chapter in: Tschacher W & Dauwalder J-P (eds.)(2003) The Dynamical Systems Approach to Cognition, (pp. 183-200). Singapore: World Scientific.

SELF-ORGANIZING SYSTEMS SHOW APPARENT INTENTIONALITY

WOLFGANG TSCHACHER, JEAN-PIERRE DAUWALDER* AND HERMANN HAKEN**

University Psychiatric Services, University of Bern, Laupenstrasse 49, 3010 Bern, Switzerland
tschacher@spk.unibe.ch

**Institute of Psychology, University of Lausanne, BFSH 2, 1015 Lausanne, Switzerland*
Jean-Pierre.Dauwalder@ip.unil.ch

***Institute for Theoretical Physics and Synergetics, University of Stuttgart, 70550 Stuttgart, Germany*
haken@theo.physik.uni-stuttgart.de

Abstract. Cognitive science is frequently confronted with mind-body issues—is there a way by which the mentalist and the physical approaches to cognition can be integrated? Can the intentional attributes of mind be understood in physical terms? We propose that synergetics, the theory of nonlinear complex systems, offers steps towards a possible solution to this notorious problem. In particular, we claim that an essential property of self-organized pattern formation lies in its functionality, i.e. the ability to respond and adapt 'meaningfully' to environmental constraints. Patterns become functional because they consume the gradients that caused their evolution, and, in addition, they consume them in the most efficient manner. This makes synergetic pattern formation appear 'intentional'. Therefore, we suggest that self-organization phenomena may be considered basic explanations of the adaptive, intentional, and purposive behavior of many complex systems, in particular cognitive systems.

1 Introduction

Cognitive Science is situated directly above the gap between mind and body, between thinking and behavior. The numerous disciplines and theories that have contributed to this research program can often be located on either side of the mind-body dichotomy.

Exploring the *mind*, on one side, entails using the terminology of intentionality. Mental theories originated, for example, from cognitive psychology and action theory, or from phenomenological philosophy. They are often centered around intentional concepts (such as 'plan', 'intention', 'wish', 'goal', etc). The constituents of these theories often rely on, and appear well accessible to, introspection. This intentional stance (Dennett, 1987) is grounded in the 'first-person' experience one has of 'being in the world'. Quite naturally, one would not hesitate to make use of intentional concepts when one tries to make sense of one's 'own' actions, thoughts, and emotions. Intentional concepts are thus frequent in colloquial language. It seems straightforward to approach cognition from an understanding of our own inner cognition, of which we are—presumably—experts. If taken to their extremes, however, intentional theories can end up in solipsism that views the physical world as a mere invention of the mind (e.g., radical constructivism). Such solipsism results from a complete closure of the mental realm which can be derived from a (mis-) application of concepts such as operational closure, self-referentiality, and autopoiesis, which have been put forward by some systems theorists (Luhmann, 1984; Maturana & Varela, 1980).

Explorations of the *body*, brain, and of physical behavior, on the other side, have the advantage that, in principle, the investigated variables are directly observable by third persons. The systems and processes under observation here are physical or chemical, which rules out an intentionalist interpretation in the first place. Instead, the laws of natural science can—and must—be applied. Information processing theory may be subsumed under these physical approaches provided that information processing is based on the physical symbol systems premise (Newell & Simon, 1972). This premise regards a 'mind' as a physically implemented symbol system and 'mental' processes as identical to symbolic operations that can in principle be run on Turing computers. The extreme version of the materialist position is eliminative materialism which claims mental entities are nonexistent or epiphenomenal at most. The reason for this reduction of mind to physics is again closure, namely the causal closure of the material world (e.g., the conservation laws of physics).

We regard the bisection of psychology and cognitive science into the mental and the physical realms as troublesome. Staying on either side of the mind-body division must eventually remain insufficient. A complete treatment of cognition would demand that intelligent, adaptive, purposeful intentionality—as perceived via introspection by an agent—be linked with physical (biological, neuronal, behavioral) facts that can be generated by observing this agent. Cognitive science as well as psychology therefore cannot stay free of the mind-body question. To the contrary, many active fields of cognition research address the association of mind and body in one way or the other. To name but a few, 'embodied cognition' (Pfeifer & Scheier, 1999) is a recent concern in artificial intelligence research and cognitive science; 'binding' is a focus of neuroscience investigating how brain sites cooperate, especially in connection with conscious mental acts (Robertson, 2003; Dennett & Kinsbourne, 1992). The history of cognitive science provides ample evidence that efforts to bridge the gap between mind and body have been most fruitful for the development of this entire research program. At the same time, however, the thoughtless mixing of mind terminology with brain terminology poses a serious threat to scientific explanatory power (Clancey (1993), for instance, has criticized the conflation of first-person and third-person perspectives in classical artificial intelligence research).

It is not the point of this chapter to discuss all the possible ways in which mind and body may be associated. In the following we wish to put forward steps towards a possible clarification of the mind-body problem by addressing the concept of intentionality. In the context of recent consciousness research, our position may be grouped among the emergence theories (Carter, 2002). The first goal of this chapter is therefore to describe a property of a class of complex non-equilibrium systems that 'looks like' intentionality. Complex non-equilibrium systems are studied by synergetics and self-organization theory. After having sketched self-organizing systems in a formal way, we will address as a second goal how their properties can elucidate intentional psychological processes and become instrumental in modeling these processes. We will then wrap up the discussion by providing some examples taken from psychology.

