Chapter 1
What Makes Cities Complex?

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Abstract The rationale of this book follows dilemma (see introduction, this volume): The last four decades have witnessed the emergence of CTC (complexity theories of cities)—a domain of research that applies complexity theories to the study of cities. Studies in this domain have demonstrated that, similarly to material and organic complex systems, cities exhibit the properties of natural complex systems and, that many of the mathematical models developed to study natural complex systems also apply to cities. But there is a dilemma here as cities are large-scale artifacts and artifacts are essentially simple systems. So what makes the city a complex system? To answer this question I first draw attention to the ways in which cities differ from natural complex systems and suggest that, as a result, we have to include the cognitive capabilities of urban agents in theorizing and simulating the dynamics of cities. In particular, I draw attention to the fact that urban agents are typified by *chronesthesia,* that is, the ability to mentally travel in time, back to the past and forward to the future. From the recognition of this cognitive capability follows, firstly, a novel view on the dynamics of cities and the role of urban planners and designers in their dynamics. Secondly, a potential for a new field of study in which planning and design are not treated as external interventions in an otherwise spontaneous and complex urban process, but rather as integral elements in its dynamics.

1.1 The City as a Complex Artifact

In 1943, Nobel laureate Erwin Schrödinger gave a lecture at Trinity College Dublin entitled "*What is Life?*"; a year later Schrödinger published it as a book in which he approaches the question by reference to entropy: matter is subject to the second law of thermodynamics, that is, to the process of entropy, while life entails a dilemma

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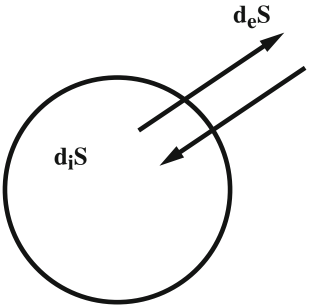

Fig. 1.1 Prigogine's Fig. 2.1 has the caption: "The exchange of entropy between the outside and the inside"

(Schrödinger 1944, Chap. 6): "How would we express the marvelous faculty of a living organism, by which it delays the decay into thermodynamical equilibrium (death)?" His answer is that 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." This notion of negative entropy was later termed *negentropy* (Brillouin 1953).

Schrödinger's view of life and his suggestion that "organization is maintained by extracting 'order' from the environment" anticipated the notion of *order out of chaos* that has become *the* motto of complexity theory. Indeed, three decades later Ilia Prigogine demonstrated, in his Nobel lecture, that in certain circumstances matter also behaves as if it has life (1977). He showed, with the aid of Fig. 1.1, that:

> The classical formulation [of entropy] due to Clausius refers to isolated systems exchanging neither energy nor matter with the outside world. […] It is easy to extend this formulation to systems which exchange energy and matter with the outside world […]. We have then to distinguish in the entropy change dS two terms: the first, deS is the transfer of entropy across the boundaries of the system, and the second diS, is the entropy produced within the system.

Prigogine termed his theory of complexity *dissipative structures*. In more or less the same period Hermann Haken (1969, 1987) developed a theory of complexity that he called *synergetics*, while Lorenz (1963) developed the theory of *chaos*; a few year later Mandelbrot (1983) developed his *fractal geometry*, Bak (1996) his *self-organized criticality*, and more recently *the new science of networks* was introduced by theorists such as Barabasi (2002) and Watts (2004). While all of the above refer to open and complex systems in far from equilibrium conditions, each of these theories emphasizes specific aspects of complexity.

Complexity theories' connection to towns and cities was there from the start. Thus in his Nobel lecture Prigogine said (1977):

> 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.

This usage of the city as a metaphor for complexity appears time and again in Prigogine's further writings. However, it was Peter Allen, a former student of Prigogine, who first developed a complexity theory of cities (Allen 1997) and by so doing created the domain of CTC—*complexity theories of cities*. Developed by a small but active community of researchers, studies in CTC have demonstrated that cities exhibit all the properties of natural complex systems: they are open, complex and self-organized, and often fractal and chaotic. They have further shown that many of the mathematical formalisms and models developed to study material and organic complex systems also apply to cities. In fact, many in the CTC community were (and still are) physicists or mathematicians running their models on data about cities.

