Intentionality: Steps Towards Naturalization on the Basis of Complex Dynamical Systems

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Article Outline

Glossary

Cognition A general concept of psychology referring to all processes and structures of the mind. These comprise the processing of stimulus "input" (i.e., perception) and the internal processing of represented information (e.g., memory functions, thinking, problem solving); the latter processes presuppose intentional features of the mind. Cognitive structures are knowledge, categories, memory, attitudes, schemata, etc., again intentional concepts.

Dynamical systems theory A system is any set of things (components, elements) that stand in relation to one another. If a rule or description exists that defines how the system changes over time (such as a differential equation or a mapping algorithm), the system is a dynamical system.

Intentionality A characterizing property of the mind. In contrast to physical systems, mental states have content, i.e., they "are about something" in the sense that they contain a reference to an object, or the representation of an object. In addition to such aboutness, intentionality demands a *functional* reference to the intentional object.

Mind-body problem The philosophical question if and how mind and brain/body are linked. Analogously, the question whether mental processes and physical processes are ontologically different or not.

Naturalization Explaining mental phenomena using concepts and models derived from the natural sciences. Naturalization efforts may be viewed as tools by which (computer) simulation models of mental processes can be developed.

Structural science Several sciences do not fit into the two established groups of scientific disciplines, the natural sciences and the humanities. Such structural sciences, e.g., mathematics, dynamical systems theory, cybernetics, or synergetics, are abstract in the sense that they are not restricted by ontology, and thus may be applied to material and nonmaterial issues.

Definition of the Subject

In the philosophical and psychological tradition, intentionality is viewed as a characterizing property of mental (cognitive) acts. Mental acts have content, i.e., they "are about something." This something is called the intentional object. Intentionality may take the form of a desired state (as in, "I wish it were Friday") or a goal (e.g., my plan for a weekend trip to the mountains). When viewing the constituents of the mind (the cognitive system) in this intentionalist manner, we stand in stark contrast to scientific descriptions of physical systems. These latter systems are material things, which are sufficiently described without reference to objects they would "be about," or to states they

might desire to realize. Therefore, are mental and physical systems qualitatively different with respect to intentionality? If yes, we are confronted with a dualist or dual-aspect view of the mind-body problem. If no, a solution is demanded that can elucidate how mental phenomena may be explained avoiding intentional language or, conversely, how physical systems may show or mimic the features of intentionality. The former project is the conceptualization of intentionality, the latter project may be named the naturalization of intentionality.

Clarifying the problem of intentionality is important in several respects. First, psychology and other cognitive sciences are conceptually divided into two approaches: the phenomenological (first-person) approach and the behavioral and/or biological (third-person) approach. The frequent conflation of first-person and third-person concepts is a serious impediment to theorizing in psychology and cognitive neuroscience. Second, modern societies have a growing demand for machines and software that can function in "intelligent" ways. Therefore, engineers of artificial knowledge-based systems need to know how intentionality may be implemented in physical information-processing machines. Third, the problem of intentionality is one of the foundational problems of philosophy of mind and of consciousness research. Any, even if partial, solution to this problem that may be derived is therefore welcomed.

The phenomenology of intentional acts is well known; phenomenology yields the features of intentionality, which can indicate how closely a formal-mathematical or physical model of intentionality approximates an understanding of the problem. These features are

- *Aboutness*, the intentional system's state must be about something in the system's environment (even about something fictitious)
- *Functionality*, intentional states should be functional or instrumental with respect to what they are about
- *Mental-likeness*, in the sense that apart from being intentional these model systems should have properties that resemble the properties of

mental states. Especially, an interpreter (homunculus) who may account for missing links in the explanation of intentional mental states must not be allowed.

Introduction

If mind and matter are qualitatively different things, what is the nature of their difference? This is an elementary question of philosophy and of scientific disciplines addressing the mind. This question and the potential answers to it, referred to as the mind-body problem, have a long history. What is the relationship between mind and body? If there is no essential difference between the two, or only a superficial difference, one may reach a monistic understanding of the problem. Monism may be idealistic, positing that mind creates its world. The contrary monism would be materialism i.e., the assumption that the mind can be reduced to matter (e.g., Churchland 1986). If, on the other hand, a real difference between mind and body exists, we enter dualistic notions (e.g., Popper and Eccles 1977). Dualism is confronted with intricate questions of how we may conceive of the interaction between mind and body. In the interest of the specific discussion of intentionality in this entry, we will refrain from giving an account of the many philosophical theories of how mind and body may be associated in general.

