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Cities Do Not Emerge from the Bottom Up

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Abstract

As indicated by its title, this study challenges the common view that as complex systems cities emerge from the bottom up. It suggests, firstly, that this common view is a consequence of applying the various complexity theories to the dynamics of cities by means of analogy to material media, namely to complex systems such as Benard cells or laser. Secondly, it suggests that when examining cities from first principles of human media that concern cognition, behavior and brain dynamics, cities emerge in a top-down manner. Thirdly, it suggests that the dynamics of cities are characterized by the simultaneous co-existence of bottom-up and top-down processes so that the question is not bottom-up or top-down, but rather how these apparently negating processes co-exist.

Keywords: complexity theories of cities; Schrödinger's *What is Life?*; order from order; synergetic cities; hybrid complex systems; internal negations

1. Introduction

The last decades have witnessed the emergence of complexity theory and, associated with it, the rise of *complexity theories of cities* (CTC)—a domain of research that applies the various theories of complexity to the study of cities [1]. The core view in these applications is that analogically to material complex systems, such as the Bénard cells [2] or Belousov–Zhabotinsky (BZ) Reaction [3], cities, too, emerge from the bottom up out of the interaction between their parts—the urban agents—a view that became a kind of a mantra in the domain of CTC. In what follows I show that this is not the case, namely, that cities represent a new kind of medium with a new message: *hybrid complex systems* (HCS). As HCS, cities do not emerge from the bottom up nor from the top down. Rather the dynamics of cities are typified by the co-existence of bottom-up and top-down processes that can be interpreted in several ways that are described below.

Interestingly, this view is in line with one of the forerunners of complexity theory—quantum physicist Arwin Schrödinger, Nobel laurate in physics 1933. However, this is not because of his contributions to quantum theory, but due to *What is Life?*—a little book he wrote a decade later [4]. The discussion below thus starts with Schrödinger's little book (Section 2). It then describes the emergence of the common view—the bottom-up mantra (Section 3). Next, Section 4, briefly introduces the view from Synergetics that somewhat differs from the other complexity theories: first, Synergetics' laser-oriented first foundation as a bottom-up approach, and then Synergetics' cognition- and brain-oriented second foundation as a top-down approach. These two approaches were applied to cities giving rise to the domain of Synergetic cities introduced in Section 5.

Synergetic cities started, like the other CTCs, as a bottom-up view on cities, but then following the attempt to consult the cognitive sciences in order to better understand urban

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agents' behavior, it has developed an alternative top-down perspective on cities, closely associated with Synergetics. Four phenomena form the foundations of this top-down approach on cities: cognitive mapping, chronesthesia or mental time travel, and cognitive planning. But the most significant outcome of the consultation with cognitive sciences is the realization that cities are hybrid complex systems (HCS) and as such are qualitatively distinct from both material and living complex systems. Section 6 thus follows the studies that have gradually given rise to the notion of HCS. The notion of cities as HCS implies that the bottom-up vs. top-down tension does not represent two competing approaches to urban dynamics that negate each other but rather two processes that simultaneously coexist in the dynamics of cities. Section 7 further suggests that the bottom-up vs. top-down tension is but one among several internal negations that characterize cities as complex systems. It then explores three general approaches to deal with internal negations, while Section 8 concludes the discussion by illustrating how each of the three refers to bottom-up vs. top-down processes.

2. Schrödinger's *What Is Life?*—A Forerunner of Complexity Theory

Erwin Schrödinger is famous for his contributions to quantum theory for which he received the Nobel in 1933, for his thought experiment *Schrödinger's cat* that became very popular, and also for his little book *What is Life?* [4], that suggests a view from the medium 'physics' on the medium 'life'; in his words on "the marvelous faculty of a living organism".

As shown [1], this little book can be considered a forerunner of complexity theory for introducing two properties of life that at a later stage became two conceptual pillars of complexity theory: First, an open system that interacts with, and extracts order from, its environment. Second, 'order from disorder' which in the parlance of complexity was rephrased to 'order out of chaos' (e.g., the title of Prigogine and Stengers' book [5]). But there is a third property of complexity in Schrödinger's little book—the tension between 'order from disorder' vs. 'order from order' which is, in fact, the tension between bottom-up vs. top-down processes that forms the focus of the present study.

At first glance, suggested Schrödinger, the phenomenon of life defies the second law of Thermodynamics according to which a closed material system tends toward maximum entropy (i.e., toward maximum disorder), that is, thermodynamic equilibrium. At the same time, he further suggested, ordered material systems such as ice crystals forming from freezing water, or the phenomenon of ferromagnetism, are examples of ordered material structures arising from disordered states. The same thus might be applied to life, e.g., to a flower that, as exemplified by Haken and Portugali [6], is a highly ordered structure and complex system, arising from disordered atoms and molecules in the atmosphere and the soil (Figure 1).

But, from the perspective of Schrödinger, life in general and thus our example of a flower, do not defy the second law; rather

> it delays the decay into thermodynamical equilibrium (death) . . . by means of the process of metabolism, a living organism. . . . feeds upon negative entropy, attracting . . . a stream of negative entropy upon itself, to compensate the entropy increase it produces by living and thus to maintain itself on a stationary and fairly low entropy level. [4] (The notion of negative entropy was later termed *negentropy* by Brillouin [7])

Yet the 'order from disorder' principle is but one aspect of, or not sufficient to explain, life, according to Schrödinger: A recent study [8] draws attention to several other concepts in Schrödinger's little book that are central to CTC but have not as yet received sufficient attention; among them is the notion of *order from order* that is relevant to the present discussion. Here is Schrödinger:

> The orderliness encountered in the unfolding of life springs from a different source. It appears that there are two different 'mechanisms' by which orderly events can be produced: the 'statistical mechanism' which produces order from disorder and the new one, producing order from order.

While the 'mechanism' of 'order from disorder' is in line with physics, emphasizes Schrödinger,

> . . . we cannot expect that the 'laws of physics' derived from it suffice straightaway to explain the behaviour of living matter, whose most striking features are visibly based to a large extent on the 'order-from-order' principle.

Schrödinger's 'order from order' principle had far-reaching consequences: On the one hand, it followed what was known in the 1940s that ". . . the gene generated order from order in a species, that is, the progeny inherited the traits of the parent". Yet Schrödinger went one step further: ". . . let me anticipate", he writes, ". . . that the most essential part of a living cell-the chromosome fibre may suitably be called an aperiodic crystal. . . . which, in my opinion, is the material carrier of life." A few years later, in 1953, inspired by Schrödinger's aperiodic crystal, James D. Watson and Francis H.C. Crick determined the molecule containing human genes—the double-helix structure of DNA. In that year, on the occasion of Schrödinger's 66th birthday, H.C. Crick wrote to Schrödinger:

> Watson and I were once discussing how we came to enter the field of molecular biology, and we discovered that we had both been influenced by your little book 'What is Life?' . . . We thought you might be interested—you will see that it looks as though your term 'aperiodic crystal' is going to be a very apt one.
>
> (Quoted in [9], Chapter 4)

Schrödinger's two principles of life—'order from disorder' and 'order from order'—correspond directly to the 'bottom-up' and 'top-down' processes and both, as implied by Schrödinger's little book, play a role in complex living systems. However, as we will see in what follows, complexity theory and CTC commenced with the first principle alone while the realization and recognition of the role of the second principle entered gradually at later stages.

