prima materia* as the indeterminate, formless, first matter as condition of what exists (Metaphysics VII 3, 1029a20 ff; on the controversy over interpreting the term see Detel 2009: 276); and the concept of the "unmoved mover", a basic component of Aristotelian theology which he develops on the basis of physical reasoning – "that

which is moved must be moved by something" (Metaphysics XII 8, 1073a26) – and which provides him with an answer to the question of the primordial cause of everything (Metaphysics XII, 1069a15–1076a5).

Chaos also had its effect on the Hellenistic philosophers. Thus the ancient philosophical historian Diogenes Laertius (in the 3rd Century) reports that Epicurus (circa 341–271/270 BC) turned to philosophy because his teacher could not explain to him Hesiod's notion of chaos (Diogenes Laertius X, 2; see also Karafyllis/ Lobenhofer 2017: 5). Epicurus further developed the atomic theory of his pre-Socratic forebears Leucippus and Democritus in order to answer the question of principles. In the Stoa, fire is regarded as the basic element of everything that exists, but its *archê* (origin) is said to lie in *hylê* (matter) and *theos* (God) (Nickel 2008: 289, 262; Arnim: SVF I 98). For the Stoics, the concept of God is strongly reason-based and is also identified with the influential term *logos spermatikos* ("reason-bearing germinal force") (Nickel 2008: 285, 258; Arnim: SVF I 102) which dwells in dampness and from there "evolves into" everything (*apogenesthai*). It is possible that the founder of the Stoa, Zeno of Citium (333/332–262/261 BC) is referring to Hesiod when he associates chaos with the verb *cheesthai* (pouring out; being poured out) (Arnim: SVF I 103). (For more details on stoic natural philosophy and cosmology, see White 2003.)

An unequivocal definition of the ancient concept of chaos is not possible: Frisk's (1979: 1073) verdict that one cannot say with certainty which ideas Hesiod and his predecessors associated with chaos within the mythological cosmogony can, with good reason, be extended to Hesiod's philosophical successors in the Hellenistic schools. One can, however, state that the attempts at interpretation range between mythologically-inspired depictions of the threatening primordial ground as "chasm" or "abyss" and cosmologically-oriented principles of space and/or material that develop from these ideas and which are important from the standpoint of a philosophy of nature. (For the antique concept of chaos in general see Karafyllis/ Lobenhofer 2017; Paslack 1996b.)

2. The Middle Ages: creation ex nihilo

In antiquity, attempts were made to answer the origin of the cosmos with the question of principles: what was there before the cosmos was there? The answers vary; the term "chaos", however, serves in mythology and philosophy as the starting point for the verbal attempt to deal with this speculative question. What the ancient thinkers have in common is the principle that nothing can develop from nothing (*nihil ex nihilo fit*) (see e.g. Aristotle: Physics I 4, 187a28–29). It was precisely this conviction that led to the various concepts of chaos, and subsequently to the *chôra* or *prima materia*. In the Middle Ages, however, the meaning of the concept of chaos waned because the idea of *nihil ex nihilo fit* was countered by that of creation from nothing (*creatio ex nihilo*). This latter idea was already defended against the ancient cosmologies and cosmogonies by early Christian thinkers such as Tatian (died circa 170 AD) and Theophilus of Antioch (died circa 183 AD) (Tatian: Oratio ad Graecos 31–34; Theophilus: Ad Autolycum II, 10; for his explicit rejection of Hesiod's chaos see ibid.: II, 12).

For the High Middle Ages, its outstanding representatives, namely Albertus Magnus (circa 1200–1280) and his pupil Thomas Aquinas (circa 1225–1274), show very clearly that under the influence of Christianity philosophical answers to the question of origin change fundamentally. Here the cosmos was not created from something, but out of nothing by a personal God. That the ancient understanding of "chaos" loses significance in the Middle Ages is also apparent from the rejection of certain related concepts: thus the "formless matter" which ostensibly preceded the cosmos is explicitly rejected by Thomas Aquinas (Summa theologica I, 66, 1; cf. Kurdzialek 1971: 981). For all the proximity to Aristotle that characterizes the scholastic philosophy of the Middle Ages, the powerful influence of Christianity is also visible in Albertus Magnus' treatment of the idea of the "unmoved mover" from Aristotelian physics: Albertus "sometimes seems to equate God with the unmoved mover, but then makes a clear distinction between this unmoved mover as first cause of a genus of causes and God as a unique first cause who made the world emerge from nothing" (Hoßfeld 1989: 80).

3. Modernity: mysticism, created chaos and dancing stars

In modernity, the idea of *creatio ex nihilo* faces renewed competition from revived ancient ideas. Paracelsus and Jakob Böhme, who are both close to mysticism, deserve special mention here. Paracelsus (1493/1494–1541) turns away from the Christian principle of creation and takes up ancient ideas: "The 'prima materia', which is also sometimes called 'Iliaster' or 'Chaos', is not created, but eternal" (Letter 2000: 127). According to Paracelsus, the world is not created from this primordial stuff but separated from it – and not only by the one God but, in a quasi-preparatory way, by an "under-creator" (ibid.: 128). The Flemish polymath and Paracelsus follower Johan Baptista van Helmont (1579–1644), who turned primarily to medicine and chemistry, is the inventor of the expression "gas", which he links explicitly to "the ancient idea of chaos": "Van Helmont's 'new term of gas' is not unlikely to have been derived from 'chaos'. He himself indicated as much, saying of gas that is was not far removed from the 'chaos of the ancients'" (Pagel 1982: 64; for more details on van Helmont's understanding of gas see ibid.: 60–70).