Apart from presenting a core problem to the philosophy of mind, the mind-body problem is of interest to a wide range of contemporary scientific disciplines, especially psychology, neuroscience, and computer science (artificial intelligence). In recent decades, a novel approach to cognitive science has appeared combining dynamical systems theory with cognitive science. This "dynamical approach to cognition" addresses mind-body topics more or less explicitly. We will sketch this approach here because it provides the background for our ensuing structural treatment of intentionality.

The dynamical approach to cognition is founded on a number of studies and empirical paradigms. In various perceptual and behavioral

tasks, researchers have observed a set of signatures of cognitive and motor systems. These signatures were typically related to temporal patterns observed in the systems, especially asymptotic stability, and in many paradigmatic cases, multistability. Asymptotic stability means that a system's pattern of behavior is stable – in the face of an external disturbance, the system returns asymptotically to this same pattern. Multistability means that several such patterns may coexist in the behavioral space of a single system.

Movement coordination has been at the center of several applications. Haken et al. (1985) provided a model of the coordination of two limbs (e.g., the hands, or the forefingers, of a person) using equations from dynamical systems theory. The rhythmic movement of the limbs generally becomes synchronized after a short time; these synchronous movement patterns are stable with respect to external inputs, i.e., they usually return to synchrony after externally induced disruptions of movement. Furthermore, they have been shown to undergo phase transitions depending on the values of the control parameter (in the Haken-Kelso-Bunz system, a control parameter is the velocity of movements prescribed by a metronome). Characteristic phenomena were observed in the context of phase transitions, such as hysteresis and critical fluctuations. Analogous findings were reported in animal locomotion. Here, especially multistability has attracted the attention of researchers because in certain regions of control parameter space two qualitatively different limb coordination patterns may occur. For instance, a horse may either gallop or trot at a given velocity.

In the seemingly unrelated field of visual perception, very similar signatures of dynamical systems were found in ambiguous stimuli (Haken 1996; Leopold and Logothetis 1999). This research on perceptual organization may be viewed as a continuation of the tradition of Gestalt psychology (Köhler 1920; Tschacher 1997). For example, apparent motion (i.e., perception of motion in the absence of real motion of the stimuli) can be induced by presenting stimuli, e.g., black disks, alternately at different positions of the visual field. Certain spatial configurations of the disks induce perception of qualitatively

different kinds of apparent motion, although identical stimuli are presented. Hence, this and related paradigms create cognitive multistability. Again, the signatures of self-organizing dynamical systems can be found in the phase transitions between the different apparent motion perceptions.

The dynamical hypothesis in cognitive science (van Gelder 1998; Tschacher and Dauwalder 2003) therefore proposes that cognitive agents may be modeled as dynamical systems (instead of, as physical symbol systems, Newell 1980). A common denominator in these dynamical approaches is to start from elementary perception-action cycles, an idea that was introduced by the concept of embodied cognition (Varela et al. 1991). Clark (1997) elaborated three bridging assumptions by which the numerous empirical findings can be integrated in the theory of dynamical systems. First, the assumption of continuity refers to cognition as continuous with its developmental foundations (Thelen and Smith 1994). Second, "off-line" reasoning and thinking is viewed as continuous with on-line motor control strategies. Therefore, abstract cognition may be decoupled from the actual environment but may still be working on the same dynamical principles; thinking is accordingly understood as "enacted" by emulated sensorimotor loops of perception-action cycles. Third, due to the dynamical hypothesis, pattern is provided not by programs but is "soft-assembled" by a continuing process of self-organization. This latter assumption was initially formulated in the interdisciplinary framework of theories of complex systems (especially Haken's synergetics: Haken 1977; and the theory of dissipative systems: Nicolis and Prigogine 1977). The self-organization approach was successively introduced to cognitive science (Haken and Stadler 1990; Kelso 1995). Historically, Gestalt psychology has developed a theoretical framework of cognition and action that was very much akin to the current dynamical systems approach (especially Köhler 1920 and Lewin 1936).