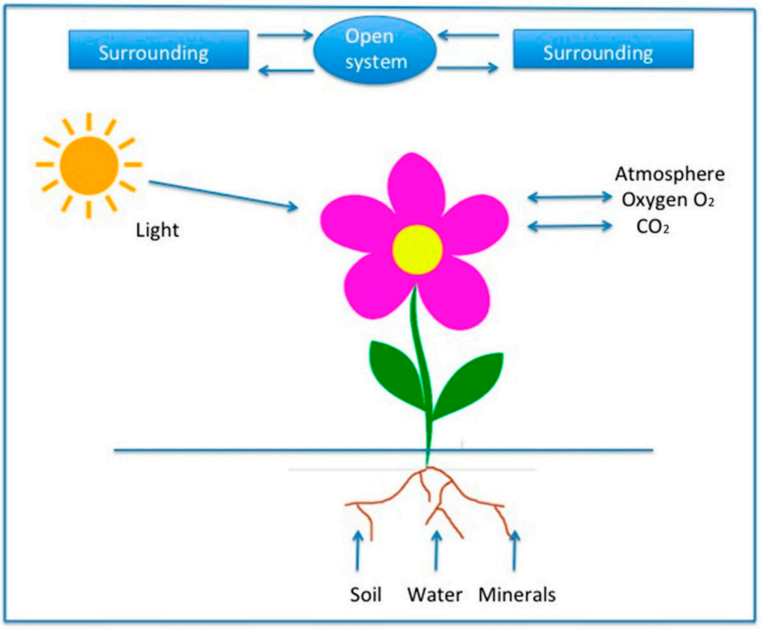


Figure 1. A flower with its surroundings as a complex system. Source: ([6], Figure 2).

3. The Emergence of a Common View

Complexity theories started to appear in the mid-/late 1960s out of thermodynamics and statistical physics and the realization that in certain situations material systems are not characterized by thermodynamic equilibrium but rather by dynamics reminiscent of living or even social systems. Cities were, from the start, associated with the various complexity theories, first as a metaphor to convey the properties of such systems. Thus, in his 1977 Nobel lecture Prigogine said the following:

> Are most types of 'organizations' around us of this nature?, [that is, characterized by thermodynamic equilibrium?]. [. . .] the answer is negative. Obviously in a town, in a living system, we have a quite different type of functional order. To obtain a thermodynamic theory for this type of structure we have to show that non-equilibrium may be a source of order.
>
> (Source: [10])

Soon after, this view that later was rephrased as *Order out of chaos* [5], was applied to cities showing that analogically to material complex systems (such as e.g., Bénard cells [2]), cities too, emerge from the bottom up out of the interaction between their parts—the urban agents. All theories of complexity followed the above lead and were applied to the study of cities giving rise to the research domain of *complexity theories of cities* (CTC). And, similarly to the core complexity theories, each CTC emphasizes a different aspect of the complexity of cities so that we now have sub-domains of Fractal cities, synergetic cities, network cities, chaotic cities, and so on [1].

In the context of cities, the meanings of "bottom-up" and its negation "top-down" were "automatically" interpreted in terms of a bottom-up, spontaneous, self-organized, urban order that emerges out of the free interaction between the urban agents, vs. a top-down urban order resulting from the actions of a central authority and planning. This distinction has led to the view that urban planning and design are an intervention in an otherwise complex system. Since then, the notion "cities emerge from the bottom-up" was accepted as absolute truism—a kind of a *mantra* in the domain of CTC.

This mantra continued to prevail despite the fact that in many of the studies the domain of CTC practically "frames cities as systems involving more than merely spontaneous order": For example, Jacobs' [11] notion of "organized complexity", the various urban simulation models (cellular automata, agent based, networks, etc.), Hillier's space syntax [12], and more. This mantra continued to prevail also following the notion of *complex adaptive system* (CAS) introduced by Gell–Mann [13] and Holland [14] as a property of living complex systems—a notion that was enthusiastically embraced by proponents of CTC [15], including planners and designers that started to interpret urban planning and design in terms of adaptation [16].

4. The View from Synergetics

Similarly to the other complexity theories, Synergetics—Haken's theory of complexity [17,18]—started as a bottom-up theory with the medium *laser* (Light Amplification by Stimulated Emission of Radiation) as its canonical case study (Figure 2 Left). In the laser, the interaction between the parts (the light atoms) gives rise to the laser beam, defined mathematically by an *order parameter*. However, unlike the other complexity theories, Synergetics suggested that the process does not terminate with the emergence of order (e.g., the laser beam) but continues in a top-down process termed the *slaving principle* in which the order parameter describes and prescribes the behavior of the parts, that by obeying, perpetuate and strengthen the order parameter, and so on in circular causality [17,18]. Haken [19] has successfully applied his interpretation of the laser process, by means of

analogies, to the processes of liquid dynamics (referring to the Bénard cells [2]) and pattern recognition, while Haken et al. [20] have applied it to Kelso's experiment of humans' finger movements in the context of coordination dynamics [21]. These four canonical case studies were presented by Haken as Synergetics' core paradigms: the *laser paradigm*, the *pattern recognition paradigm*, the *pattern recognition paradigm* and the *finger movement paradigm* [22]. Note that the last two refer to the media cognition and brain functioning.