In other words, we will address the intentionality issue from the natural science side of the mind-body division. We advocate a systems-theoretical perspective that regards physical systems as the givens, and defines intentional acts consequently as the explananda of cognition research and theory. This preference is admittedly biased by our personal backgrounds as well as, maybe, by the zeitgeist of contemporary cognitive science. It is conceivable to proceed in the opposite direction, i.e. to start out with the well-founded phenomenological or experiential access to consciousness (Varela & Shear, 1999) and from there move on to physical systems. The direction of motion is probably irrelevant as long as there is hope to find a viable bridge.

2 Synergetics

Synergetics is an interdisciplinary field of research that deals with systems composed of several or many components (Haken, 1983; 1996; 2000). By means of their interaction, these components can produce new qualitative features on macroscopic scales. In other words: synergetics studies the emergence of new qualities. Its main question is whether there are general principles that govern the behavior of complex systems when qualitative changes occur. These situations are probably of particular interest. In a large class of systems it has been shown that they become accessible to unifying mathematical and conceptual approaches.

Synergetics starts from the observation that the behavior of many systems is strongly determined by the environmental conditions. These conditions may be divided into constant (structural) conditions or constraints (e.g. that there are solid walls and containers that confine fluid systems) and further environmental conditions that 'energize' or 'drive' the systems. In the mathematical approach these latter environmental conditions are taken care of by control parameters. In many cases control parameters have the form of externally applied *gradients*. Gradients are imposed on the system from the outside such as, for instance, a temperature difference between the top and the bottom boundaries of a fluid layer (the Bénard experiment, e.g. Bianciardi & Ulgiati, 1998; see Fig. 1). The general strategy of synergetics is as follows: it sets out from a state of a system that is already known under a certain control parameter value. When one or several control parameters are changed, the system may become unstable. Then it may tend to leave its state and develop a new structure or behavior. The system is described by the states of its individual components by means of a state vector q. The individual components in the Bénard system, for instance, are the motions of single fluid molecules; components may also be, with respect to applications to psychology, attributes of members of a social group or neurons in a brain.

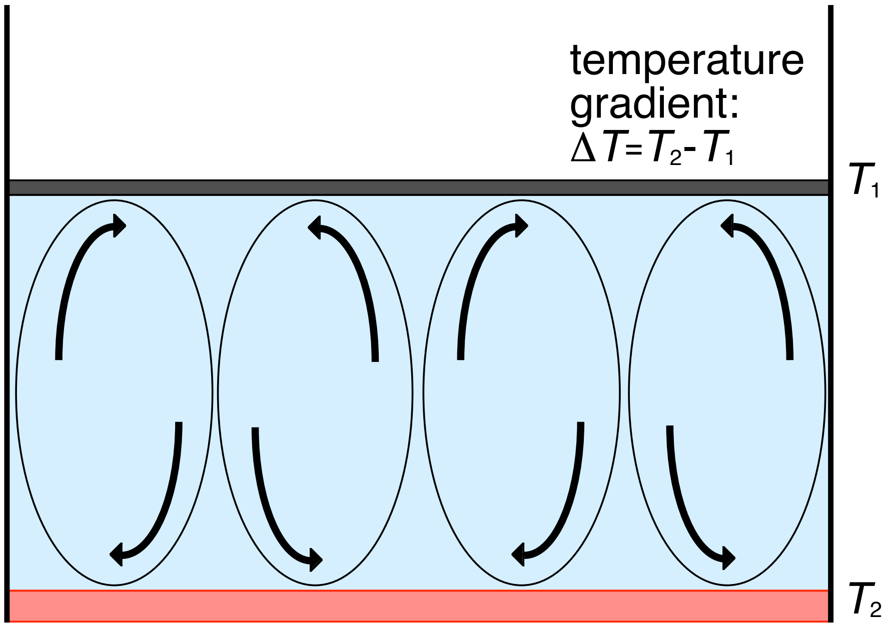

Fig. 1. Schema of the Bénard system. A layer of fluid is heated with temperature T_2 from below. The temperature at the upper surface of the fluid is T_1. Arrows symbolize the convection patterns that emerge beyond a critical value of $\Delta T = T_2 - T_1$

Synergetics shows that the behavior of the system close to instability points is described and determined by few quantities, the order parameters. According to synergetics, the—in general few—order parameters enslave, i.e. determine, the behavior of the many individual components. This implies an enormous information compression, because it suffices to describe the order parameters instead of all the components. On the other hand, the individual components react on the order parameters and, in this way, even generate the order parameters. Thus, the relationship between order parameters and components is based on *circular causality*. Quite often order parameters show very simple behavior, for instance bi- or multistability, i.e. a system can acquire different states under the same external conditions. An example of visual perception is shown in Fig. 2, a multistable Gestalt array.