Cognitive science, especially its computational mainstream after behaviorist psychology had turned cognitive in the 1960s, has had a tendency to start with "higher" cognitive functions such as

goals, beliefs, and, in the context of goal-directed behavior, plans. The dynamical approach has avoided the problem of symbol grounding (Harnad 1990) that arises in a computational framework, and has therefore proceeded in a bottom-up fashion instead. Higher cognition is assumed to emerge from a basis of elementary sensorimotor loops. Rather than focusing on symbol grounding, the dynamical view addresses symbol emergence that occurs depending on control parameters. These control parameters comprise the ecological embedding of cognition, i.e., the context and environment of the cognitive agent. Therefore, the dynamical approach views cognition predominantly with reference to its embedding, and in this perspective, cognition is seen as embodied (Tschacher and Bergomi 2011), extended (Clark and Chalmers 1998), and situated (Greeno and Moore 1993).

Intentionality and Representation

The dynamical view in cognitive science thus naturally leads to the concepts of embodied, extended, and situated cognition. Consequently, intentionality of mental acts can be discussed anew under these premises. Rather than searching, in a top-down fashion, for a fundament of experienced intentionality of the mind, the dynamical systems heuristic can be formulated differently: If the mind is conceptualized as arising from self-organization processes, is there a way by which emergent mental acts can be conceptualized as *being about something*?

Intentionality was introduced as a characterizing property of mental acts by Franz von Brentano, a philosopher and early psychologist. In the late nineteenth century, Brentano was professor at the University of Vienna, where Edmund Husserl, Sigmund Freud, Carl Stumpf, and other later protagonists of philosophy and psychology counted among his students. According to Brentano (1874), mental phenomena are always directed towards an object (the intentional object). In other words, mental states contain within themselves something else ("*intentionale Inexistenz*," i.e., intentional existence within). No physical phenomenon has such intentional content, therefore according to Brentano intentionality constitutes the distinctive feature of the mind. Many concepts of contemporary cognitive psychology are in this sense intentional. The basic concepts *goal*, *wish*, *plan*, and *intention* of volitional psychology (Gollwitzer and Bargh 1996; Kuhl and Beckmann 1994) obviously have intentional content. The same applies to *achievement*, *valence*, and *need* within motivation psychology (McClelland et al. 1953). *Affects* and *emotions* are also commonly about something and are thus intrinsically intentional concepts.

It should be noted, however, that intentionality may not provide a sufficient and necessary condition for a state or process to be mental. Not all mental states are intentional; some emotional states (e.g., moods such as a pervasive feeling of melancholy or of serenity) do not necessarily possess intentional content because they are not about something; yet they are undoubtedly experienced mental states. Furthermore, intentionality is likely not the only property that distinguishes mental from physical systems. Many current philosophers of mind suggest that in addition to intentional content, the phenomenal content of mental states must be considered (Nagel 2012). This immediately leads to the topic of consciousness, which however cannot be addressed here.

A concept closely related to intentionality is *representation*. Representation plays a central role in cognitive psychology (as schema: Neisser 1976), in the philosophy of mind (as language of thought: Fodor 1975) and in artificial intelligence (as physical symbol system: Newell 1980). In all of these fields, representation of knowledge is a foundational concept, yet at the same time constitutes a core problem. If a cognitive agent is to have representational knowledge of its environment, the obvious idea is that there must be some kind of mental map or mental model of the environment "inside" the agent. On the basis of information thus represented, the agent would then perform cognitive actions such as memory functions, manipulations for problem solving, and the like. One may note the close analogy of representation with Brentano's intentional object.

The naive, folk-psychological intuition of an inner map or depiction of the environment, on which cognitive functions can then be performed, is however unsatisfactory (Bickhard and Terveen 1995; Clancey 1993). The map concept per se is not explanatory. The reason for this is simply put: if the problem of some information-processing agent is to make sense of its physical environment, the solution to this problem will not be alleviated at all by representation alone; the agent's task of making sense of the *represented* environment is just as demanding. The theory of direct perception (Gibson 1979) has therefore proposed that information pick-up must occur right at the moment of perception, without any representational interlude. For analog reasons, the "storehouse metaphor" of memory has been rejected by researchers of cognitive science (Glenberg 1997). Memory is likely not a passive store out of which represented items, some hypothetical memory engrams, can be retrieved at a later time, but a more active, constructive process (neural reuse: Anderson 2014). Psychological eyewitness research (e.g., the "false memory syndrome": Loftus 2003) has emphasized how modifiable and adaptive the represented contents of memory actually are. Representation-as-mapping has therefore been criticized as merely providing a pseudo solution to a deeper problem, which is likely the very conceptualization of intentionality.

