Chapter 3
Self-organization and Design as a Complementary Pair

J.A. Scott Kelso, Egbert Stolk and Juval Portugali

Abstract Self-organization implies that order and regularity can come into being (emerge) spontaneously as a purely bottom-up process. Design implies the exact opposite: that order and organization come into being by virtue of a designer in a top-down manner. In this paper we treat these apparent contraries as a complementary pair, and use the notion of SIRN to show how they may coexist.

3.1 Introduction

At first blush, the title invites a contradiction: self-organization implies that order and organization can come into being (emerge) spontaneously as a bottom-up process, whereas design usually means the exact opposite, namely that order comes into being by virtue of a designer in a top-down, pre-planned manner. Neither side of the dichotomy is quite true: self-organization requires both Bottom-up and top-down processes (somehow initial conditions, parameters must be set) and design ignores bottom-up collective effects at its peril. In the spirit of "Contraria sunt complementa"—the words on the coat of arms of the great Danish physicist Niels Bohr—we aim to treat design and self-organization as a complementary pair.

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We use the notion of SIRN (Synergetic Inter-representation networks) to show how apparent contraries may coexist in practice. The notion of SIRN integrates Synergetics, which is Haken's (Haken 1983) theory of self-organization in open, nonequilibrium systems, with the notion of IRN (inter-representation networks) as introduced by Portugali (1996). The scientific basis for complementary pairs comes from Coordination Dynamics (Kelso 1995; 2009) itself grounded in theories of self-organization in physics, chemistry and biology but tailored specifically to the functions of animate, living things (moving, perceiving, feeling, thinking, deciding, learning, remembering, etc.) on multiple levels of description (neural, behavioral, cognitive, social, etc.). The paper starts with a section on Synergetics, IRN and the HKB model (Sect. 3.2). Section 3.3 is about complementary pairs and their scientific underpinnings which lie in *metastable* coordination dynamics. In Sect. 3.4 self-organization ~ design is described as a complementary pair. The paper concludes with some remarks on future research (Sect. 3.5).

3.2 Synergetics, IRN and the HKB Model

Synergetics—the science of structure—focuses on how the many microscopic parts of a complex system work together to produce structure and pattern at a macroscopic scale. As such it is one of the founding theories of complex systems (Haken 1983). Since its early beginnings in laser theory in physics, synergetics has embraced a wide spectrum of domains ranging from chemical clocks, biological pattern formation, the economy, cognition, brain function and even the sociology of science itself (Haken, 1984)—as well as society and of course cities (Portugali 2011).

As a means of understanding, the concepts and methods of synergetics were developed in the context of specific phenomena that became its basic paradigms: the laser paradigm, the fluid dynamic paradigm, the pattern recognition paradigm, and the finger-movement paradigm. The scenario common to all the various cases may be described as follows: A given internal or external control parameter that is acting on the system promotes or enhances interaction between the system's many parts. The resulting motion may be interpreted as a consequence of several systemic partially ordered states competing among themselves. When the control parameter crosses a certain threshold, the hitherto rather chaotic form of motion suddenly and spontaneously gives rise to a coherent movement and interaction where all the parts behave in concert. This coherent movement, which can be precisely quantified, is called an *order parameter*. The process by which the many parts abruptly "obey" the order parameter and in this way support and reproduce it is called the *slaving principle*. This is illustrated in Fig. 3.1. In Haken's (1984) words (for the case of the laser):

> Because the order parameter forces the individual electrons to vibrate exactly in phase, thus imprinting their actions on them, we speak of their "enslavement" by the order parameter. Conversely, these very electrons generate the light wave, i.e. the order parameter, by their uniform vibration.