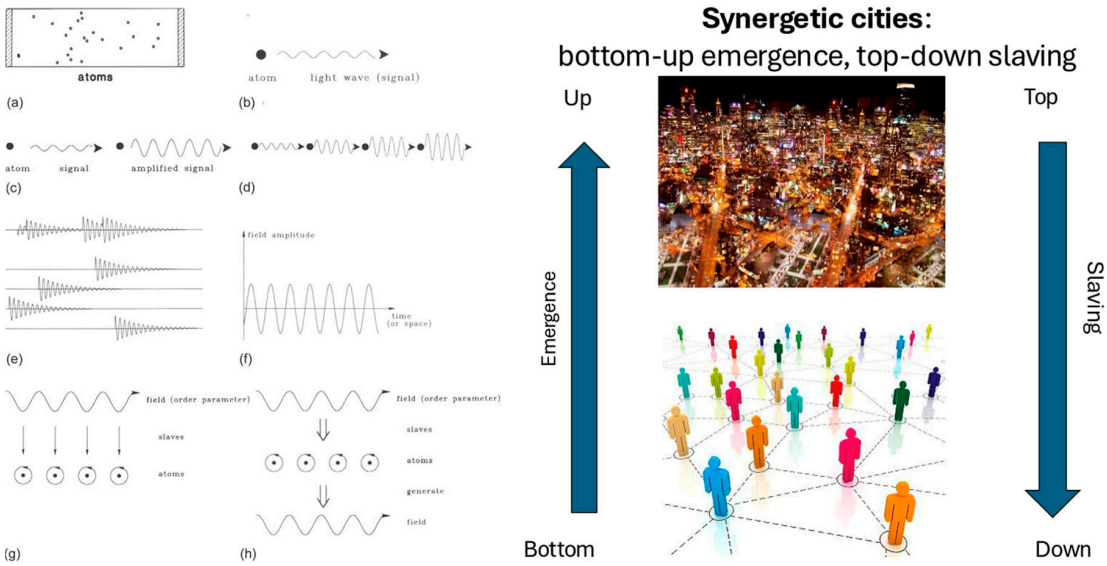


Figure 2. Synergetics' laser paradigm and its application to cities. (**Left**): The canonical laser paradigm. (**a**) A typical setup of the laser: A glass tube is filled with gas atoms, and two mirrors are mounted at its end faces. The gas atoms are excited by an electric discharge. Through one of the semi-reflecting mirrors, the laser light is emitted. (**b**) An excited atom emits light wave (signal). (**c**) When the light wave hits an excited atom, it may cause the atom to amplify the original light wave. (**d**) A cascade of amplifying processes. (**e**) The incoherent superposition of amplified light waves produces still rather irregular light emission (as in a conventional lamp). When sufficiently many waves are amplified, they strongly compete for further energetic supply. That wave that amplifies fastest wins the competition, initiating laser action. (**f**) In the laser, the field amplitude is represented by a sinusoidal wave with practically stable amplitude and only small phase fluctuations. The result: a highly ordered, i.e., coherent, light wave is generated. (**g**) Illustration of the slaving principle. The field acts as an order parameter and prescribes the motion of the electrons in the atoms. The motion of the electrons is thus "enslaved" by the field. (**h**) Illustration of circular causality. On the one hand, the field acting as order parameter enslaves the atoms. On the other hand, the atoms by their stimulated emission generate the field. (**Right**): Analogically to the laser paradigms, the interaction between the urban agents from the bottom up gives rise to the city, that once comes into being, it top-down enslaves the agents' behavior and their interaction and so on in circular causality.

As can be seen, the notion of 'slaving principle' is central to Synergetics. It was first formulated in the above context of the laser as a mathematical notion that takes care of the process by which a system's order parameter that emerged bottom-up by means of self-organization (the laser coherent light), top-down affects the behavior of the parts (light atoms) that created it in the first place. It thus shows that the laser light is not a consequence of a one-directional process, but rather of an ongoing circular process. In this context the term 'slaving' is used metaphorically to describe an aspect of the mechanical system laser. The problem starts when Synergetics was applied to the human domains of cognition, society, cities and urbanism (as elaborated below). Here the term "slaving" is not anymore a metaphor but has a specific social meaning and connotation. (Note that the same problem exists with notions such as Catastrophe theory, chaos theory and more.) Haken was fully

aware of this and in the book *Synergetics in Psychology*, Haken and Schiepek [23] made a distinction between 'strong' and 'weak' forms of slaving, the first referring to a process by which an order parameter directly determines the behavior of the parts, while the second refers to processes in which it indirectly affects the parts. In the case of cities, such an order parameter might be a city planning law stating that . . . (strong slaving) vs. a city's land-use plan allowing high-rise buildings only in a certain urban neighborhood thus indirectly affects the socio-economic composition of the residents of this area (weak slaving).

At a later stage however, the top-down germ of Synergetics (i.e., the slaving principle) evolved into a full-scale top-down theory of complexity: Following the application of Synergetics to the media of cognition and brain functioning [24,25], not by means of analogies to material phenomena as before but by commencing from first principles of cognition and brain dynamics, it was realized that in the cognitive and brain complex systems the processes evolve in a top-down manner as anticipated by Schrödinger's [4] 'order from order' dynamics in his *What is Life?* (cf. Section 1 above). This is due to the findings, firstly, that cognition is *embodied* [26] in two interrelated respects: One, in the sense that action is not causally determined by perception but rather the two are aspects of a single action-perception process. And two, that living agents do not perceive the environment as tabula rasa, but rather as environmental *affordances*, namely, the action possibilities affording to a specific body properties by specific environmental properties. Secondly, as shown by Friston's and co-workers' *free energy theory*, cognition and brain are complex systems whose main function is to minimize prediction error, avoid surprise and thus avoid phase transition [27]. Thirdly and as a consequence from the above, "the brain is a kind of inference machine" in which top–down predictive models are compared with bottom–up representations by means of embodied action–perception ([6], p. 88).

In light of the above, Haken has termed the laser-oriented bottom-up approaches "synergetics' first foundation" and the cognition-oriented top-down approaches "synergetics' second foundation". The various properties of the second foundation were elaborated in two main books: *Information and Self-Organization: A Macroscopic Approach to Complex Systems* [28] and *Synergetic Computers and Cognition: A top-down approach* [24]. As implied by their titles, the first approaches the issue from the perspective of Shannon's information theory [29,30], while the second does so from a neural networks perspective. Recently, Haken and Portugali [6] have further elaborated the relations between the bottom-up microscopic first foundation, and the top-down macroscopic second foundation, demonstrating how each of the two approaches leads to the probability distribution that mathematically describes the complex system in question—the city in the present case.

5. Synergetic Cities and the Emergence of an Alternative View

A similar process took place in the domain of CTC with respect to Synergetic cities: The first applications of synergetics to the domain of cities were made by analogy to the laser suggesting that, similarly to other applications of complexity theories, cities indeed emerge from the bottom up out of the interaction between their parts—the urban agents (Figure 2 Right). However, unlike other CTC, Synergetic cities continue that analogically to the above laser paradigm; once emerged, cities top-down determine ("enslave") the behavior of the parts (the urban agents/inhabitants and users) who created them in the first place, and so on in circular causality [1].

One such approach to cities was developed by Weidlich [31], based on Weidlich and coworkers' application of Synergetics to sociodynamics [32]. At the core of their approach was the Synergetic principle of "time-scale separation" referring to the fact that complex systems are typified by the co-existence of slow and fast processes or variables. As a consequence, if a complex system's variables "can be separated into slow ones and

fast ones, a few of the slow variables . . . are predestined to become 'order parameters' dominating the dynamics of the whole system on the macroscale" [31].