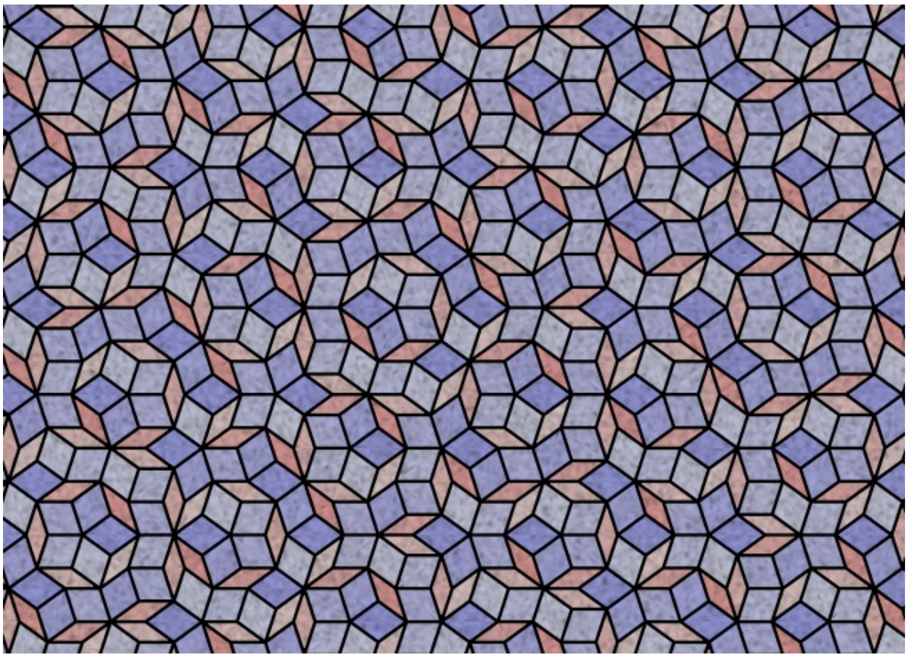

Fig. 2. A pattern (Penrose tiling) that generates multistable visual perceptions. (Note: observe the tiling for some time to allow a number of depth illusions emerge. Illusions are mutually exclusive visual Gestalts)

3 Thermodynamical and statistical considerations

Let us first focus on closed systems, i.e. systems in thermal equilibrium. Classical thermodynamics deals with closed systems throughout. In a strict sense, closed systems cannot even be observed because any observer must interact with the observed system from outside the boundaries of the system, thus ‘opening up’ the system. In addition, self-organizing systems are always open systems because they depend on gradients (quantified by control parameters). It is therefore only for the sake of idealization that we deal with closed systems first.

We can estimate the probability of all configurations of components of the (closed) system. When we deal with a complex system that consists of many components, there are very many possible realizations of the state vector q, namely the number of all combinations W of the states of components. Only a small fraction of these realizations are regular, well-organized patterns. A vast majority of realizations, however, will represent a state of mixture. If, as an initial condition, ordered patterns exist, it is far more probable that the temporally consecutive system states 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. In the context of thermodynamics, this touches on the concept of entropy S ('disorder') according to Boltzmann's statistical approach which directly related S 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 (maximum entropy principle). Thus, the spontaneous generation of order is highly improbable. To the contrary, a spontaneous generation of disorder is to be expected. In other words, the emergence of a pattern from a state of mixture requires explanation—the phenomenon of self-organization must be driven by an external source.

Unfortunately, the concept of entropy is defined only for equilibrium or close-to-equilibrium systems. In order to study a self-organizing system using the entropy concept it may seem consequent to address some enveloping closed system where the second law of thermodynamics is applicable. The self-organizing system under study (which is an open system) could be embedded in this larger closed system. But even then the partial entropy of the embedded open system is still ill-defined. Generally, this makes a discussion of self-organizing systems based on the concept of entropy unfeasible (cf. Nicolis & Prigogine, 1977; Swenson & Turvey, 1991). Therefore, an alternative formulation of thermodynamics is necessary to address open systems (a formalized approach towards a new kind of thermodynamics based on information is given in Haken, 2000).

Several authors chose to reformulate the laws of thermodynamics in a fashion convenient for the study of self-organizing systems. The 'restated second law' (Schneider & Kay, 1994) 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. A physical example of a gradient is the temperature gradient ΔT imposed on Bénard's fluid system described in the previous section. As soon as such gradients dwell in its environment, the system will, due to 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 & Kay, 1994). Accordingly, Schneider & Kay proposed that self-organized systems are not governed by a principle of maximum entropy production, as was hypothesized by Nicolis & Prigogine (1977). Their restatement of the second law sidesteps the problem of defining entropy and entropy production by focussing on the destruction of gradients instead. We may add that this 'destruction of gradients' is only virtual (in analogy to the principle of virtual work in mechanics) because in general the gradient is maintained by the environment.

If, however, the self-organizing system and its *finite* environment act as a closed system, the gradient reduction becomes real. The main point is: *Organized systems reduce gradients quicker than random linear processes*. The more a system has departed from equilibrium the greater its resistance to being departed further away from equilibrium. This can be measured from a perspective external to the system as follows: The demand on free energy ('exergy') that must be provided by an external source in order to maintain the gradient increases as the system becomes more organized.

This principle can easily be applied to the Bénard system. As soon as ΔT exceeds zero this system responds to the temperature gradient by conducting heat. Beyond a critical value of the parameter ΔT a self-organized pattern emerges that is characterized by a different way of heat transfer, namely heat convection (Fig. 3).