Synergetics

We have proposed that cognitive phenomena have attributes of dynamical systems and that higher functions and more complicated mental processes are constructed bottom-up from simpler components by a process of self-organization. Both dynamical systems theory and self-organization theory are *structural sciences* that have been elaborated for interdisciplinary applications in diverse fields of science. It is the goal of our line of argument to show that intentionality can be conceptualized using a structural framework. The final step prior to our formulation of intentionality in terms of structural science is to introduce self-organization theory.

Here we will rely largely on the interdisciplinary modeling approach of synergetics. Synergetics deals with complex systems, i.e., systems composed of multiple components (Haken 1977, 1996, 2000). By way of their interactions, these components can produce new qualitative features on macroscopic scales. Synergetics focuses on the emergence of these new qualities and proposes that general principles govern the behavior of complex systems whenever such qualitative changes occur. This has been shown for a large class of systems – they are accessible to unifying mathematical and conceptual approaches, which characterizes a structural science approach. A paradigmatic physical system is the Bénard system (e.g., Bianciardi and Ulgiati 1998), which is comprised of a layer of fluid heated with temperature T_2 from below. The temperature at the upper surface of the fluid is T_1. Beyond a critical value of $\Delta T = T_2 - T_1$ extended coordinated motion of the components of the fluid system emerge. Compared to the erratic Brownian motion of the single components, these patterns are an example of the emergence of the new qualities.

Synergetics puts the focus on context – the behavior of complex systems is strongly determined by their environmental context. Context may be given by constant material constraints (e.g., the shape of solid walls that confine fluid systems such as the Bénard system) and by further environmental conditions that energize the systems (e.g., the heat source that drives the Bénard system). In the mathematical approach, these latter driving forces are expressed by control parameters. In many cases, control parameters take the form of externally applied gradients, which are imposed upon the system from outside, such as the difference in temperature ΔT of the Bénard system. The general strategy in synergetics sets out from a state of a system that is already known under a certain control parameter value. When the control parameter is changed, this system can become unstable and show a tendency to modify its state to develop a new type of behavior. The system in question is described by the states of its individual components, by means of a state vector q. The individual components in the Bénard

system, for example, are the motions of single fluid molecules; components may also be, with respect to applications in psychology, the attributes of members within a social group, or the activity of neurons in the brain (Atmanspacher and beim Graben 2007).

Synergetics shows that the behavior of the system close to instability points is described and determined by few quantities, namely the order parameters. In the case of a single order parameter n of a complex system, a typical equation reads

$$dn/dt = cn \qquad (1)$$

where c is the "effective" control parameter.

For $c > 0$, n increases exponentially,

$c < 0$, n decreases exponentially,

$c = 0$, n remains constant.

As was mentioned, c denotes the control parameter, a relevant parameter imposed on the system from outside, i.e., from the environment of the system. The generally few order parameters enslave, i.e. entrain, the behavior of the many individual components. This implies an enormous information compression, because the description of the order parameters alone, rather than that of each component, suffices. In the case of the Bénard system, description of the coordinated motion yields a much more parsimonious description of system behavior than the description of all molecular movements in the Brownian motion state of the fluid. This information compression is the hallmark of self-organization.