Jakob Böhme (1575–1624) associates chaos with what he calls "Mysterium Magnum": "The *Mysterium Magnum* is that *Chaos*, out of which Light and Darkness, that is, the foundation of Heaven and Hell is flown from Eternity, and made manifest" (Böhme: Clavis VI, 22/1764: 8). Böhme understands the origin of the world as "divine self-appropriation" (McGinn 2016: 188), at the beginning of which stands the Mysterium Magnum, which reveals two beings: on the one hand the "the unity of God, that is, the Divine Power and Virtue, the outflowing Wisdom", on the other hand "the separable will" (Böhme: Clavis VI, 21/1764: 8), which corresponds to "the desire to create properties and distinctions" (McGinn 2016: 187). Böhme and Paracelsus show that the attempts at a "neutralisation [of the concept of chaos – S. L.] by Albertus Magnus and Thomas Aquinas and its replacement by a theological world order [did not] catch on" (Hülsewiesche 1992: 275).

John Ray (1627–1705) makes a new attempt at the theological containment of the concept of chaos. In his 1693 work *Three Physico-Theological Discourses*, Ray, theologian, classical philologist and "Father of English Botany", deals with what is known as the "cosmological proof of God": The "argument from design" attempts to prove God's existence from the apparent orderliness and complexity that the cosmos reveals – someone must be behind the whole as "designer". The first of the three treatises of the aforementioned work is entitled "Of primitive chaos and creation". There Ray deals with the "pagan thinkers", among them Hesiod, and comes to the following conclusion: "That which I chiefly dislike in this opinion of theirs, is, that they make no mention of the Creation of this *Chaos*, but seem to look upon it as self-existent and improduced [i.e. not produced]" (Ray [1693] 1713: 4). Ray combines the hypothesis of chaos with theological principles, seeing it as God-created and as the starting point of ever more complex processes of creation. Immanuel Kant (1724–1804) also takes up the idea that chaos is always "in order", but he rejects a theological explanation of this: Kant "reduces the existence of God in the sense of the deism of simplified religious teleology to the principle of fundamental lawfulness" (Irrlitz 2015: 80). In the preface to his early pre-critical work of 1755 *Universal Natural History and Theory of the Heavens*, Kant writes that "a God exists precisely because nature cannot behave in any way other than in a regular and orderly manner, even in chaos" (Kant [1755] 2012: 199). From the point of view of the philosophy of nature, the 18th century thus "puts chaos in order". Even if not argumentatively derived from Kant, this reversal of chaos is continued by modern natural science and mathematics. In the period immediately after Kant, however, the use of the concept of chaos initially distanced itself from the philosophy of nature.

With Friedrich Wilhelm Joseph Schelling (1775–1854) the concept of chaos takes an idealistic turn, culminating in a definition of chaos as "a 'metaphysical unity of spiritual potencies', i.e. the self-identical before its separation into different beings" (Dierse/Kuhlen 1971: 982, with quotations from Schelling 1857: 600; for Schelling's important concept of potency see Gloy 2012). With Friedrich Wilhelm Nietzsche (1844–1900), the association of chaos with creativity or creative power comes to the fore. Zarathustra's saying is well known: "I say to you: one must still have chaos in oneself

in order to give birth to a dancing star" (Nietzsche [1883–1885] 2006: 9 = Zarathustra I, Preface 5). During Nietzsche's lifetime, however, the foundation stone was laid for the second major epoch of chaos.

4. Recent Times: deterministic chaos

While the ancient concept of chaos still tends to fit with today's everyday usage – chaos as a state of disorder or, more correctly, non-order – there is a gulf in meaning between the everyday and the scientific ideas of modern chaos theory. As Klaus Mainzer puts it, "the concept of chaos is superficially chic (mostly due to misunderstandings on the part of the public). But the real interdisciplinary research issue is the nonlinear dynamics of complex systems in nature and society, which are difficult to control" (Mainz 1996: 8). To understand what this "nonlinear dynamics of complex systems" has to do with chaos, i.e. the core topic of modern chaos theory, one must begin with the mathematician Henri Poincaré (1854–1912). Attempting to solve a prize question set by the Swedish king in 1888, Poincaré investigated the so-called "three-body problem", the problem of predicting the trajectory of three bodies under the influence of their mutual gravitational attraction. The problem lies in the mathematical recording and description of this process. Though Isaac Newton (1642–1726) had described in mathematical terms the behaviour of two bodies in relation to each other within the framework of Kepler's laws, the behaviour of three (or more) bodies in relation to each other proved to be much more complex. Poincaré was able to show "that under certain circumstances a system of three bodies can exhibit peculiar behaviour: depending on their initial conditions, the bodies' movements vary greatly. Even minimal changes in the initial conditions of the system lead to large variations in their movements" (Jaeger 2015: 359). If a system with a number of degrees of freedom is described by linear equations, this sensitive dependence of processes on initial values cannot be represented mathematically and thus the dynamics of chaotic systems are not possible to predict in detail. A widely employed definition of chaotic systems thus refers to this sensitive dependence on initial values and/or the unpredictability of processes as definitions. However, there is no consensus about definitions in the scientific literature, since even the behaviour of non-chaotic systems can be unpredictable (Werndl 2009: 217). Werndl therefore proposes as a definition the idea of "mixing": "Defining chaos via mixing. Intuitively speaking, the fact that a system is mixing means that any bundle of solutions spreads out in phase space like a drop of ink in a glass of water" (ibid.: 204; on the question of definition see also the first section 'Defining chaos: determinism, non-linearity and sensitive dependence' by Bishop 2017).