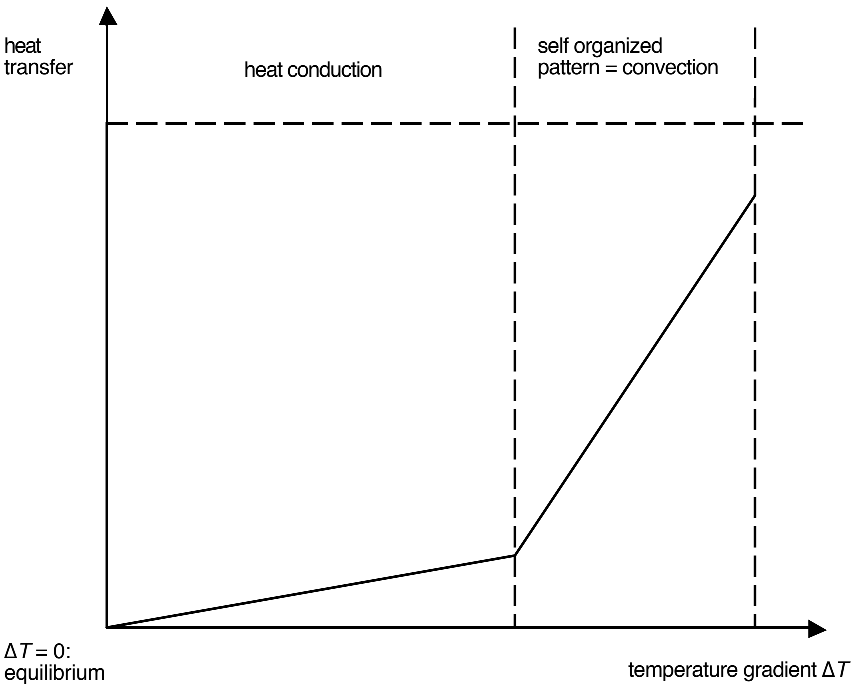

Fig. 3. Schematic representation of the relationship between gradient ΔT and heat transfer in the Bénard system (adapted from Swenson & Turvey, 1991, p. 335). The same diagram holds for other systems, e.g., the laser, where output power is plotted against input power (Haken, 1983)

Heat convection is realized by extended coordinated motions of the components of the fluid system, the so-called roll patterns (cf. Fig. 1). One may notice a pivotal attribute of self-organization—the ordered patterns provide a qualitatively different means to dissipate heat. In other words, self-organization in this system is caused by the environmental conditions (by the temperature difference), yet in turn self-organization exerts an influence on the environment as well (because the self-organizing system tends to lower the temperature difference, the environment must react in order to maintain that prescribed difference, i.e. the prescribed control parameter). Thus, the emergence of order parameters has a virtual impact on the control parameters that have lead to order in the first place. In addition to the circular relation between order parameters and components described in synergetics, a *second circularity* is found in systems that thrive on gradients (cf. 'self-steering', Keijzer, this volume).

Generally, the observable behavior of the system, its work, can be expressed in terms of the macroscopic variables. Haken (1983) introduced the square of the order parameter as a measure of the work performed. The efficiency of the system can then be defined as the ratio of the change of work and the change of the gradient driving the system. In the case of the Bénard system, Fig. 3 shows that the efficiency has increased in the convection regime compared to the conduction regime. Thus, this system becomes more efficient as it enters the self-organized state.

In summary, using a tentatively generalized formulation, the following hypotheses have been derived in this section using thermodynamics and synergetics as theoretical backgrounds.

- *Self-organization and thermodynamics*: Self-organization phenomena can be treated in connection with a restated second law of thermodynamics. The consequence of spontaneous increase of order in an open system can be discussed as a corollary of the second law.
- *The functionalist view of self-organization*: The restated second law regards pattern formation in the service of gradient reduction. Thus, pattern formation is functional, it may 'look' intentional.
- *Optimality of self-organization*: In principle, there may be several patterns each of which can be functional in reducing the gradients imposed on the system. These patterns can be attributed different efficiencies. If a specific pattern provides the optimal (most efficient) way to dissipate the gradients, exactly this pattern will be realized in the system. The better dissipative pathway is preferred.

4 Relevance for psychology

The second goal of this article is to investigate the applications of the concept of self-organizing, far-from-equilibrium systems to psychology. In this context, the described second circularity (between environment and system) is of obvious importance because psychology traditionally deals with the mutual relationship between environment and system (e.g., the relationship between stimulus and response). We will argue in the following section that psychological systems must be viewed as continually interactive systems in this sense (Tschacher & Scheier, 2003; Thelen & Smith, 1994)—'interactive' referring to the system-environment circularity. This interactive loop regulates how efficiently the system deals with its environment, i.e. how efficiently the system reduces the applied gradients, either really or virtually. This functionality of a system must in turn be grounded in the synergetic relationship between emergence and slaving, the 'first circularity' between order parameters and the microscopic components of a self-organizing system.