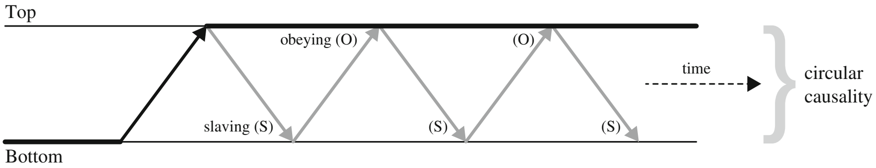

Fig. 3.1 The local interaction/synergy between parts (*bottom*) gives rise to an order parameter (*top*) that then enslaves the behavior of the parts (*bottom*). By 'obeying', the parts strengthen and reproduce the order parameter and so on in a so-called circularly causal fashion

It is easy to imagine how one may substitute other kinds of parts (e.g. neurons, muscles, molecular species, individuals producing a wave, etc.) in other kinds of system (brains, chemical reactions, social settings, etc.) for the same circularly causal principle to be applied.

3.2.1 Inter-representation Networks

IRN (inter-representation network), the second component of SIRN, started from the observation that many cognitive processes that cannot be executed by a single cognitive act are implemented by a sequential interaction between internal representations constructed in the minds/brains of people and external representations constructed by them in the world in the form of utterances, texts, drawn figures and the like (Portugali 1996).

In developing SIRN, Haken and Portugali (1996) formulated a general SIRN model that is illustrated in Fig. 3.2 (right). This general SIRN model can be seen as symbolizing a complex self-organizing active agent—say, a designer—that is

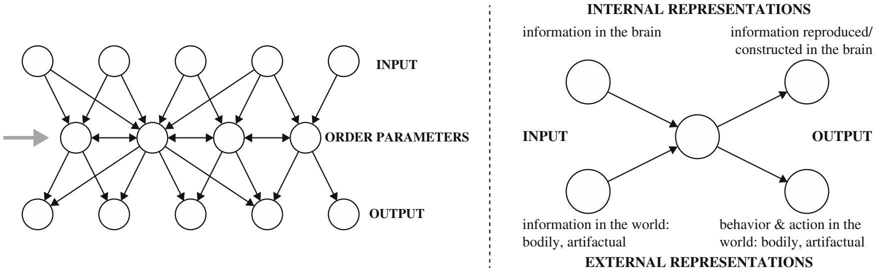

Fig. 3.2 *Left* Haken's synergetic computer. *Right* The basic SIRN model as derived from the synergetic computer. SIRN symbolizes a self-organizing agent that on the one hand is subject to two forms of information (internal and external) and on the other actively constructs two forms of information, again internal and external. It is obvious that the SIRN model is a transformation of the synergetic computer: to appreciate this, view the latter from the side (*grey arrow*), make the distinction between internal and external representations and rotate it 90° counterclockwise

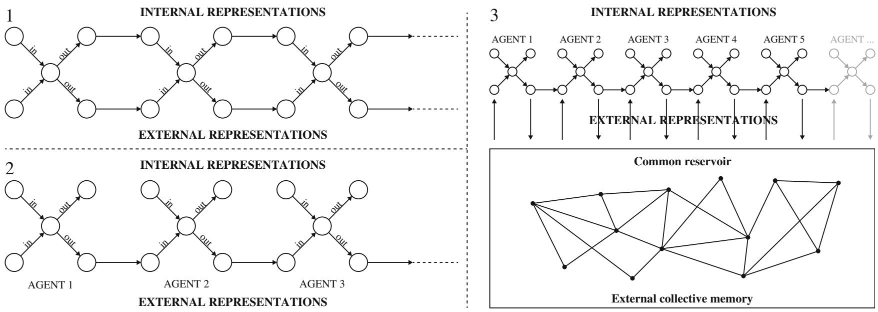

Fig. 3.3 Three SIRN sub-models. *1* the intrapersonal model; *2* the interpersonal-sequential model; and *3* the interpersonal-collective model

subject to two flows of information: internal and external. The first is coming from the mind/brain, in the form of ideas, fantasies, dreams, thoughts, imagination, emotions and the like, while the second comes from the ‘world’ via the senses, the agent’s body and/or artifacts. The interaction between these flows gives rise to an order parameter that governs the agent’s action and behavior, as well as the feedback information flow to the agent’s mind. In an analogous fashion, the ‘feedback information flow’ refers to the formation of internal representations, such as images or learned patterns. The order parameters are determined by a competition along the lines of synergetic pattern recognition.