Similarly to the founding complexity theories, each complexity theory of cities sheds light on different complexity properties of cities (Portugali 2011): *dissipative cities* emphasizes the link to the environment, *synergetic cities* the bottom-up interaction between the urban agents and the top-down 'slaving principle,' *fractal cities* looks at the fractal structure and morphology of cities, and so on.

But there is a dilemma in the current state of CTC for cities are artifacts: A city is a large-scale artificial built environment, composed of smaller scale artifacts such as buildings, roads, bridges and, parks, each of which is composed of still smaller artifacts—and so on; and, artifacts are essentially simple systems. Some artifacts, such as supercomputers, are very complicated, but are nonetheless essentially simple systems (for further information about cities as complex systems see Batty 2005; Portugali 2000, 2011): Buildings, roads, bridges, neighborhoods, cities or even metropoles do not—by themselves—interact either with their environment or among themselves. So what is it that makes the artifact city, inherently a simple system, into a complex one?

1.2 Cities as Dually Complex Systems

The straightforward answer to the question is that the city as an artifact becomes a complex system due to its urban agents. But how do these agents fit into the definition of the city as a system? Cities are composed of material components and organic components, including humans. As a set of material components alone, the city is an artifact: a simple system. However, seen as a set of human components—the urban agents—the city is a complex system. The city, of course, is both. It is thus a *hybrid simple-complex system*, and it is the urban agents that by means of their interaction—among themselves, with the city's material components and with the environment—transform the artifact city into the complex artificial system city.

But the city is a dual complex system in several other ways. First, as a complex artificial system, the city emerges out of the interactional activities of its agents. But once it emerges, its structure and dynamics affect (or "enslave," in the language of synergetics) the behavior of its agents and so on in circular causality—a process that in the domain of social theory is termed *socio-spatial reproduction* (Portugali 2000, 2011). In other words, the city is a large-scale collective and complex artifact that, on the one hand, by means of the activities of its inhabitants and users (the urban agents), interacts with its environment, while on the other, as a consequence of its size, functions as an environment for the large number of people that live and act in cities. This latter property of cities is becoming increasingly prominent as the proportion of people living in cities grows; specifically so in the last century that has witnessed the fastest population growth in human history and the fastest urbanization processes with the result that, for the first time, more than 50 % of the world population lives in cities (Wimberley et al. 2007). The city in this respect is a *complex artificial environment* (Portugali 2011, Chap. 11).

Second, artifacts are not just the outcome of human interaction but are also *the media of interaction*; artifacts such as texts, cities, buildings or roads are *external representations* of ideas, intentions, memories and thoughts that originate and reside in the mind of urban agents—that is to say, of *internal representations*. However, just as artifacts cannot directly interact among themselves, neither can ideas, thoughts, intentions, plans and other internal representations. They interact by means of the externally represented artifacts, be they texts, clothes, buildings, neighborhoods or whole cities and metropoles. Urban dynamics thus involve ongoing interaction between external and internal representations. The notion of SIRN (Synergetic inter-representation networks) captured this interaction between internal and external representations (Portugali 2011, Chap. 7).

Third, as discussed at length in CCCity (*Complexity, Cognition and the City*, Portugali 2011), the city as a whole is a hybrid complex system and each of its agents is also a complex system. This is not the case with material complex systems in which complexity is a property of the global system but not of the parts. Organic complex systems are different, as each of their parts is a complex system too; however, since the parts of organic complex systems (such as plants or animals) are subject to the slow process of natural Darwinian evolution, the short-term feedback effect of the global system (such as a flock of birds or fish) on the parts in negligible and thus the duality of such systems can be ignored. The situation is different with respect to cities as hybrid complex systems, as their agents are simultaneously subject to two evolutionary processes: very slow natural evolution, which they rarely witness in their lifetime, and very fast cultural evolution, whose effect on the urban agents in instantaneous—urban agents have to adapt to the quickly-changing urban environment. But *how* do they adapt to fast cultural changes? By means of their cognitive capabilities! The implication is that we have to include the cognitive capabilities of the urban agents in our treatment of the dynamics of cities.