The psychological relevance of self-organization and of pattern formation in complex systems has been claimed by several authors. The application of models from synergetics to fields such as movement coordination has resulted in a wealth of experimental studies that indicate how synergetic concepts can be operationalized and how hypotheses derived from synergetics can be tested (Haken et al., 1985; Kelso, 1995; Haken, 1996; Temprado et al., this volume). Frank & Beek (this volume) propose a mathematical dynamical model of personality. In the field of cognitive science, the dynamical systems approach to cognition (Clark, 1997) has become a major approach that incorporates self-organization theory (Haken & Stadler, 1990; Kruse & Stadler, 1995; Port & van Gelder, 1995; Tschacher & Dauwalder, 1999). The notion of self-organization is also essential for the contemporary neuroscientific discussion about neuronal synchronization as a correlate of cognitive acts (Singer & Gray, 1995; Rodriguez et al., 1999; Miltner et al., 1999). In clinical psychology and psychiatry multiple applications have been developed on the background of dynamical systems concepts, e.g. in psychotherapy research (Tschacher, 1997; Grawe, 1998) and by the use of dynamical systems methodology and measures (e.g. Tschacher et al., 1997; Thomasson et al., 2000; Pezard, this volume).

Throughout these applications, however, pattern formation is generally treated without addressing the question of the functionality of these patterns in a given context. Therefore our present question, 'How efficient is a self-organized system with regard to environmental gradients?' should be given much higher priority. This problem was raised in the previous section in general terms. We will now pursue this question in three 'classical' psychological contexts.

4.1 'Aufforderungscharakter' as gradient

A forerunner of the synergetic view in psychology is the Gestalt tradition. Its central tenet is that mental events have the essential property to be structured or organized. Such structures (i.e., Gestalts) cannot be reduced to the properties of their components because they possess additional emergent properties. For example, the perceptual system adds apparent depth to the planar tiling shown in Fig. 2.

The Berlin Gestalt school served as background to Kurt Lewin (1926) who addressed topics of general psychology, especially the concepts of intention, volition and motivation. Lewin's phenomenological analysis started with the statement that an individual's psychological environment is not given by "the sum of optical, acoustic, tactile stimuli" but by "things and events". These patterns of stimuli are seldomly neutral to the individual—they usually *afford* specific behavior. Lewin termed such properties of environmental things and events 'Aufforderungscharakter' (later translated by himself (Lewin, 1936) as valence; in a related theory (Gibson, 1979), affordance). Viewed this way, the environment is both the motor of the individual's behavior as well as merely arena to an individual's motivational tensions. Lewin observed that volitional action (e.g., taking a letter to the mailbox) and behavior instigated by drives (e.g., being hungry or being in love) are equivalent in several respects. For instance, the valences of the environment change in accordance with psychological motivation. Not seldom, the change in these external valences would be perceived *before* the individual is conscious of any change of his or her own 'inner' needs and motives.

Lewin's analysis did not ultimately clarify the agency of action. The status of the valent environment—is it motor or arena?—was left open. In addressing volition, he indicated that environmental valences are determined by an individual's needs and intentions. On the other hand, perception of the environment may even allow the agent to know his or her own 'true' needs and intentions in the first place. The important point, however, is that basic needs (e.g. hunger) and quasi-needs (those originating from volition) are treated in parallel. Needs and intentions are both seen as depending on environmental properties, the Aufforderungscharakter of things and events. The environment loses its valent properties not until an action is completed (e.g., not until the letter has been deposited in the mailbox); or, in reverse, completion of actions is guided by environmental valences.

From the viewpoint of our theses elaborated above, Lewin's letter-affording-delivery is an example of a psychological gradient. This gradient shapes the individual's action until the gradient is finally reduced, virtuality has been converted into reality. Reducing gradients in daily life is usually more complicated than throwing a letter into the mailbox; there may be competing or otherwise interlinked gradients. The letter may end up forgotten in the pocket because the corresponding gradient had been superseded by more urgent affairs. There are several empirical studies on delayed gradient reduction with later reuptake of the interrupted action that have been performed in Lewin's laboratory (Zeigarnik, 1927) and in recent cognitive psychology (Gollwitzer & Bargh, 1996).

The outlined approach shows how the 'goal' of some willed action can be reformulated as a gradient or tension existing in the environment of the agent. The problem of willed action (an intentional concept) thus becomes consistent with the theoretical framework of self-organizing systems outlined above. In addition to the Gestalt formulation this recent framework contributes one essential conceptual step that was missing in the traditional picture of volition as Aufforderungscharakter. This step is the 'purposive' function of self-organization that selects efficient ways to reduce gradients. If action is self-organized ('soft-assembled', Thelen & Smith, 1994) it will follow the better dissipative pathway; the Gestaltist claim of understanding formation of 'good Gestalts' without implying a homunculus is finally satisfied in this general thermodynamical framework. A step-by-step execution of a hierarchy of plans, the core metaphor of cognitive psychology, must by necessity imply a hidden homunculus. In our view, good Gestalts are formed simply because they are good dissipative pathways. This requires neither a central controller nor a master plan. ‘Volitional’ behavior is thus explainable as a continuing process of the formation of ‘good’ (volitional-looking) patterns. In this conception, Lewin’s ambiguity (‘motor or arena?’) is resolved.