In order to apply the general SIRN model to specific case studies, Haken and Portugali (1996) derived three prototypical sub-models that refer to three principal cognitive contexts: the *intrapersonal*, the *interpersonal-sequential*, and the *interpersonal collective,* as shown in Fig. 3.3. The first refers to a solitary agent, the second to the sequential dynamics of several agents, and the third to the simultaneous interaction among many agents.

3.2.2 The Classical HKB Model of Coordination Dynamics: Multistability and Phase Transitions

The most primitive form of self-organization in nature’s open systems is the non-equilibrium phase transition (Haken 1983). Near instabilities where patterns form and change, certain features are predicted such as critical slowing down (when the system is perturbed it takes longer and longer to restore the value of the order parameter) and fluctuation enhancement (the variability of the system’s state increases dramatically as a critical point approaches). Can such signatures of self-organization be found in complex, biological systems? This is important because—consistent with the present theme—the observed order and regularity in living systems is often attributed to a designer-like ‘plan’ or ‘program’ (usually located inside the system) that is said to be responsible for the order and regularity

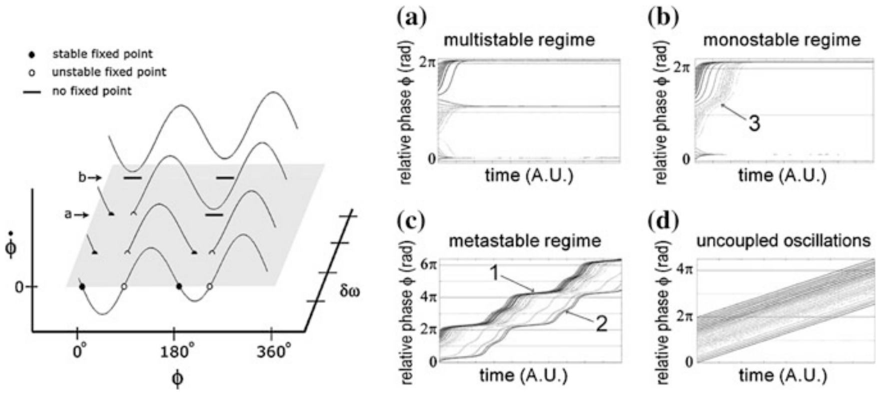

Fig. 3.4 Multi- and metastable coordination dynamics: *Left* The broken symmetry version of the HKB model [12]. δω represents the heterogeneity of the individual coordinating elements. At low values of δω there are two stable fixed points (*solid circles*), resulting in a bi-stable regime. At (*a*) due to changes in control parameters one of the two fixed points disappears and the system switches spontaneously from being bi-stable to being monostable. At (*b*) a saddle node or tangent bifurcation occurs and all fixed points disappear, yet remnants or ghosts of the attracting and repelling fixed points remain. This is the metastable regime. *Right* The four different types of dynamical trajectories. Note the dwell ~ release dynamics characteristic of metastability where the trajectories pause near places where the stable fixed points used to be. Image source (Engstrøm and Kelso 2008, Figs. 1 and 2)

observed. The Haken-Kelso-Bunz (HKB) model (Haken et al. 1985) and its stochastic, Fokker-Planck version (Schoner, Haken & Kelso 1986) were formulated to account for the discovery of nonequilibrium phase transitions in human bimanual coordination (Kelso 1984) (the so-called finger movement paradigm referred to earlier)—a clear demonstration of self-organized behavior in an individual person. Phase transitions and associated phenomena were also found in experiments in which individuals had to coordinate their body with external stimuli (Kelso et al. 1990) and even between two people when they spontaneously coordinated with each other (Schmidt et al. 1990). The HKB model uses concepts of synergetics (order parameters/collective variables, control parameters, instability, etc.) and the mathematical methods and tools of nonlinearly coupled dynamical systems (attractors, bifurcations, fluctuation measures, relaxation times, etc.) to account for self-organized behavior at both cooperative, coordinative levels and at the level of the individual coordinating elements. The system's dynamics may exist in monostable or multistable regimes (see Fig. 3.4 right, a and b) (Kelso 2008). Engstrøm and Kelso (2008) describe the essence of multistability as follows:

> In the case of multistability, which attractor is reached in the multistable regime primarily depends on initial conditions. Once the system has settled into an attractor, a certain amount of noise or a perturbation is required to achieve a switching to another attractor. If control parameters such as attention or frequency are modified, a bifurcation or phase transition from multistable to monostable states and vice versa may occur.