While they are being determined by the order parameters, it is the individual components that react on the order parameters and, by so doing, even generate the latter. The relationship between order parameters and components is, therefore, founded on *circular causality*, which can explain the generally avalanche-like onset of, and transition between, macroscopic states. In other words, synergetic theory favors neither top-down nor bottom-up modeling but claims that both processes are entangled. Order parameters, after they have been generated in this fashion, quite often exhibit very simple behavior, for instance, asymptotic stability.
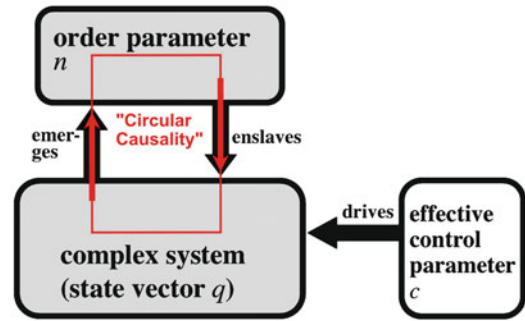
Intentionality: Steps Towards Naturalization on the Basis of Complex Dynamical Systems, Fig. 1 Schematic illustration of circular causality as viewed by synergetics

Obviously, the system depicted in Fig. 1 is an open system. Self-organizing systems are invariably open systems in that they depend on control parameters. In terms of thermodynamics, they are nonequilibrium systems.

Let us however first focus on closed systems, in other words, systems in thermal equilibrium. Classical thermodynamics deals with closed systems throughout. The probability of all configurations of components within the (closed) system can be estimated. When dealing with a complex system consisting of a multitude of components, many possible realizations of the state vector q exist, namely the number of all combinations W of the states of components. Only a small fraction of these realizations will manifest as regular, well-organized patterns. The vast majority of realizations, however, will represent a state of mixture. Should ordered patterns exist as an initial condition, it is far more probable that the temporally consecutive system states will be characterized by less order, owing to the statistical fact that the majority of possible consecutive states will be states with less order rather than states with the same, or even a higher degree, of order. Within a thermodynamics context, this touches on the concept of entropy S (disorder) in accordance with Boltzmann's statistical approach, in which S is directly related to the number of combinations W. The second law of thermodynamics states that any real closed system can only proceed in the direction of increasing entropy, thus following

a maximum entropy principle. Hence, the spontaneous generation of order is highly improbable as indeed a spontaneous generation of *dis*order is to be expected. In other words, the emergence of pattern from a state of mixture requires explanation; the explanation is that the phenomenon of self-organization is driven by an external source, so that the premises of closed systems do not apply. Since the concept of entropy is defined only for equilibrium or close-to-equilibrium systems, one may base the discussion of self-organizing systems on the concept of information (Haken 2000; Tschacher and Haken 2007).

Some authors have applied the laws of thermodynamics in order to allow the study of self-organizing systems. The "restated second law" of thermodynamics (Schneider and Kay 1994; Schneider and Sagan 2005) addresses non-equilibrium systems, i.e., systems that are forced away from equilibrium by the application of gradients. The degree to which a system is moved away from equilibrium is measured by the gradients imposed on the system. As soon as such gradients dwell in the system's environment, the system will, as a consequence of the restated second law, "(...) utilize all avenues available to counter the applied gradients. As the applied gradients increase, so does the system's ability to oppose further movement from equilibrium" (Schneider and Kay 1994). Schneider and Kay's restatement of the second law avoids some of the problems of defining entropy and entropy production by focusing on the destruction of gradients instead.

It should be kept in mind that this "destruction of gradients" is only virtual (in analogy to the principle of virtual work in mechanics), because in open systems gradients are generally maintained by the environment. If, however, the self-organizing system and its *finite* environment act as a closed system, the gradient reduction becomes real. In other words, the effective control parameter c depends on the order parameter n,

$$c = c_0 - \alpha n \qquad (2)$$

where c_0 is the control parameter prescribed from the outside and α a constant. The effective control parameter (2) obeys the differential equation

$$dc/dn = -dV/dc \qquad (3)$$

where

$$V = \alpha c \qquad (4)$$

is a potential and thus the right-hand side of Eq. 3 a gradient.

Discussing the time-evolution of n and c according to Eqs. 1 and 2, we assume that, initially, $n = n(0)$ is close to zero and $c \approx c_0 > 0$.