In line with this, *CCCity* was a first attempt in this direction with emphasize on one cognitive capability—the capability of *cognitive mapping*. In it I propose that the behavior of the complex parts of the city—the urban agents—is mediated by, and thus strongly influenced by, their cognitive maps of the city. This is significant because studies on the “systematic distortions in cognitive maps” (Tversky 1992; Portugali 2011, Chap. 6) have shown that “the map is not the territory.” In other words, cognitive maps are not one-to-one representations of the environment; rather, they are often systematically distorted in several specific ways. In what follows, I aim to direct attention to a second cognitive capability by means of which urban agents adapt to fast cultural changes, namely, their relation to *time* and by implication to planning and design. The urban agents—the parts of the complex system city—are parts of a special kind: they are typified by *chronesthesia*, the ability to mentally travel in time to both the past and future. Unlike cognitive mapping that typify many species including humans, the cognitive property of chronesthesia seems to be unique to humans (Suddendorf and Corballis 2007).

1.3 Chronesthesia and the City

The notion of *Chronesthesia*, also known as *mental time travel* (MTT), was originally hypothesized by Tulving (1983) with respect to *episodic memory*. It refers to the brain's ability to think about—"mentally travel" to—the past, present, and future. The notion is associated with several domains of cognition. One example is *cognitive planning*, a domain that studies the cognitive ability of humans to think ahead to the future and to act accordingly now (Miller et al. 1960; Das et al. 1996; Morris and Ward 2005; Portugali 2011, Chap. 13). A second domain is the study of *prospective memory*, which explores human ability to remember to perform an intended or planned action (McDaniel and Einstein 2007; Haken and Portugali 2005). A third domain concerns cognitive processes that support *episodic simulation of future events* (Schachter et al. 2008). Recent neurological studies further indicate that certain regions in the brain "were activated differently when the subjects thought about the past and future compared with the present. *Notably, brain activity was very similar for thinking about all of the non-present times (the imagined past, real past, and imagined future)*" (Nyberg et al. 2010). "These processes together," write Schacter et al. (2008), "comprise what we have termed "the prospective brain," whose primary function is to use past experiences to anticipate future events."

The suggestion here is that the planning and design of artifacts are direct manifestations of humans' chronesthetic memory. Humans are, in this respect, natural planners and designers. And not only do humans have this ability to mentally travel in time, and are thus capable of MTT, but they also *cannot not mentally travel in time*; studies show that "unlike other animals," human beings spend about half of their waking hours "*thinking about what is not going on around them, contemplating events that happened in the past, might happen in the future, or will never happen at all*" (Killingsworth and Gilbert 2010). So much so, that "stimulus-independent thought" or "mind wandering" has been shown to be the brain's default mode of operation (Raichle et al. 2001; Buckner et al. 2008).

This tendency also includes urban agents—they too are natural planners and designers and as such *cannot not* plan or design.[1] The natural tendency to plan and

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[1] Obviously not all human action and behavior is planned and we thus need to distinguish between *planned behaviors* and *un-planned behaviors*.

design, as well as the fact that we seem unable to not do it, shed light on two properties of cities which are discussed below. The first concerns urban planners and designers in relation to the urban planned and designed, and the second concerns the nature of the urban landscape.

1.4 Planning and Design Behavior

Often the various cognitive capabilities are associated with distinct forms of behavior. For example, the ability of animals and humans to construct cognitive maps (Tolman 1948) is termed as *cognitive mapping* (Downs and Steas 1973, 1977), while their related ability to find their way informs *wayfinding behavior* (Golledge 1999). Related to both is *exploratory behavior*, referring to the animal (and human) tendency to start a process of exploration when introduced to a new environment (Drai et al. 2001; Eilam and Golani 1989; Blumenfeld-Lieberthal and Eilam 2016). In a similar way, I have shown (Portugali 2011) that the various cognitive planning capabilities of humans entail a distinct form of behavior that can be called *planning behavior.* To this I now add that design capabilities are also associated with planning capabilities and one may speak of *design behavior* as well as planning behavior.