3.2.3 *The Extended Version of the HKB Model: Metastability*

In complex systems, component parts and processes are seldom identical–structurally or functionally. If left to its own devices, each participating element will tend to display its own intrinsic behavior. Such heterogeneity breaks the (spatiotemporal) symmetry of the HKB model and changes its entire dynamics (Kelso 1995; Kelso et al. 1990). One truly novel outcome is that the combination of coupling and symmetry breaking (represented in extended HKB as $\delta\omega$, cf. Fig. 3.4) can give rise to *metastability*. In the metastable regime all the fixed points, whether stable or unstable, have vanished. Yet the formerly stable fixed points act as magnets or *tendencies* or *dispositions* that can be quantified by the distribution of their *dwell* times and *escape* times. Engstrøm and Kelso (2008) describe the essence of metastability as follows:

> …in the metastable regime of coordination dynamics, successive visits to remnants of the fixed points are intrinsic to the time course of the system, and do not require any external source of input (Kelso 1995). This is an important difference between multistability and metastability, and likely translates into palpable differences in fidelity of performance, as a system in its metastable regime isn't hindered by fixed point behavior, while a multistable regime is. An important point—especially for those who study multistable phenomena—is that the extended HKB model of coordination dynamics captures both multistability and metastability.

Although Kelso and colleagues focus on brain dynamics in their research on the *metastable brain* (Kelso 2001, 2012; Tognoli & Kelso 2014), metastability is not viewed as limited to the level of human brain and behavior, but is proposed to be an essential property of all complex systems (Kelso 1995; 2009).

3.3 Complementary Pairs

Kelso and Engstrøm describe a "philosophy of complementary pairs" in their book *The Complementary Nature* (Kelso and Engstrøm 2006). Complementary pairs are those things, events and processes in nature that may appear to be contraries, due in part to our ubiquitous tendency to dichotomize, but are mutually related and inextricably connected. Kelso and Engstrøm introduce the tilde or squiggle (~) to indicate the complementary nature of a complementary pair, to emphasize the *dynamical* and *relational* nature of the two aspects of a complementary pair. These apparently polarized entities are referred to as *complementary aspects* (ca1 and ca2 in Fig. 3.5). For example, body and mind are complementary aspects of the complementary pair body ~ mind. The general idea is that contraries are complementary, not contradictory (though one should be careful with language; complementary and contradictory may themselves be viewed as a complementary pair!). Importantly, it is not only the polar complementary aspects of complementary pairs that matter, but also all the stuff and all the action falling in between

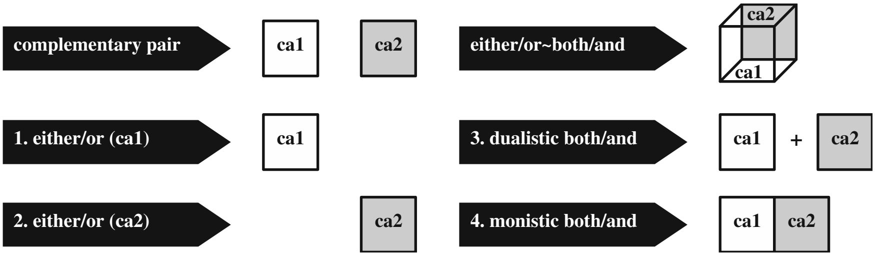

Fig. 3.5 Kelso and Engstrøm's illustration of four basic interpretations of complementary pair *ca1* ~ *ca2* and their reconciliation. Image source (Kelso and Engstrøm 2006, Fig. 1)

them. In Fig. 3.5 four basic interpretations of a complementary pair ca1 ~ ca2 are given. The Necker-cube represents the inextricable relation between the complementary aspects.