The application of the above to cities was straightforward as cities were traditionally perceived and theorized as hierarchical systems. Thus, the slow urban processes typify national or regional systems of cities at the top of the urban hierarchy, whereas the fast urban processes typify the smaller cities at the bottom of the urban hierarchy, where in between might exist middle size and pace regional or metropolitan urban systems. In line with synergetics, the relations between the various levels in the hierarchy are determined by the slaving principle [1], where

> . . . on the one hand, the regional system serves as the environment and the boundary condition under which each local urban microstructure evolves. On the other hand, the . . . regional macrostructure is . . . the global resultant of many local structures.
>
> [31]

The second and main application of Synergetics to cities started, like all other CTCs, by an analogy between complex material systems and cities [1], that is, between the laser and pattern formation paradigms and cities. As illustrated in Figure 2 Left, in the laser, the interaction between the parts (the light atoms) gives rise to an order parameter (the laser beam) that, once it comes into being, describes and prescribes the behavior of the parts (a process termed the *slaving principle*) and so on in circular causality. In direct analogy, in cities (Figure 2 Right), the interaction between the parts (the urban agents) gives rise to an order parameter (the structure of the city), that, once it comes into being, "enslaves" (i.e., describes and prescribes) the behavior of the urban agents, that once obeying, reproduces the urban structure, and so on in circular causality. This circular process is similar to what in social theory-oriented urban studies is termed *socio-spatial reproduction* [33].

Interestingly, an empirical support to this top-down view on the circular urban dynamics was recently added by *urban allometry* (or *urban scaling*) studies showing positive correlation between city size and urban agents' behavior [34]. Namely, first, that similarly to natural organic complex systems, in cities, too, ". . . important demographic, socioeconomic, and behavioral urban indicators are, on average, scaling functions of city size that are quantitatively consistent across different nations and times" [34]. Based on big data, urban allometry studies indeed established the existence of the phenomenon but did not explain how and why. Such an explanation was provided by Ross and Portugali's notion of *urban regulatory focus* (URF), that, as elaborated below, demonstrated empirically that city size and dynamics—"pace of life"—are affecting the motivational tendencies and behaviors of urban agents ([6] Chap. 13) and thus as further elaborated by Haken and Portugali, the dynamics of cities ([6], Chap. 2).

At a later stage, following the view that cities emerge by means of the interaction between the urban agents, an attempt was made to consult the cognitive sciences in order to get a deeper understanding on the way urban agents interact. This consultation entailed new insights similar to those of the synergetic second foundation: Namely, that human behavior, and thus urban agents' interaction in the context of the dynamic cities, is a top-down process in several respects that concern *cognitive mapping*, *chronesthesia* or *mental time travel*, *cognitive planning* and *urban regulatory focus* (URF):

Cognitive mapping. Introduced by Tolman's [35] seminal paper—"Cognitive maps in rats and men"—the notion of a cognitive map is due to empirical studies indicating that animals (humans included) navigate in space according to cognitive maps constructed in their brain while moving in the environment. Subsequent studies further revealed fascinating brain properties associated with cognitive maps: O'Keefe and Dostrovsky [36]

revealed the existence of the brain's "place cells"—neurons in the hippocampus activated when an animal encounters a particular place in the environment; O'Keefe and Nadel [37] published their *The Hippocampus as a Cognitive Map*, while O'Keefe, May-Britt and Edvard Moser received the 2014 Nobel Prize in physiology or medicine for discovering the brain's *Grid Cells* that function as "... a positioning system, an "inner GPS" in the brain that makes it possible to orient ourselves in space, demonstrating a cellular basis for higher cognitive function" (From the announcement. see: https://www.nobelprize.org/prizes/medicine/2014/press-release/, accessed on 3 November 2015) (see also [38]). In the domain of cities, studies demonstrated that urban agents move and behave in the city not according to its exact geographical structure, but rather according to the agents' cognitive maps of the cities which are not exact representations of the urban landscape but are systematically distorted; not because of representation errors but as a consequence of the way the mind–brain processes information ([39] and [1], Chap. 6).

Chronesthesia or mental time travel. Recent studies indicate that human memory is *chronesthetic*, typified by *mental time travel* (MTT) tendencies to the past but also to the future [40,41]. The implications are as follows: first, urban agents' action and behavior in the here and now urban present, are determined, on the one hand, by their past experience, and on the other, by their future expectations [6,42]. Second, not only do urban agents have the capability of MTT, but they cannot not travel in time to the past and to the future. This latter property is associated with two forms of chronesthesia: One is *prospective memory* (PM), referring to human action determined by "a remembered future... in contrast to retrospective memory that refers to a remembered past", that is, to "the realization of delayed intentions or plans" involving "the future use of memory—one 'remembers to remember' ([6] Chap. 15). The second form of chronesthesia is *cognitive planning* that is discussed next.

Cognitive planning. As a corollary from the above and as implied from studies in the research domain of *cognitive planning*, planning is a basic cognitive capability of humans [43,44]—every human being and thus every urban agent is a planner at a certain scale with the implication that inter-agent interaction in a city is an interaction between a huge number of agents/cognitive planners of which the official city planning team is but one agent. As a consequence, due to the non-linearity that typifies complex systems, the plan of a single urban agent is often more influential in determining the structure of the city, than that of an official urban planning team (for specific case studies see [1], Chap. 15; [42]; and [6] Chap. 10).

Urban regulatory focus. As just noted, urban allometry studies established the existence of the phenomenon but did not explain how and why it occurs. Such an explanation was provided by Ross and Portugali's ([6], Chap. 13) notion of *urban regulatory focus* (URF), that extends and applies psychologist Higgins' [45,46] *regulatory focus theory* (RFT) to the domain of cities. Higgins' theory posits that a person's motivational system, that is, his or her goal-directed behavior, is regulated by two behavioral tendencies termed *promotion* and *prevention*, so that some persons are *prevention oriented* while others are *promotion oriented*. He further developed a way to quantify each person's promotion–prevention characteristic mix termed *chronic regulatory focus* [47]. While Higgins refers to individuals only, Faddegon et al. [48] demonstrated empirically that a person's chronic regulatory focus tends to be affected by the group to which one belongs—such as working place, thus giving rise to a *collective regulatory focus*. Ross and Portugali's ([6] Chap. 13) URF 'have taken the phenomenon to the city', demonstrating empirically that cities differing in their size and thus in their 'pace of life' affect their citizens' chronic regulatory focus. In a follow-up study Haken and Portugali [6] have complemented 'the way to the city' by demonstrating the various ways URF is affecting the dynamics of cities—cf. Section 7.1 below.

In all the above processes, the interacting urban agents never enter the interaction *tabula rasa*; rather, they always commence the interaction equipped with previous knowledge constructed, and stored, in their memory—as such, as noted above, they act top-down as "inference machines".