Thus, according to Eq. 1, n increases exponentially. As a consequence, according to Eq. 2, c decreases, and the exponential increase of n slows down. This process goes on until $c = 0$ and n reaches a time-independent, i.e. steady, state. In practice, the transition to the new state is completed while the gradient has been reduced. In the Bénard example, the coordinated motion patterns have consumed the applied temperature difference and have reduced ΔT to 0. Then the motion patterns subside and steady state remains. This relationship between emergent pattern and control parameter is thus in line with the notion of gradient destruction. The reduction of c by n establishes a second kind of *circular causality*, which is schematically illustrated in Fig. 2.
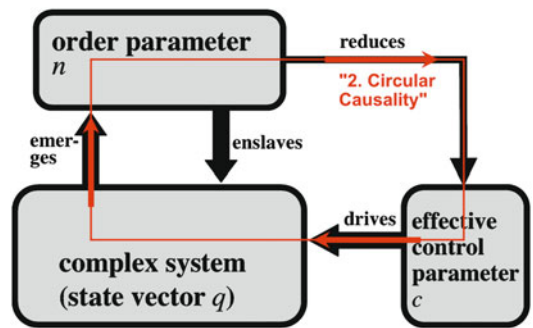
Intentionality: Steps Towards Naturalization on the Basis of Complex Dynamical Systems, Fig. 2 Schematic illustration of the relationship between control parameter and order parameter ("second circular causality")

Discussion: A Structural Science Concept of Intentionality

The steps above have put us in a position where a novel conceptualization of intentionality comes within reach. We propose that this can be achieved on the basis of the properties of self-organizing complex systems (Tschacher and Haken 2007; Haken and Tschacher 2010). In this section, we will therefore discuss to what extent the features of intentionality (listed in section "Definition of the Subject") can be approximated by such systems – the structural science of synergetics is used for the conceptualization of intentionality.

Aboutness

Intentionality implies that a system state is about something else, namely the intentional object. In terms of cognitive psychology, this process is called representation, by which a "cognitive map" of the object is generated, particularly during perceptual or memory processes.

For being capable of intentionality and representation, a minimum requirement is that the intentional system must be an open system. Many open systems can provide representations in the sense of mappings of environmental impacts. The silver particles of a light-sensitive surface of a photographic film can "represent" the objects in front of the lens, however in a trivial, weak sense. As has been shown in the previous section, a self-organizing system can likewise "represent" and thus generate the feature of being about something. In the latter system, the order parameter is a component in the loop labeled "second circular causality" (Fig. 2). Within this loop the complex system "represents" an external object by the generation of an order parameter. The intentional object in this case is the external control parameter c. The environmental context described by control parameters is what self-organized patterns are about.

The mechanisms of representation are clearly divergent in these two systems, as is the nature of the intentional objects. In the photographic system, the mapping of the environmental objects onto the representing system is unidirectional, whereas in the self-organizing system there is

continuous interaction between environmental objects and system. This circularity is illustrated in Fig. 2 and provides an important and desirable aspect of the kind of aboutness realized by self-organizing systems – circularity guarantees that an intentional system is capable of exerting a retrograde effect back on what has been represented. This effect is generally a reduction of the gradient that was quantified by the control parameter.

Functionality

Intentionality must be functional in order to make representation explanatory, i.e., make representation more than just a mapping of environmental states onto the system's state. The functionality of open systems has previously been approached from the angle of thermodynamics. Schneider and Sagan (2005) pointed out that self-organizing systems maintain and increase their levels of organization by dissipating nonequilibrium gradients. If the gradient is to be kept constant, the demand on free energy (so-called exergy) that must be provided by an external source increases as the system becomes more organized. Alternatively, the efficiency of the system can be defined as the ratio of the change of work and the change of the gradient driving the system. This can be shown by findings in simple physical systems that generate patterns; e.g., mentioned Bénard cells reduce the temperature gradient more efficiently as soon as they have generated ordered convection structures. Efficiency has thus increased in the self-organized convection regime in comparison to the linear conduction regime of the fluid. Analogous relationships are found in further self-organizing systems such as the laser when output power is plotted against input power (Haken 1977). In other words, pattern formation in these open systems is in the service of gradient reduction. The association of pattern formation with gradient reduction makes pattern formation "functional."

In situations of multistability, several patterns are possible, so that each of these can be functional in reducing the gradients imposed on the system. These alternative patterns can be associated with different efficiencies. It is theoretically

suggestive that the two circular loops pointed out in Figs. 1, and 2 interact and thereby create a Darwinistic scenario in which a competition between microscopic modes q arises; the environmental forces c exert a selective impact on this competition of modes. From a mathematical modeling point of view, it is not however clear whether the optimal pattern is necessarily selected, nor under which circumstances the optimal pattern will be chosen. In some systems, such as quadruped movement coordination, it was empirically found that the specific pattern providing the most efficient behavior (measured by the metabolic cost of transport of the animal) will be realized by the system (Hoyt and Taylor 1981). The generalizability of such findings of optimality is not yet established.