The scientific basis of complementary pairs stems from metastable coordination dynamics: "in coordination dynamics, where apartness and togetherness coexist as a complementary pair—where a whole is a part and a part is a whole—there are no equilibria, no fixed points at all." (Kelso and Engstrøm 2006, p. xiv). Multistability ~ metastability and states ~ tendencies are considered key complementary pairs of coordination dynamics. Engstrøm and Kelso conclude: "to gain more understanding of the mechanisms of metastability, it seems necessary to invent new strategies that study metastable coordination patterns in different fields, systems and levels, and to establish criteria for the differentiation of state transitions and patterns of converging ~ diverging dwell ~ escape behaviors" (Engstrøm and Kelso 2008).

3.4 Self-organization~Design

3.4.1 Design Thinking

Design Thinking, or Design Cognition, is a domain of research that studies the general process of design as it is implemented in various domains ranging from engineering to architecture, crafts, arts and more. Stolk and Portugali (2012), Portugali and Stolk (2014) suggest that designing is a *cognitively complex activity*. Such an activity starts with a vague idea in mind that is externalized by sketching/drawing, followed by interplay between several internal and external representations.

In the practical process of design, designers need to constrain the so-called *design-space*. For this purpose they often impose a (top-down) *primary generator* or use bottom-up opportunistic design strategies or combinations of both. By doing so designers explore the 'design territory' in which the design problem and solution co-evolve (Dorst and Cross 2001). (Note problem ~ solution are a complementary pair).

The design medium, as an active participant in the design process, is highly relevant for the outcome. Sketching, for example, is known for its ambiguous nature, offering emergent properties that were not intentionally put there (Tversky and Suwa 2009). Computer models are known to lead to fixation in the design process, but can be useful to complement the limitations of our mind ~ brain (Mallgrave 2010). Internally, associative memories, precedent knowledge and design expertise can play a crucial role. Reading between the lines, the domain of Design Thinking shares a lot of properties with SIRN (Portugali and Stolk 2012).

The focus of the domain of Design Thinking was always the individual designer and small-scale objects (relative to the human body). Recently, however, we see a growing interest in collective design and the entire context surrounding the design situation. What is still lacking is a focus on the design of large-scale objects such as cities.

3.4.2 SIRN Design: Three Forms of Design Processes

Derived from the general SIRN model the above noted SIRN sub-models suggest to Design Thinking three forms of design that correspond to the three aspects through which design may be said to be complex (Portugali and Stolk 2014): the *intrapersonal SIRN design process* implemented as it is by a single designer corresponds to the fact that the designer is a complex system; the *interpersonal-sequential SIRN design model* that is specifically appropriate to model the space-time evolution and/or diffusion of design forms and styles corresponds to the property that the design situation is a complex system; and finally the *interpersonal-simultaneous SIRN design process* that is implemented as a group dynamics by several designers working together (but also by a single urban designer), corresponds to the finding that in the case of cities and urban design, the designed object—for instance the city—is itself a complex system.

3.4.3 Self-organization~Design at Three Complementary Levels

From The Complementary Nature we learn to look at a (seemingly) contrary pair as consisting of two complementary aspects of a single complementary pair—in our case the *self-organization aspect* and the *design aspect* of the self-organization ~ design pair. From SIRN we learn to describe the urban design process on three interrelated levels. These relate to two complementary pairs: intrapersonal ~ interpersonal and sequential ~ simultaneous—which link the three sub-models as shown in Fig. 3.6.

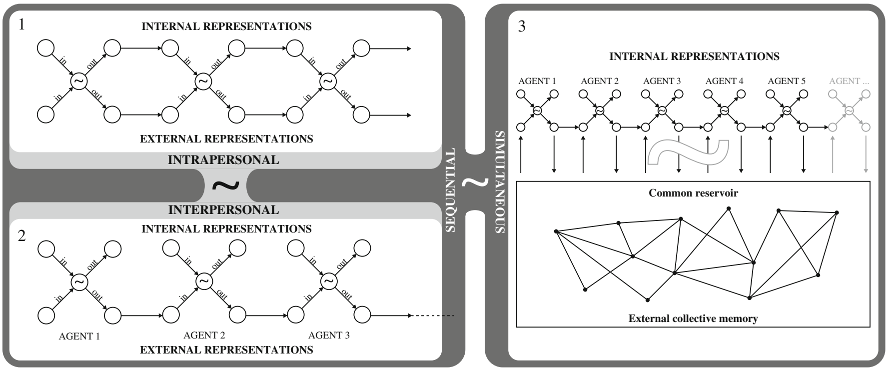

Fig. 3.6 The three SIRN sub-models as a related metastable ∼ multistable system (see text for discussion)