The notions of planning behavior and design behavior lead to a new view of the city and the urban landscape: When observing a city, urban agents perceive not only the existing urban landscape of visible building, streets, parks an the like, but also *expected* buildings and other urban elements, that is, they see an urban landscape composed of urban entities that have been planned or designed but do not yet exist and might never be realized.[2] As a consequence, agents' behavior and action in cities is determined not only by responses to the present city, but by uncertain plans that have not yet materialized—that is, by what they and other agents expect, plan or intend to do.

Out of this observation a twofold question arises: How can we describe the city as a landscape of potentialities (of uncertain plans that have not yet materialized) and the way urban agents behave in it? I suggest we can do so by means of an interplay between two forms of information: Shannon's information and semantic information. This interplay has recently been termed *information adaptation* (Haken and Portugali 2015).

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[2] This might sound bizarre, but note, firstly, that agents' behavior in the stock markets, for example, is very similar to this perception of the planned/designed city in that it is largely dominated by expectations about uncertain future events—expectations that affect our immediate future whether they come to pass or not.

1.5 Information Adaptation and the City

1.5.1 Shannon's Information Theory

Information theory, developed by American mathematician Shannon (1948), deals with the capacity of *communication channel*s to transmit *signals* of all kinds, where a 'communication channel' might be anything from a telephone or a computer to a text, picture, dance or a bird's song, while 'signals' might similarly range from the "*bip, bip*" of Morse code to the letters of a text in any language, the notes of a melody, the colors of a painting or the behavioral body movements of a human or animal. This capacity depends on the statistical properties of the signals, but not on their meaning. In this sense, channel capacity is a fixed physical quantity in each specific case, devoid of meaning. Shannon suggested several notions of information quantity. The most common is Shannon's *information bits* (Shannon and Weaver 1949), which can be defined as follows:

$$I = \log_2 Z \tag{1.1}$$

where Z is the number of possible states the system can take.

An example of its use is the case of rolling a dice, where Z = 6 and I (the quantity of Shannonian information enfolded in the process of rolling of a dice) is about 2.5 bits. The more general definition of information bits, however, is Shannon's famous formula that defines information in terms of entropy:

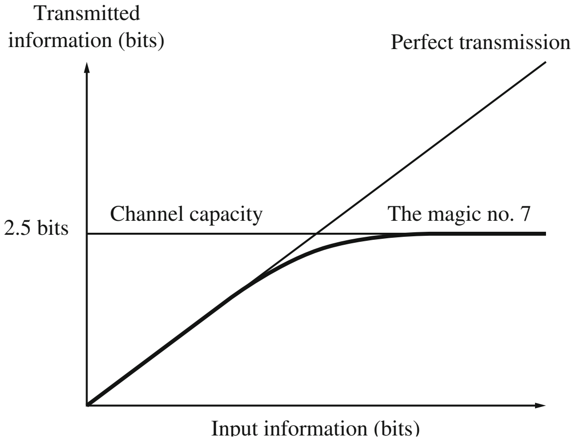
$$i = K \sum_k p_k \ln p_k, \tag{1.2}$$

This definition allows us to calculate the (information) entropy $\boldsymbol{i}$ of any signal with a known $\boldsymbol{p}$, that is, the relative frequency (or probability) of distribution of symbols, distinguished by the index k.

1.5.2 The Face of the City Is Its Information

Since Shannon launched information theory with his seminal paper (1948, for a review see: Gleick 2011), the theory has provided, and still provides, the foundation to any discussion of information; it was and still is central to the development of computer technology and science, communication and information sciences, and cognitive sciences. One early application in cognitive science was Miller's famous 1956 study: "The magic number seven plus or minus two: Some limits on our capacity for processing information." As the title indicates, Miller proposed evidence demonstrating that there is a limit the human capacity to process information in short term memory; it is about 2.5 bits (see: Fig. 1.2).