Mental-Likeness

In this discussion, we have so far found that the aboutness of intentionality and representation can be modeled by open systems. A subclass of open systems additionally provides functional representations – especially self-organizing non-equilibrium systems appear to show both the features of aboutness and of functionality.

It is obviously useful to reserve the predicate "intentional" for mental systems alone. Thus, even though some physical self-organizing systems may show circular causality loops and thus stand the tests of aboutness and functionality, we would still not categorize systems such as lasers, Bénard cells as mental. We may say that such self-organizing physical systems behave "as if they were intentional," i.e., they are proto-intentional systems. Let us finally investigate under which conditions self-organizing nonequilibrium systems may also show mental features and, with this, we address the possible naturalization of intentionality. This final step is basically a discussion of the validity of the statement that physical self-organizing systems can show intentionality.

- *Complexity reduction* is a core hallmark of mental processes. The ability of a system to simplify, group, and coordinate environmental information is a necessary premise for any system to be mental. This property of information compression is addressed in the circular causality concept of synergetics illustrated in Fig. 1. With respect to complexity reduction, physical self-organizing systems are mental-like.

- *Stability* together with related signatures of stability (e.g., hysteresis, critical fluctuations) is a further mental property, which is empirically well founded especially in the psychology of perception. Again, the emergent order parameters of physical self-organizing systems generally show this property.

- *Autonomy* is required of intentional mental systems, i.e., mental systems must be able to function in the absence of external agents. This ability addresses the "homunculus-problem" that has already been introduced together with the feature of functionality. We may say that generally self-organizing systems do not require external supervision for producing order parameters (therefore, *self*-organizing). This does not rule out that several autonomous systems may be nested inside one another (cf. Minsky's (1985) society of mind, or the notion of subsumption architecture of Brooks' (1991) robotic agents). Thus, physical self-organizing systems are also autonomous.

- Is the nature of the *intentional content* mental-like, and which aspect of the environment is being represented by self-organizing systems? Order parameters are intentional with respect to those environmental parameters that drive the system. In other words, the intentional content is generally connected to what energizes the system. This is a satisfactory model in all those instances where mental intentionality is of a motivational character, resembling a psychological "drive" (Freud 1923). In the introduction, we named wishes, desires, affects, intentions, goals, and the like as intentional. Such intentional states can be directly modeled by self-organizing systems that act to reduce the driving parameters (in Freudian terms, drive reduction). The self-organization model, however, is less applicable whenever intentionality is of a language-like, propositional type (Fodor 1975). It would be not straightforward to model, for instance, the intentionality

inherent in the belief that "there is a unicorn grazing in the garden," using simple physical self-organizing systems. Therefore, the discussion of mental-likeness of self-organizing systems remains restricted to nonlinguistic intentionality.

- The only mental systems known to date, despite the efforts of several decades of artificial intelligence research, are linked with *neuronal networks* hosted by biological organisms. Therefore, can the argumentation above be applied to brain dynamics and to pattern formation in neural networks? One may then associate the gradient of c with intentionality in a neurocognitive sense. Haken (2002) has discussed synchronization, i.e., self-organization, of neural nets using various mathematical frameworks. Friston (2012) has applied a free-energy principle to brain dynamics. Haken and Tschacher (2010) have specifically addressed the reduction of the effective control parameter on the basis of the Wilson-Cowan equations describing cortical dynamics (Wilson and Cowan 1972). They suggested that the general findings on circular causality in the relationship between order parameter and control parameter can be readily applied to neural networks.

- Contrary to von Brentano's supposition, mental phenomena are intentional as well as *phenomenal-experiential*. Conscious mental states are characterized, from a first-person perspective, by a specific quality, by "what it is like" to experience this state (Nagel 1974). The qualia and "what-it-is-likeness" of phenomenal consciousness is not modeled by our present conceptualization. This comes as no surprise, as it relates to the "hard problem" (Chalmers 1996) of consciousness. Thus a constitutive ingredient of many mental processes, the phenomenal-experiential qualities, are not generated by physical self-organizing systems.