Describing *self-organization ∼ design* as a complementary pair within the context of the three SIRN sub-models offers a new understanding of the designer and its context. Firstly, the design process consists of the complementary pair *internal ∼ external representation*, as briefly described in Sect. 3.4.1. Here we find some other complementary pairs. *Ambiguity ∼ clarity* refers to the different types of representation used in design. The concept of fixation is part of the *fixation ∼ flowing* pair–where the concept of 'flow' implies a metastable state of mind, guided by tendencies, while the concept of 'fixation' implies a mono/multistable state of mind, fixed by states. Another distinction is made between analysis and synthesis, describing them as different, time-bound phases as commonly used in Design Thinking literature (Braha and Maimon 1997). *Analysis ∼ synthesis* suggests that designers actually apply both at the same time, as noticed by some experienced practicing designers/architects (Kleijer 2004). Secondly, the *intrapersonal ∼ interpersonal* pair gives an idea about the *designer ∼ design* situation. And thirdly, in the case of urban design, it gives a hint about the coordination dynamics of *individual ∼ group* designer(s) and the *human ∼ environment* or more specifically *urban designer ∼ city.*

3.5 Concluding Remarks

This short paper is a first exploration of the relation between the concepts of complementary pairs, metastability, synergetic inter-representation networks and (urban) design. The contradiction of top-down design and bottom up self-organization vanishes in light of the complementary pairs and SIRN: bottom-up and top-down are complementary, not contradictory. This view needs to be and will be extended and elaborated in more depth, to come up with a more comprehensive view on the three SIRN levels of urban design. Nevertheless, it can be concluded that such a perspective has the potential to shed new light on the process of (urban) design—a design field without, as yet, a strong tradition of explicit theorizing from a self-organizing ~ design-thinking point of view. At the same time, urban designers have developed ways of dealing with complex systems in a more implicit way, which can inspire scientists to come up with useful insights on the dynamic nature of urban design. If designers will learn to exploit their multistable ~ metastable mental capabilities better, by not sticking to contraries as contradictions or polarized opposites, they might face the challenges of the rapid urbanization worldwide in a more effective way.[1]

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[1] Throughout the *2nd Delft International Conference on Complexity, Cognition, Urban Planning and Design*, one is struck by the relevance of complementary pairs and their (coordination) dynamics in numerous presentations and contexts. A few examples in no particular order are: Design cannot be a solitary activity (Batty: solitary ~ team, individual ~ collective). Cities create creativity; there is spatialization of the social and socialization of the spatial (Hillier, social ~ spatial, boundary ~ domain). Termite architecture; a balance of thermodynamically forward flux (TFF) and physiological flux(PF) (Turner, dispersal ~ deposition; homeostasis ~ homeodynamics; intensive ~ extensive). Rats exploring novel environments (Hediger, repeated routes ~ creating places). The brain's maps and neural networks (Haggard, cognitive ~ affective, unity ~ diversity, symbolic ~ dynamical; syntax ~ semantics). Knowledge and uncertainty (Sela, ontological ~ epistemological). Working with water, the Delta, 'in between' zones (Meyer, layered ~ rhythmic, spatial ~ temporal, past ~ future, dispersion ~ deposition, slow modes ~ fast modes). Cities as Complex (Portugali, artifactual ~ natural, potentialities ~ possibilities, simple ~ complex, parts ~ together, this contribution). The City in history, the built environment (Harbruken, simple ~ complex, unifying principles ~ diverse mechanisms; stasis ~ change; rules ~ dynamics; create ~ reproduce, variety ~ consensus, modularity(parts) ~ design (whole).

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