Fig. 1.2 The relations between input information and transmitted information according to Miller (1956): up to about 2.5 bits of information there is perfect transmission; beyond that threshold, transmitted information levels off. (*Source* Portugali 2011, Fig. 1.1)



A second set of cognitive applications was in Gestalt theory, in which it was used to show that "*good gestalt* is a figure with some high degree of internal redundancy" (Attneave 1959, 186). From the latter follow two implications: First, different (abstract or specific) forms transmit different quantities of information that can be measured by means of Shannon's information bits; Second, the quantity of information conveyed by an abstract or specific form "is a function not of what the stimulus is, but rather of what it might have been" (Garner 1974, 194). Thus, in Fig. 1.3, rotating the circle four times by 90° conveys zero information bits, as the circle remains the same whatever its rotation. A circle in this respect is "a good gestalt." On the other hand, rotating an L-shape form four times by 90° conveys two information bits ($i = \log_2 4 = 2$), as 90° rotations could give rise to four different forms. The first implication provided the starting point for the application of Shannonian information to cities (Haken and Portugali 2003), while the second property is key to the usage of information in this paper as a landscape of potentialities.

In "The face of the city is its information," we show that different elements in the city, as well as different configurations of these urban elements, afford the perceiving urban agents different levels of information that can be measured by Shannon's information bits (Haken and Portugali 2003; Portugali 2011, Chap. 8). Thus, as shown in Fig. 1.4, when all buildings in a street are similar to each other (top line), information *i is low;* when they are different (second line down), *i is high* but hard to memorize, because of Miller's "magic number seven"; when landmarks (i.e. high rises) are added to a street with otherwise identical buildings, at different

Fig. 1.3 Rotating a circle conveys zero bits of information; rotating an L-shape conveys two bits

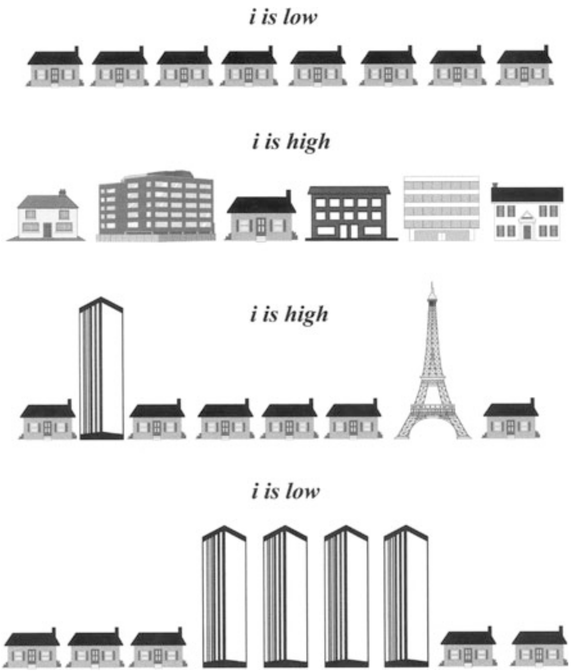


Fig. 1.4 When all buildings are similar (*top line*), *i is low;* when they are different (*second line down*), *i is high* but hard to memorize; when landmarks are added, but separated from each other (*third line down*), *i is high*; and when they are grouped (*bottom line*), *i is low*

Fig. 1.5 The tower house at Piazza del Campo, Siena (*left*), versus the tower houses of San Gimignano (*right*)

points (third line down), *i increases*; and when the high rises are grouped (bottom line), *i decreases*.

The last two cases can be exemplified by a comparison between the towns of Siena and San Gimignano, both in Tuscany (a region of Italy). In Siena, the tower overlooking Piazza del Campo (Fig. 1.5, *left*) acts as a landmark that clearly indicates the central square of the town. In San Gimignano (Fig. 1.5, *right*), the towers are too many and too similar, and as a consequence lose their meaning as landmarks within the city. However, as a group, they have become a symbol of the city of San Gimignano as a whole, distinguishing it from the more ordinary medieval typology of a single central tower, such as Siena's.