6. Cities Are Hybrid Complex Systems

The above attempt to consult the cognitive sciences' media in order to shed further light on the way urban agents interact entails a more fundamental insight: Cities represent a medium that qualitatively differs from both material and living complex adaptive systems in that they are *hybrid complex systems* (HCS) in two interrelated respects: One, they are composed of artifacts (buildings, roads, etc.), which are by definition simple systems, and urban agents each of which is itself a complex system; and it is due to the urban agents that the city as a whole is a complex system [42]. Two, in the sense that human urban agents are CAS of special kind, they adapt not only by change of behavior, as the rest of animals, but also by means of the production of artifacts. This latter property of humans has far-reaching consequences that extend beyond the scope of the present study; of these consequences, I will emphasize here two:

Firstly, the production of artifacts is only partly an adaptive response to changing environmental conditions (as in regular CAS); rather, it also involves human curiosity and imagination, which are by definition top-down processes. This shows up in the relations between Gibson's [26] notion of 'affordances' noted above, and Norman's [49] notion of 'perceived affordances' in his *The Design of Everyday Things* (originally published in 1988 as *The Psychology of Everyday Things*). While both notions are essentially top-down processes, Gibson refers primarily to animals, including humans, in the environment at large, while Norman refers to "... the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used" ([49], p. 9).

Secondly, artifacts are subject to the process of cultural evolution to which as CAS humans have to adapt. As a consequence, humans are subject to two evolutionary processes: the very slow Darwinian evolution and the extremely fast cultural evolution [1,50]. Furthermore, as anticipated by Schrödinger and proved by Watson and Crick, due to the role of genes, biological evolution is what Schrödinger has termed an "order from order" process (cf. above Section 2). As shown [8], while there are no genes involved in cultural evolution, Dawkin's [51] notion of memes functions in a way similar to biological genes. The implication is the production of artifacts does not emerge from the bottom up nor from the top down; rather it emerges out of the interaction between simultaneous bottom-up and top-down processes. We are thus coming full circle to Schrodinger's order from disorder and order from order.

As can be seen, artifacts form the core of the notion of HCS and its above properties. And yet, this paper intentionally refrains from a comprehensive ontological discussion on artifacts and urban artifacts. Instead, it refers to artifacts according to the way they are commonly used, namely, as objects intentionally made by humans, "in order to accomplish some purpose" [52,53]. This is despite the fact that there has recently been stimulating debate on the ontology of artifacts in the context of cities [54–56]. As with the above two issues, participating in the above ontological debate requires an independent study that extends beyond the scope of the present study.

The notion of HCS was first introduced in 2016 [42] and further developed in several subsequent studies [6,22]. On the other hand, however, it was implicit in early studies on the role of cognition in the dynamics of cities from their day one: First, in the notion of *Inter-Representation Networks* (IRN) suggesting that while mainstream cognitive science

tends to focus on internal representation and ignore external ones (Figure 3 Left), cities require both as illustrated in Figure 3 Right [57].

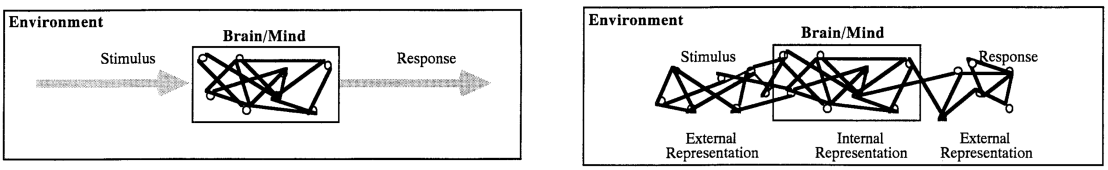


Figure 3. (**Left**): Mainstream cognitive science's view on cognition. (**Right**): The IRN view on cognition. Source: ([57], Figure 1).

Second, it was implicit in the conjunction between IRN and Haken's [24] Synergetic computer that gave rise to the Synergetic IRN (SIRN) model that represents a typical urban agent ([6] Chap. 4). As illustrated in Figure 4, the derivation of the SIRN model commences from Haken's [24] synergetic computer by adding to its internal input and output information externally represented input and output information, giving rise to a typical urban agent. According to the SIRN model, each urban agent is ongoingly subject to two flows of information: one that comes from the agent's mind–brain and another from the environment. The interaction between the two gives rise to two outputs in the form of action and behavior in the city, and of feedback to the mind–brain.

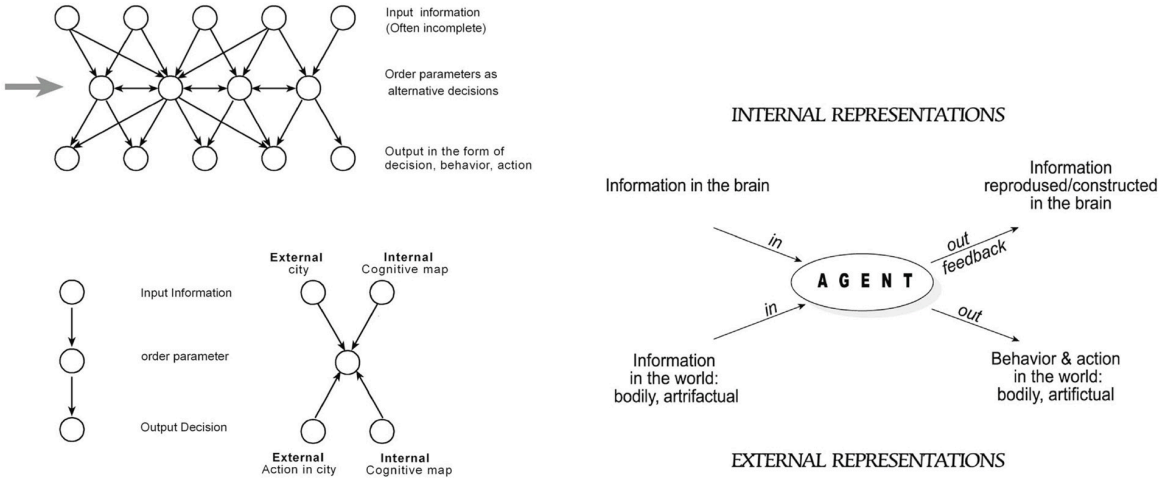


Figure 4. (**Top-left**): The derivation of the SIRN model starts by looking at the network of Haken's [24] synergetic computer from the side, as indicated by the arrow. The result is shown at (**Bottom-left**). Adding to the latter external inputs and outputs, (**Bottom-center**) and rotating the result 90 degrees to the right, we arrive at our basic SIRN model (**Bottom-right**).

Third, it was implied in Haken and Portugali's study "The face of the city is its information" ([6] Chap. 4), in which it was shown that external representations are (among other things) the artifacts of which cities are built and that these artifacts convey three forms of information: quantitative *Shannonian information* and two forms of qualitative information: semantic and pragmatic. Shannonian information can be measured by means of Shannon's information bits [29,30]. For example, when all buildings in a city are similar to each other, the information conveyed by the city is low (Figure 5 Top). If, on the other hand, all houses in a city are different from one another, we are dealing with high information content (Figure 5 Bottom). Qualitative *semantic information* refers to meaning per se (e.g., this is a pavement), while qualitative *pragmatic information* refers to the action possibilities afforded by an object (e.g., this pavement affords walking).