4.2 Dissonance as gradient

The theory of cognitive dissonance (Festinger, 1964) has been dominating social psychology for more than one decade in the 1960s and 1970s. It has since passed its zenith of influence, yet still stands out as one of the most encompassing theories in psychology (whereas psychology as a whole suffers from an abundance of insufficiently linked theories with small scopes). We mention cognitive dissonance here also because of the broad empirical research that was stimulated by dissonance concepts.

Dissonance is defined as an aversive motivational state caused by conflict and imbalance among the different cognitions (e.g. beliefs, attitudes) of an individual. Dissonant relationships between relevant beliefs and attitudes were found to induce behavior capable of reducing the dissonance. In addition it was demonstrated that individuals also reduced their dissonance by altering their beliefs and attitudes.

The impact of dissonance was demonstrated in a variety of social circumstances, for instance the so-called forced compliance situation (e.g. Zanna & Cooper, 1974). In this paradigm, subjects holding some cognitive belief *X* are instructed to act as if non-*X* (e.g., in an essay defend a thesis non-*X* although they actually believe *X*). Writing an essay against one’s own conviction obviously induces dissonance. Subjects are consequently rewarded for their ‘counterattitudinal’ behavior. If the subjects experience their commitment in the procedure as voluntary they tend to reduce their dissonance by changing their attitude about *X* in the direction of non-*X*. Thus, dissonance theory could explain the astonishing finding that the higher the reward for the subjects the less did they change their attitudes—the explanation being that high reward for counterattitudinal behavior arouses the lowest degrees of dissonance.

In most non-laboratory situations, several different strategies may be available that can reduce dissonance. Which of these will be chosen? Social psychologists have consequently defined a measure of ‘change resistance’ of single cognitions to predict the preferred strategy of dissonance reduction: those cognitions will be altered first whose change resistance is lowest.

A recent application of dissonance theory and systems theory to clinical psychology addressed the dissonant relationships among an individual patient’s plans and goals (Grawe, 1996). This ‘inconsistency’ was viewed as being responsible for psychological suffering and disorders because it favored the generation of psychopathological attractors, the presenting problems of patients. Accordingly it was proposed that the task of psychotherapy is to provide or enable resolution of such inconsistency.

Dissonance theory presents us with a further approach with potentially many psychological applications. In the context of this chapter, we recognize that dissonance theory is again in agreement with the idea that self-organized behavior reduces gradients. The various behavior patterns investigated in social psychology tended to reduce dissonance, whereas self-organized patterns reduce non-equilibrium gradients. The concept of change resistance was introduced to predict the direction dissonance reduction was likely to take—this is congruent with 'the most efficient pathway' (see section 3 above) that is preferred by dissipative non-equilibrium systems. All in all, we therefore propose that dissonance can be defined as a specific gradient effecting social and cognitive systems. Realizing the close connection of dissonance with the view that gradients control pattern formation, we suggest to use the bulk of literature on dissonance as a reservoir to show under which conditions gradients lead to changes of cognitive organization.

4.3 Gradients in perception

Many illustrative examples of pattern formation in perception have been presented by Gestalt psychology. In any of the various Gestalt displays, the extraction of figures from a background can be observed introspectively. A striking example is apparent motion: if two near-by lamps are flashed alternatively, the phenomenological impression is not that of two lamps ignited alternatively but that of one lamp moving from place to place (phi-phenomenon, Wertheimer, 1912). If several such lamps are mounted in a circle, the perception is of circular apparent motion moving either clockwise or counterclockwise (and sometimes back and forth). Thus, bistable and multistable perceptual events can be generated experimentally. 'Gestalt flips' are then a common finding—established Gestalt perceptions break down after a certain time and give way to the alternative perception.

Several authors have recently pointed to the similarity of Gestalt formation and pattern formation as described by synergetics (Haken & Stadler, 1990). Perceivers of bistable stimuli, for instance, report the fingerprints of nonlinear phase transitions such as hysteresis and critical slowing down of relaxation behavior close to instability. Without going into detail here, we may denote this approach as the synergetic view of Gestalt perception. This approach states that the cognitive processes active in Gestalt perception are based on a process of self-organization. This premise consequently opens up many possibilities to study the relationship between gradients and Gestalt perception.

The initial step must be to operationalize 'gradients' in perceptual tasks such as those generating apparent motion perceptions or other Gestalt perceptions. The predictions proposed above could then be tested empirically. The optimal (most efficient) ways to dissipate the gradients in perception have been termed ‘good’ or ‘pregnant’ Gestalts. It has been shown repeatedly that in experiments using multistable displays the more pregnant Gestalts are usually perceived first. After a certain period of time, though, the perceptual system switches to alternative Gestalts even if these are less pregnant. If Gestalts are conceptualized as self-organized cognitive patterns this observation is consistent with the prediction that Gestalts reduce gradients; as soon as the gradients are reduced below a certain threshold a flip event is likely to occur.

What would folk psychology say?—discovering Gestalts in your surroundings is a matter of curiosity, and depends on a vigilant state of mind. Therefore, watching an apparent motion display that holds but few possible Gestalts becomes boring after a while. The resulting impressions will be less arousing with the passage of time, the stimulation less salient—therefore the time you will invest into any single Gestalt perception becomes shorter and shorter. This is actually what is reliably found in experiments: flip times are decreasing monotonously in a single individual (e.g. Kruse et al., 1992). Curiosity/vigilance may be viewed as the gradient that causes Gestalt perception in the first place, and that will then vanish unless something totally new happens. Various psychological terms address such a process in one way or the other, such as habituation, saturation, or extinction.