In conclusion, we have argued that a formulation of intentionality is feasible on the basis of the theory of complex dynamical systems. When such systems are removed from thermodynamical equilibrium, they acquire the capability of producing self-organized patterns. Pattern formation consequently puts the systems in a specific relationship to environmental parameters, the contexts of these systems. Owing to the accompanying circular loops, these systems show aboutness, the defining property of intentionality, as well as functionality, which is essential for making the aboutness of intentional states explanatory. We find, however, that this structural conceptualization of intentionality is not entirely mental-like because the phenomenal and experiential aspects of conscious cognition cannot be addressed by it.

Future Directions

We may conclude that nonexperiential intentionality can be conceptualized to a considerable extent using nonequilibrium complex systems. The limitations that have turned up during the above discussion may provide points of departure for future research.

First, it is as yet unclear whether the resulting self-organized patterns obey an optimization principle. In some empirically described systems showing multistability, it could be shown that the more optimal pattern wins the competition among order parameters, but the generality of such findings is yet to be corroborated. Correspondingly, Haken and Tschacher (2010) have discussed "second circular causality" in the case of only one order parameter. A mathematical model comprising $m > 1$ order parameters would be a desirable next step.

Second, we found that conceptualization, and even naturalization, of intentional states is achievable when these states comprise motivation, goals, intentions, or drives; these may be viewed as basic intentional states related to behavioral strivings. At the moment, however, the intentionality problem appears intractable when intentional states are of a symbolic and propositional nature. The difficulties of modeling Fodor's *language* of thought do indeed complicate the modeling of intentionality beyond its basic form (cf. Churchland 2002, p. 304). At the present time, we may consider nonlinguistic intentionality as one of two problems of a conceptualization of

intentionality, which in fact seems accessible. The more fundamental problem is however the second, the intentionality of an experiencing, conscious, linguistic agent. Structural conceptualization from a complex systems point of view addresses solely the basic aspect of intentionality, yet not the phenomenal nature of intentionality. This limitation points to a failure of the naturalization of conscious intentionality altogether. In a strict sense, naturalization is the explanation of mental phenomena by physical phenomena, and we have encountered serious obstacles of this approach. Eliminative physicalism, i.e., the totality of all possible naturalizations, is likely not a tenable program. As a future direction, one may have to further develop the structural science solution and, in philosophical approaches, contemplate dual-aspect theories (Atmanspacher 2017).

Third, the topic of intentionality has numerous implications beyond the philosophy of mind and theoretical psychology. In psychiatry and psychotherapy research, intentionality is a topic of considerable significance because intentional mental acts and states are often characteristically altered or disturbed during a mental disorder. Many such psychopathological conditions are found especially among the symptoms of schizophrenia, such as disorders of formal thought as well as of thought content, disorders of perception, and ego disorders. The symptoms are heterogeneous and manifold. A majority of these symptomatic alterations, however, involve changes in the cognitive coordination of the patients (Tschacher et al. 2017). Recent schizophrenia research has shown that a considerable portion of variance of psychotic symptoms can be explained by cognitive coordination measures (e.g., Tschacher et al. 2008). While no generally accepted encompassing theory of schizophrenia exists, a theory of intentionality may have the potential to contribute to progress in psychopathology. It may help to link the phenomenology and neurobiology of schizophrenia and other psychiatric disorders by introducing a dynamical systems perspective.

Fourth, artificial intelligence is a completely different field but is also confronted with intentionality as a core problem. During recent decades, the computational approach to machine intelligence has failed to a large extent; especially, no mental-like intelligence could be generated. Consequently, the field has turned to the more basic tasks of designing autonomous agents and robots with rudimentary adaptivity in the real world (Braitenberg 1986; Pfeifer and Bongard 2006). In this framework, intelligence is expected to be closely associated with embodiment (hence, embodied intelligence, mind-body coevolution), rather than with symbol manipulation and the programming of symbol systems. The latter constituted the classical approach to artificial intelligence. One of the novel directions of development is using emergence principles for the design of intelligent agents or multi-agent systems; this is closely related to the structural view on intentionality proposed here. The engineering approach of embodied agent design and the dynamical systems proposal of intentionality have the potential of subserving each other in artificial intelligence research.

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