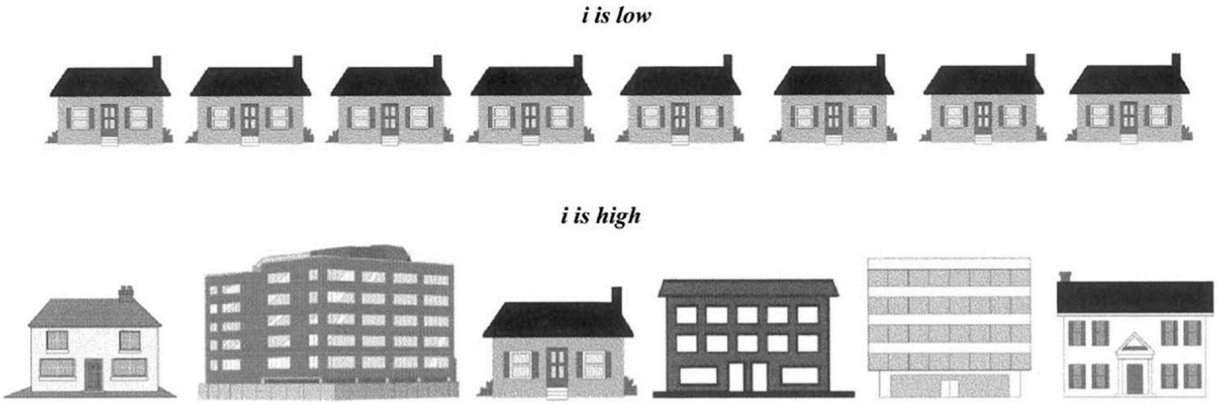


Figure 5. The concept of Shannonian information provides us with a rigorous mathematical formulation to quantify the amount of information conveyed by different urban landscapes. For example, when all buildings in a city are similar to each other, as in the top row, the information conveyed by the city is low (or zero). If, on the other hand, all houses are different from one another, as in the bottom row, we are dealing high information content.

Fourth, it was implied in the notion of *Information Adaptation* (IA) that specifies the dynamics of the interaction between the information that comes from the urban agent's brain and the information that comes from the environment [6]. Figure 6 illustrates the various facets of the IA process. IA's canonical case study is the process of vision (Figure 6 Left and second from the Left): in line with the SIRN model, it commences from the two flows of information to which an urban agent is subject—one that comes from the mind–brain and another from the environment. The interaction between the two evolves as follows: when the information flow from the environment is partial and incomplete, IA is implemented by means of *information inflation*, that is, by adding information to the scene, as in the Kaniza triangle Illusion (Figure 6, third from the Left). When the information flow from the environment is superfluous, IA is implemented by *information deflation*, that is, by extracting information from the scene (as in the "Olympic rings" illusion—Figure 6 Right).

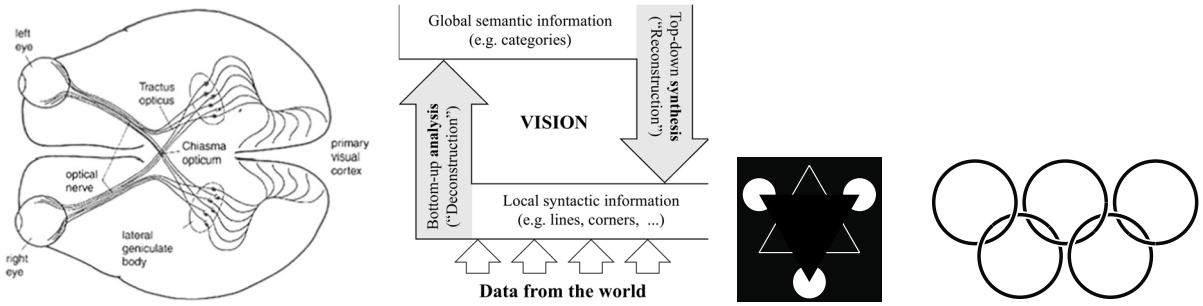


Figure 6. The various facets of IA. **Left:** the links between the eyes and the brain. Second from the left: Schematic representation of the visual pathway of a human: data from the world is first analyzed by the brain, in a bottom-up manner; this local information triggers a top-down process of synthesis that gives rise to global information—that is, to seeing and recognition. Third from the left: The Kaniza triangle Illusion. **Right:** the "Olympic rings" illusion. Source: ([6], Figures 4.7, 4.8).

Finally, and fifth, it is implied in the SIRNIA model—the conjunction between SIRN and IA—which is the basic model that forms the core of the city as HCS. As detailed in Figure 7, each urban agent is ongoingly subject to two flows: a flow of semantic information (SI) that originates in the agent's mind–brain, and a flow of data from the environment transformed into Shannonian information. The interaction between these flows—the process of information adaptation (IA)—is implemented by means of information inflation

or deflation and entails two forms of output: one in the form of semantic information (SI) that feeds back to the mind–brain, and a second in the form of pragmatic information (PI) that takes the form of the agent's behavior and action in the city including the agent's involvement in the production of the artifacts of which the HCS city is composed.

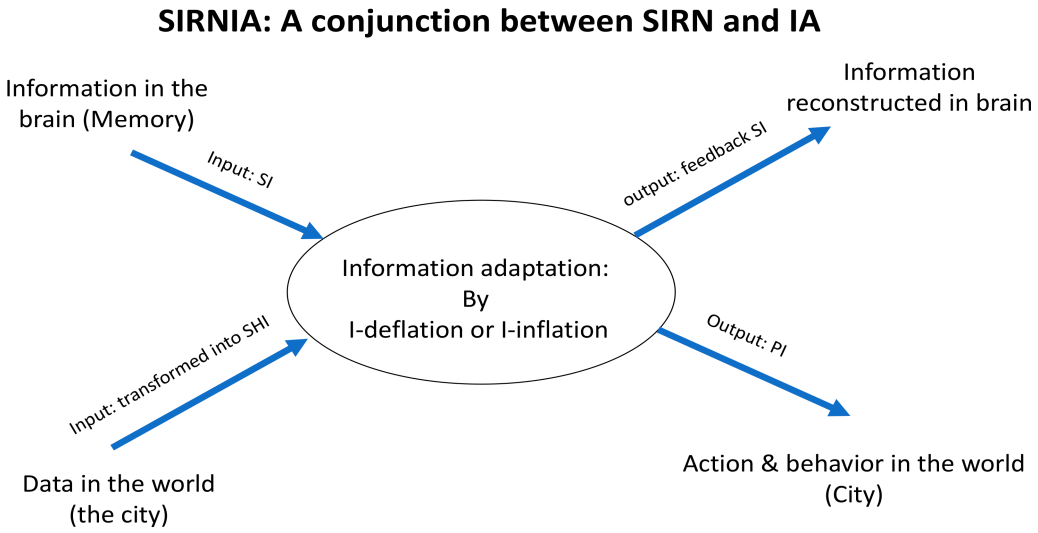


Figure 7. The SIRNIA model as a conjunction between SIRN and IA. For details see text.