A further step consists of investigating the neuronal activity correlated with these phenomena. Struber et al. (2000) have shown that gamma-band enhancement is found in the EEG during flip events, especially in subjects with higher rates of switching. Müller et al. (1999) conducted an EEG study of apparent motion perception, finding a slowing of EEG main frequency immediately prior to the flip and a frequency overshoot after the event. They interpreted the initial frequency decrease as a sign of thalamic deactivation (decreased vigilance), followed by an arousal reaction (signaled by desynchronization, i.e. higher frequency) due to the Gestalt flip. This is quite close to the folk psychology explanation.

Varela (1995), in a more general context, connected attention with gamma-band activity—gamma frequencies function as a ‘neuronal glue’ that forms transient aggregates of cells in the cortex, the cell assemblies. He sees gamma-induced synchrony as the hallmark of “nonstationary processes that self-organize into cognitive aggregates in a fraction of a second”. Therefore, thalamic activity (linking the cortex with the ascending reticular system) can be viewed as a gradient that induces cortical pattern formation experienced as perception of a Gestalt. The established Gestalt (or rather, its neuronal correlate, the cell assembly) in turn consumes this gradient. Gestalts thus deplete the attentional resources that launched their own evolution in the first place, a nice demonstration of ‘second circularity’ dynamics described above in section 3.

5 Discussion

Control parameters, valences, affordances, vigilance, etc., are all of the same kind—they are non-equilibrium gradients. Gradients act on complex systems of various realms, driving these systems towards pattern formation. The evolving patterns lie within certain bounds as they must constitute a compromise between which patterns can possibly be built from the systems components to begin with, and the structural constraints of the environmental situation. Such patterns are *emergent* productions of these systems, because they are determined neither by the components, nor the gradients, nor the environmental constraints alone. For this reason one may speak of self-organization.

In the context of cognitive science, the essential point of self-organized pattern formation is its *functionality* with respect to its environment. Functionality rests in the fact that the patterns consume the gradients that caused their evolution, and they consume them in the most efficient manner. This makes pattern formation of this sort appear 'intentional', while at the same time pattern formation does not conflict with the laws of natural science, especially not with the second law of thermodynamics. Therefore, we have suggested that self-organization phenomena may be considered basic explanations of the adaptive, intentional, and purposive functioning of many complex systems, especially of cognitive, biological, and social systems.

It has been observed that during the last decades psychology had moved from considering 'hot', motivational cognition towards 'cold' cognition, i.e. information processing. We hold that the investigation of gradients and valences tells a different story—cognitive pattern formation can be understood more appropriately if we assume that we deal with systems removed from equilibrium. Their driving forces are always motivational gradients. Thus, there is probably no such thing as cold cognition (Ciompi, 1982).

Contemporary cognitive science, especially in studies of consciousness, introduced the distinction between the 'easy' and the 'hard' questions (Chalmers, 1996; Carter, 2002). According to this distinction, we have dealt with 'easy' functionality issues in this chapter, namely the question of 'How can self-organizing complex systems model intentional cognition?'. We believe that synergetics can provide the template to study and ultimately answer these questions. Our systems-theoretical approach may be labeled 'apparent intentionality' (apparent motion being a paradigmatic, well-studied Gestalt phenomenon). The hard problem, however, lies with qualitative experience—what it is like to be a conscious 'self' in the here-and-now, what it is like to perceive an emotion, to possess free will, etc. (Beckermann, 2001). Does real intentionality exist? Answering the questions of qualia is probably beyond the horizon of scientific systems theory.

References

Beckermann A (2001). Analytische Einführung in die Philosophie des Geistes. Berlin: de Gruyter.

Bianciardi C & Ulgiati S (1998). Modelling entropy and exergy changes during a fluid self-organization process. *Ecological Modelling*, *110*, 255-267.

Carter R (2002). Consciousness. London: Weidenfeld & Nicolson.

Chalmers D (1996). The conscious mind. Oxford: Oxford University Press.

Ciompi L (1982). Affektlogik. Stuttgart: Klett-Cotta. (published in English (1988): The psyche and schizophrenia. The bond between affect and logic. Cambridge MA: Harvard University Press).

Clancey WJ (1993). Situated action. A neurophysiological interpretation response to Vera and Simon. *Cognitive Science*, *17*, 87-116.

Clark A (1997). Being there: Putting brain, body, and world together again. Cambridge: MIT Press.

Dennett DC (1987). The intentional stance. Cambridge: MIT Press.

Dennett DC & Kinsbourne M (1992). Time and the observer: The where and when of consciousness in the brain. *Behavioral and Brain Sciences*, *15*, 183-247.

Festinger L (1964). Conflict, decision, and dissonance. Stanford: Stanford University Press.

Gibson JJ (1979). The ecological approach to visual perception. Boston: Houghton Mifflin.

Gollwitzer PM & Bargh GA (eds) (1996). The psychology of action: Linking Cognition and Motivation to Behavior. New York: Guilford.