After Poincaré's beginnings, it took some time before such reflections were developed into a recognized theory, modern chaos theory: "Probably because of the complexity of the problem and [the] lack of powerful computers, this kind of movement, which is today called deterministic chaos, remained unexplored for a long time" (Haken 2007: 34f.). Just a few decades after Poincaré, the meteorologist Edward N. Lorenz (1917–2008) picked up – albeit by chance – the thread again (Lorenz 1963). Today he is regarded as one of the founding figures of modern chaos theory. It was Lorenz who coined the term "butterfly effect", well known in popular culture, in his lecture "Does the flap of a butterfly's wings in Brazil set off a tornado in Texas?" (Lorenz 1972). The occurrence or absence of the wing beat of a butterfly can – according to Lorenz's vivid illustration – determine the occurrence or absence of a tornado on the other side of the planet. Chaotic systems, such as the weather, are non-linear dynamic systems that cannot be predicted in advance because a change in the initial conditions can lead to any number of changes in their behaviour. Nevertheless, these systems, like linear systems, are subject to the principle of causality and so are not indeterminate but determined – to this extent, the system-theoretical concept of chaos does not correspond to the everyday understanding of chaos. In contrast to linear systems, however, the relationship between cause and effect in non-linear systems is not directly proportional. In particular, feedback between parts of the system can lead to chaotic behaviour (though not every system with feedback is a chaotic system). This can be illustrated by the double pendulum, in which a second pendulum is attached to the end of a pendulum so that its suspension point is moved. The behaviour of the

double pendulum is chaotic, since its two subsystems' movements feed back upon each other. It can be observed that despite similar initial conditions, the various final states of the double pendulum system differ massively – unlike in the normal pendulum, which always oscillates uniformly back and forth (on the pendulum, see Eckhardt 2004: 7–23).

The tracks or pathways into which dynamic systems are drawn over a certain period of time are called "attractors". A fixed-point attractor stands for a state of equilibrium towards which a linear system tends. A chaos attractor is characterized by irregular and non-periodic behaviour that is distinctive of non-linear systems. When a chaos attractor forms a so-called "fractal", one speaks of a "strange attractor". Fractals are geometric objects where the parts of the object resemble the whole object (self-similarity). Named after the discoverer of fractals, the mathematician Benoît Mandelbrot (1924–2010, see e.g. Mandelbrot 1987), the most famous fractal is the "Mandelbrot set" (cf. the second chapter "Classical fractals and self-similarity" in Peitgen et al. 1992a: 81–159). In these strange attractors the regularity that is also present in chaotic processes can be seen. It is the peculiarity of the theory of chaos in modern complexity research that a once wholly indeterminate chaos has been brought back into order via modern mathematics and physics in the sense of fundamental laws.

Summing up, it can be said on the one hand that the term "chaos" marks the beginning of reflection upon numerous fields within the philosophy of nature, for example space and matter, particularly at the beginning of Western philosophy. On the other hand, it must be noted that through contemporary chaos theory the concept of chaos has regained importance in a new form and is now enormously successful in a growing number of disciplines, i.e. chaos theory can be applied in many diverse fields. Chaos occurs whenever a system or certain aspects of a system can be described with mathematical equations that have certain properties. In the context of complexity research, the concept of chaos now plays a role in the most diverse branches of science (Mainzer 2008), for example in neurology, psychology, economics as well as in the social and historical sciences (for the latter, see Herbst 2004). This development has also led to the emergence of new fields of research, such as "emergence" and "self-organization". With these terms the "spontaneous emergence of order" is addressed, "without external instructions or internal programs determining this order" (Küppers 1996b: 122). From a disordered, chaotic state, a new macroscopic order emerges solely by means of the microscopic properties of the elements/components involved, and which owes its existence to a "blind" dynamic. According to this view, order emerges by itself from chaos, without any ordering entity (Mainzer 1992: 270–275).

However, this strong interdisciplinary tendency of the concept of chaos is also the reason for a general point of criticism, namely that complexity and chaos research may be so all-encompassing as to be too unspecific to serve as a scientific theory (Jaeger 2015: 362).

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