The result at the city scale is the city as an HCS. As noted above, it is composed of artifacts which are simple systems and human agents, each of which is a complex system. Each agent interacts with these two components of the city: on the one hand, with (a) the many artifacts of which the city is composed and (b) the "face of the city" as a whole. Both, as noted, convey data from which the agent extracts information. On the other hand and in parallel, each agent interacts with the other urban agents. This latter interaction can further be divided into direct inter-agents' interaction that affects the city in a bottom-up manner, and indirect interaction via the city as a whole that functions as a mediator between the many urban agents and thus affecting the city in a top-down manner.

The general and practical planning implications of the city as HCS and of SIRNIA as its model is that central to the dynamics of cities is an interplay between two kinds of urban agents that act simultaneously in a bottom-up and top-down manner ([58], p. 204): "institutional-professional planning and cognitive planning as a basic cognitive property of every human being and as such of every urban agent."

7. Internal Negations and the City

What follows from the above is that the tension between "bottom-up" and "top-down" does not represent two competing approaches to, or interpretations of, urban dynamics that negate each other in a zero-sum game, but rather two configurations that simultaneously coexist and play a role in the dynamics of cities. At stake here, thus, is a more general issue that has not as yet received sufficient attention in the domain of CTC: Cities as complex systems are characterized by internal negations and contradictions of which the above bottom-up vs. top-down negation is but one example.

The question thus is how to interpret internal negations and contradictions in complex systems and in cities as complex systems? Inspired by Bohm's [59] theory of orders, the answer suggested here is that it depends on the theoretical medium through which one looks at this issue: According to Bohm ([59], p. 4), "a theory is primarily a form of insight, i.e., a way of looking at the world, and not a form of knowledge of how the world is." In terms of the present discussion, a theory is a medium through which to look at the world.

Three such theoretical media to internal negations have already been introduced in the context of cities: one by Haken's [17,60] theory of Synergetics in terms of hierarchy of order parameters, a second by Kelso and Engstrøm [61,62] in the context of coordination dynamics, and a third that approaches the issue from the perspective of Bohm's theory of orders [63].

7.1. Hierarchy of Order Parameters

The notion of *order parameter* stands at the core of Synergetics as we have seen above. Central also to Synergetics is the principle of *time–scale separation*. Their conjunction leads to view certain complex systems in terms of a hierarchy of order parameters where the slow order parameter dominates the slow order parameter(s). Cities and systems of cities have traditionally been theorized as hierarchical systems, starting in Auerbach's [64] rank-size rule, continuing in Christaller's [65] and Lösch's [66] central place theories and ending with the recent urban scaling/allometry studies [34]. It is therefore no surprise that the notion of hierarchy of order parameters was smoothly applied to the domain of cities. One such application is Weidlich's [31] reference above to the slow processes typifying "macrolevel of whole regions, or systems of cities that function as order parameters to the slow moving urban microlevel of "of building sites, streets, subways, etc."

A second application followed the urban allometry studies that, as noted above, demonstrate that city size and dynamics ("pace of life") affect the behaviors of urban agents. As further noted above, Ross and Portugali ([6] Chap. 13) have shown empirically that a city's pace of life (associated as it is with population size) affects the motivational system of urban agents by a certain quantity termed *response biased* that measured "the extent to which fast-paced cities versus slow-paced cities affected the personal (chronic) regulatory focus of the subjects" [6]. In a follow-up study Haken and Portugali [28] have employed the response biased as an order parameter in their hierarchical, three-layered urban system (Figure 8). In it the response bias is the system's top first layer order parameter; the system's second layer order parameters represent the two groups of promotion-oriented vs. prevention-oriented urban agents, referring to the inhabitants of small cities characterized by a slow pace of life vs. those of large cities characterized by a fast pace of life. In line with Synergetics' slaving principle, the inhabitants of the third layer are "... enslaved by the order parameters of layer 2 that in turn are enslaved by the top order parameter. Now, according to the circular causality principle, the order parameter at the top level is fixed by the total behavior of the individuals (3rd layer)." ([6], p. 169).

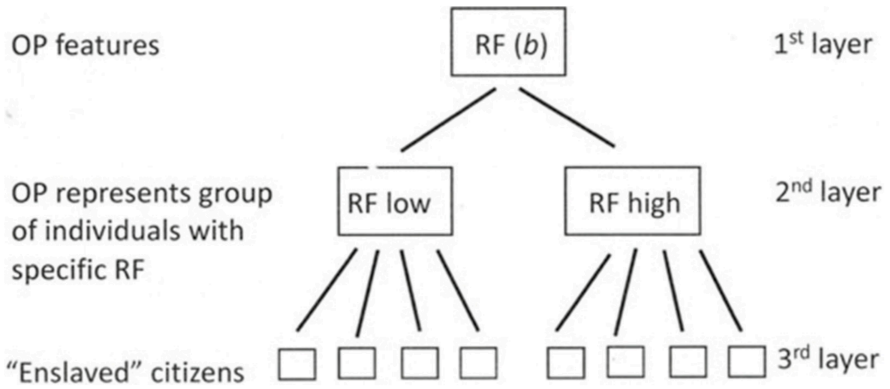


Figure 8. An urban system of three-layered hierarchy referring to the dynamics of the motivational tendencies of the inhabitants of an urban system composed of small/slow cities vs. big/fast cities. Source: ([6], Figure 11.2). (For an earlier version of this model see [61]).

7.2. Complementarity and Metastability

Due to humans' ubiquitous tendency to dichotomize, claim Kelso and Engstrøm [62] in their *The Complementary Nature*, many aspects of reality appear to be contraries, whereas in essence they are mutually related and complement each other, thus forming a *complementary pair*. Kelso and Engstrøm assign the tilde sign (~) as an indicator of such a pair [61,62]. In the context of Synergetics, contraries are conceptualized in terms of bi-stability or multistability in which the system (symbolized by the ball in Figure 9 Left) eventually settles in one of the attractors/valleys. Kelso and Engstrøm's complementary pair refers to the phenomenon of *metastability*—literally meaning "beyond stability": It is common that if a complex system is subject to two forces (attractors), it will eventually settle (reach a steady state) dominated by either the first or the second attractor (A or B in Figure 9 Right). A metastable regime refers to situations in which the system does not settle in one of the attractors/valleys (A or B) but rather moves back and forth between two aspects ($a \sim b$) of these attractors, as in Figure 9 Right.