1.5.3 Semantic Information Enters in Disguise

"The face of the city is its information" also discusses the relations between Shannonian information, semantic information and complexity from the perspective of Haken's *Information and Self-Organization* (1988/2003). Given a receiver modeled as a dynamical complex system that has a number of attractor states, semantic information is defined as a message that carries meaning in the sense that it causes a specific effect on that receiver. The messages (signals) carrying semantic information are considered different if they cause the dynamical system to reach different attractor states. One can visualize such a dynamical complex system as a ball resting on a peak in a hilly landscape where the valleys represent basins of attraction into which, as a consequence of some initial conditions, the ball might roll (Fig. 1.6). Semantic information can thus be likened to a landscape of attractors representing different potentialities carrying different meanings.

We then claim that in the domain of cognition, semantic information enters in disguise into the definition of Shannonian information. ("In disguise", because Shannon's information is assumed to be independent of semantics). Intuitively, and with respect to Fig. 1.6, we can say that semantic information determines the landscape of hills and valleys, which from the point of view of Shannonian information defines the various possibilities open to the system (the ball on top of the hill). Mathematically this is so since the choice of the index $\boldsymbol{k}$ in (1.2) above requires the

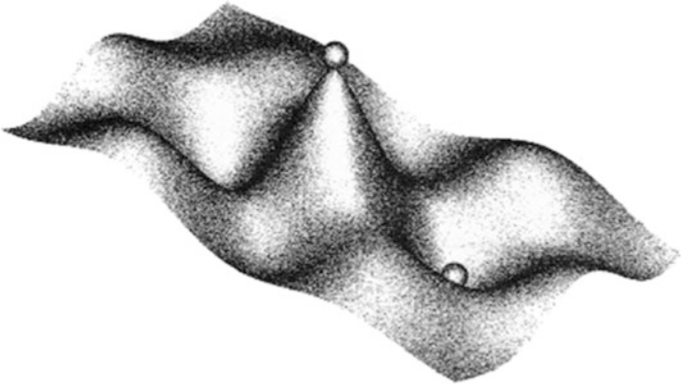


Fig. 1.6 Semantic information as a landscape of potentialities. (*Source* Haken 2004, Fig. 4.7. See also: Haken and Portugali 2011, Fig. 7.1)

categorization of urban elements such as buildings into, say, building styles (modern, postmodern and so on), functions (such as residential, offices, or industrial) or a combination of the two. Such a categorization implies giving *meaning* to different urban elements or, in other words, *applying semantic information.*

1.5.4 Information Adaptation

Semantic information thus participates in the determination of Shannonian information; but what about the inverse relations? Does Shannonian information affect, or participate in, the determination of semantic information? In our recent monograph on the topic (Haken and Portugali 2015) we explored the relations between Shannonian and semantic information more deeply. The result of this exploration is the notion of *information adaptation* (the title of the monograph) that emerges out of *the interplay between Shannonian and semantic information* (its sub-title). More specifically, we show that in cognition, Shannonian and semantic information are interrelated as two aspect of a process of information adaptation in which (as we've seen above) Semantic information controls Shannonian information, while Shannonian information generates semantic information.

A case in point is the process of vision, recently summarized by Kandel (2012) and modeled by Poggio and Serre (2013), on the basis of Hubel and Weisel's seminal studies (1959, 1962, 1965) and on Livingstone's more recent findings (2002), as well as the work of Freiwald and Tsao (2010). The process is illustrated in Fig. 1.7. Data from the environment is first analyzed (or "deconstructed," in Kandel's words) by the mind/brain, in a bottom-up manner, into local information of lines, corners and similar elements; this local information triggers a top-down