Grawe K (1998). Psychologische Therapie. Göttingen: Hogrefe.

Haken H (1983). Synergetics—An introduction. Berlin: Springer.

Haken H (1996). Principles of brain functioning: A synergetic approach to brain activity, behavior, and cognition. Berlin: Springer.

Haken H (2000). Information and self-organization: A macroscopic approach to complex systems. Berlin: Springer. (2nd ed.)

Haken H, Kelso J, & Bunz H (1985). A theoretical model of phase transitions in human hand movements. *Biological Cybernetics*, *51*, 347-356.

Haken H & Stadler M (eds) (1990). Synergetics of cognition. Berlin: Springer.

Kelso JAS (1995). Dynamic Patterns: The self-organization of brain and behavior. Cambridge: MIT Press.

Kruse P, Stadler M, Pavlekovic B, & Gheorghiu V (1992). Instability and cognitive order formation: Self-organization principles, psychological experiments, and psychotherapeutic interventions. In: Tschacher W, Schiepek G, & Brunner EJ (eds), Self-organization and clinical psychology, (102-117). Berlin: Springer.

Kruse P & Stadler M (eds) (1995). Ambiguity in mind and nature. Berlin: Springer.

Lewin K (1936). Principles of topological psychology. New York: McGraw-Hill.

Lewin K (1926). Vorsatz, Wille und Bedürfnis. *Psychologische Forschung*, *7*, 330-385.

Luhmann N (1984). Soziale Systeme: Grundriß einer allgemeinen Theorie. Frankfurt: Suhrkamp.

Maturana HR & Varela FJ (1980). Autopoiesis and cognition: The realization of the living. Dordrecht: Reidel.

Miltner W, Braun C, Arnold M, Witte H, & Taub E (1999). Coherence of gamma-band EEG activity as a basis for associative learning. *Nature*, *397*, 434-436.

Müller TJ, Federspiel A, Fallgatter AJ, & Strik WK (1999). EEG signs of vigilance fluctuations preceding perceptual flips in multistable illusionary motion. *NeuroReport*, *10*, 3423-3427.

Newell A & Simon HA (1972). Human problem solving. Englewood Cliffs NJ: Prentice-Hall.

Nicolis G & Prigogine I (1977). Self-organization in non-equilibrium systems. New York: Wiley.

Pfeifer R & Scheier C (1999). Understanding intelligence. Cambridge: MIT Press.

Port R & van Gelder TJ (eds) (1995). Mind as motion: Explorations in the dynamics of cognition. Cambridge MA: MIT Press.

Robertson LC (2003). Binding, spatial attention and perceptual awareness. *Nature Reviews Neuroscience, 4*, 93-102.

Rodriguez E, George N, Lachaux J-P, Martinerie J, Renault B, & Varela FJ (1999). Perception's shadow: Long-distance synchronization of human brain activity. *Nature*, *397*, 430-433.

Schneider ED & Kay JJ (1994). Life as a manifestation of the second law of thermodynamics. *Mathematical and Computer Modelling*, *19*, 25-48.

Singer W & Gray CM (1995). Visual feature integration and the temporal correlation hypothesis. *Annual Review of Neuroscience*, *18*, 555-586.

Struber D, Basar-Eroglu C, Hoff E, & Stadler M (2000). Reversal-rate dependent differences in the EEG gamma-band during multistable visual perception. *International Journal of Psychophysiology*, *38*, 243-252.

Swenson R & Turvey MT (1991). Thermodynamic reasons for perception-action cycles. *Ecological Psychology*, *3*, 317-348.

Thelen E & Smith LB (1994). A dynamic systems approach to the development of cognition and action. Cambridge: MIT Press.

Thomasson N, Pezard L, Allilaire J-F, Renault B, & Martinerie J (2000). Nonlinear EEG changes associated with clinical improvement in depressed patients. *Nonlinear Dynamics, Psychology, and Life Sciences*, *4*, 203-218.

Tschacher W (1997). Prozessgestalten. Göttingen: Hogrefe.

Tschacher W & Dauwalder J-P (eds) (1999). Dynamics, synergetics, autonomous agents—nonlinear systems approaches to cognitive psychology and cognitive science. Singapore: World Scientific.

Tschacher W & Scheier C (2003). Der interaktionelle Ansatz in der Kognitionswissenschaft: Eine Positionsarbeit zu Konzepten, Methoden und Implikationen für die Psychologie. *Zeitschrift für Psychologie*, *211*, 2-16.

Tschacher W, Scheier C, & Hashimoto Y (1997). Dynamical analysis of schizophrenia courses. *Biological Psychiatry*, *41*, 428-437.

Varela FJ (1995). Resonant cell assemblies: A new approach to cognitive function and neuronal synchrony. *Biological Research*, *28*, 81-95.

Wertheimer M (1912). Experimentelle Studien über das Sehen von Bewegungen. *Zeitschrift für Psychologie*, *61*, 165-292.

Zanna MP & Cooper J (1974). Dissonance and the pill: An attribution approach to studying the arousal properties of dissonance. *Journal of Personality and Social Psychology*, *29*, 703-709.

Zeigarnik B (1927). Über das Behalten von erledigten und unerledigten Handlungen. *Psychologische Forschung*, *9*, 1-85.