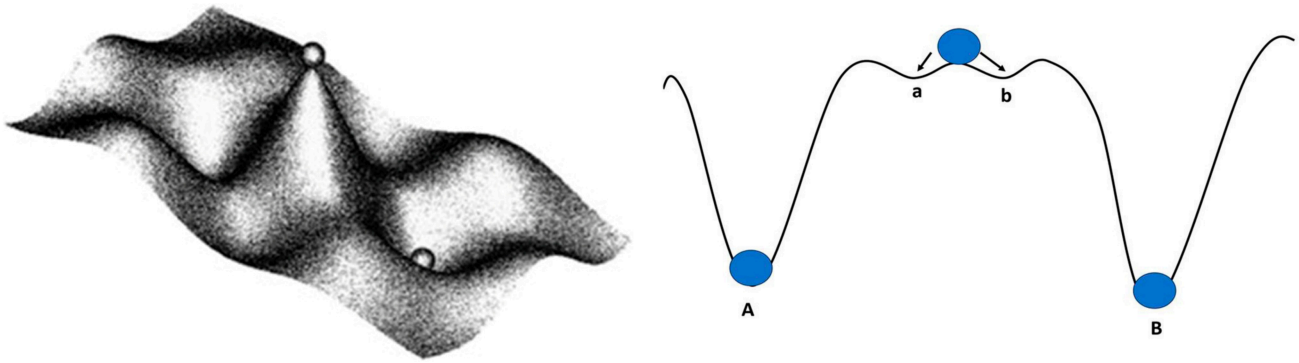


Figure 9. (**Left**): a potential landscape in which the ball on top illustrates a multistable system while that in the valley illustrates a stable one. (**Right**): A potential landscape describing two dichotomized regimes (A or B) and the coordinative regime of metastability A~B (the ball on top), where a and b are aspects of A and B. Source: [22].

Kelso and Engstrøm's [63] main domain of research is coordination dynamics; Kelso et al. [67] have applied the notion of complementary pair to the domain of cities, referring to the negation between urban order that emerges by means of self-organization versus order emerging by means of urban planning and design. Their conclusion: bottom-up self-organized urban order and top-down designed and planned urban order are complementary, not contradictory ([67], p. 51).

A second application of the notions of *complementarity* and *metastability* to the domain of cities focused on the negation between public and private domains in the landscape of cities, specifically between the living apartment as a private domain versus the street as a public domain in the urban landscape of Tel Aviv [22]. Here it was shown that while formally Tel Aviv has a clear-cut distinction between public and private domains, practically they form a complementary pair typified by a metastable regime in which the typical open balconies of Tel Aviv are part of the streets' scene, and vice versa too—the street and the activities that take place in it are part of the private apartment [22].

7.3. Implicate, Explicate and Generative Orders

Theories of cities and urbanism as evolved since the mid/late 19th century were and still are typified by a gap and dis-communication between two streams that correspond to Snow's [68] two cultures of science [1]: one culture of cities that attempts to develop the study of cities as a quantitative formal science and another that argues that cities and urbanism should be studied in line with the humanities and social theory. In a recent

paper, it was argued that Bohm's [59] theory of implicate, explicate and generative orders, developed by him in the context of quantum theory, can inspire and form "a basic for a unified urban theory" that will close the century-old gap between the two cultures of cities [63].

In brief, one of the major challenges of theoretical physics is the inconsistency between quantum theory and Einstein's theory of relativity. In Bohm's ([59], p. 223) words:

> . . . these two theories have never been unified in a consistent way. Rather, it seems most likely that such a unification is not actually possible. What is very probably needed instead is a qualitatively new theory, from which both relativity and quantum theory are to be derived as abstractions, approximations and limiting cases. The basic notions of this new theory evidently cannot be found by beginning with those features in which relativity and quantum theory stand in direct contradiction. The best place to begin is with what they have basically in common. This is undivided wholeness. Though each comes to such wholeness in a different way, it is clear that it is this to which they are both fundamentally pointing.

The above-noted suggestion for a unified urban theory proposes "to apply the same way of thinking to the two cultures of cities" [63]. This, firstly, is done by showing the links that do exist between the two cultures of cities that proponents of the two cultures tend to overlook. Secondly, it does so by elaborating on "why is such a unified urban theory necessary". Thirdly, it does so by exposing links between Bohm's theory of order and CTC, on the one hand, and social theory-oriented urban theories, on the other. The general aim of such a unified urban theory is not to replace one theory by another but to identify a deeper theoretical level from which existing disconnected theories can be generated.

The crucial question is how to identify such a deeper theoretical level? The answer suggested by Bohm [69] is by a process he referred to as "dialogue" whose aim is to identify a common ground from which differing/varying/competing views can emerge and on the basis of which people can communicate (cf. Stolk [70] on this issue). In his *On Dialogue* Bohm ([69], p. 7) writes:

> In a dialogue, . . . nobody is trying to win. Everybody wins if anybody wins. . . . there is no attempt to gain points, or to make your particular view prevail. . . . a dialogue is something more of a common participation, in which we are not playing a game against each other, but with each other. In a dialogue, everybody wins.

In the above-noted study [63], the aim was to prepare the ground for a dialogue between the two cultures of cities that will create "a basic for a unified urban theory" that will close the century-old gap between the two cultures of cities—a task that will have to await further studies.

8. Concluding Notes

Looking at the tension between "bottom-up" and "top-down" in the dynamics of cities from the perspective of Haken's hierarchy of order parameters, it can be said that given a three-layered urban structure (Figure 8), the first layer is, for example, the city's order parameter that enslaves its inhabitants by means of the second layer order parameters referring to the bottom-up and top-down urban processes that enslave the third layer in the hierarchy composed as it is by the city's urban agents.

From the perspective of Kelso and Engstrøm [61,62], cities are characterized by a metastable regime in which the system city does not settle in one of the bottom-up or top-down attractors but rather moves back and forth between two aspects of these attractors, as in Figure 9 Right. Bottom-up and top-down urban processes thus form the complementary pair bottom-up~top-down.

From the perspective of Bohm's theory of order, the negation between bottom-up and top-down in the dynamics of cities is a property of the explicate urban order which, according to Bohm's point of view, is generated from a deeper, holistic implicate urban order.

The above three approaches in themselves raise a question: are they contradicting, complementing or unrelated to each other? While a full-scale response to this question will have to await a subsequent full-scale study, some clue can be gained from a preliminary study demonstrating similarity between Haken's notion of order parameter and Bohm's notion of generative order ([50], Chap. 18): According to Bohm, every order is generative with the implication that often the implicated order generates two explicate orders that negate each other [69,71]. These negating explicate orders resemble Haken's lower scale order parameters and Kelso's metastable complementary pair. These, however, are just preliminary thoughts toward a subsequent full-scale study of this issue.

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