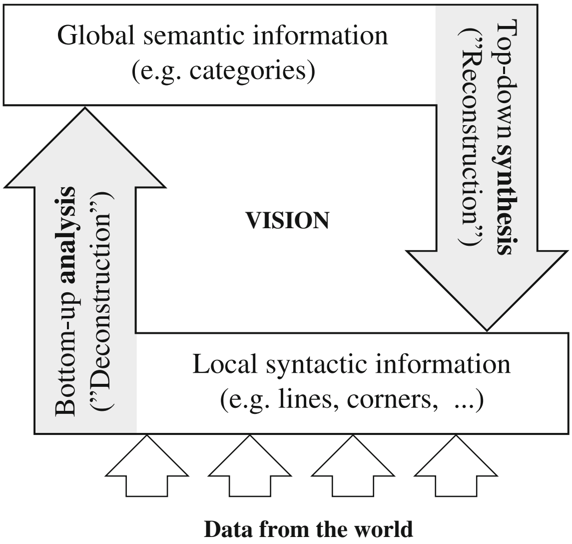


Fig. 1.7 A schematic description of the process of vision: data from the world is first analyzed by the brain, in a bottom-up manner; this local information triggers a top-down process of synthesis that gives rise to global information—that is, to seeing and recognition (See Haken and Portugali 2015)

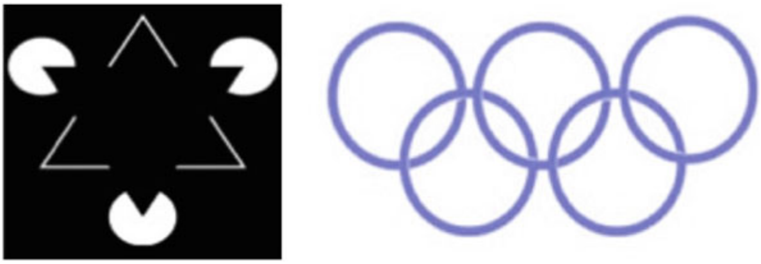


Fig. 1.8 *Left* the Kaniza triangle illusion. *Right* the "Olympic rings" illusion

process of synthesis ("reconstruction," for Kandel) that gives rise to global information—what we experience as seeing and recognition. In the synthetic process, global semantic information, such as categories, interacts with quantitative Shannonian local information. In this interaction, Shannonian information is adapted to semantic information by information inflation or deflation.

An example of information adaptation implemented by means of *information deflation* is the 'Kaniza triangle' illusion (Fig. 1.8, *left*), in which we see lines where there are none; our brain adds virtual line where no lines exist to mark out intersecting triangles. The "Olympic rings" illusion (Fig. 1.8, *right*) serves as an example of information adaptation implemented by means of *information inflation*: we see five circles in superposition and overlook the many geometric forms of which this figure is also be composed.

1.5.5 Information Adaptation in Behavior

In our recent monograph on information adaptation (Haken and Portugali 2015), our focus was on cognitive processes such as perception, learning and pattern recognition. Here I want to draw attention to an additional form of information adaptation related to cognition, namely information adaptation by means of *behavior*. I would also like to link information adaptation by means of behavior to 'chronesthesia and the city' and the implied planning and design behaviors discussed in Sect. 1.3. My suggestion is, first, that every urban element conveys *objective* or *syntactic* Shannonian information that refers to its potential possible states or uses of which, at each given time, one is materialized. As noted by Weaver (Shannon and Weaver 1949) Shannonian information can be (intuitively) interpreted also as a measure of "freedom of choice". For example, if a given element in the city is legally defined as a warehouse, it can be used in one way only which implies no choice; its Shannonian information is thus 0 bits:

$$I = \log_2 1 = 0 \text{ bits}$$

Second, I suggest that every urban element conveys *subjective* semantic information referring to the specific way each urban agent perceives that urban element.

For example, for a poor artist desperately looking for a place to live and to work, the warehouse conveys different meanings than it might to another urban agent, as a consequence of the many ways the artist could potentially use it: as an apartment, a studio and even a shop. Its semantically determined Shannonian information will now be about 1.5 bits:

$$I = \log_2 3 \approx 1.5 \text{ bits}$$

How does the artist urban agent come to perceive the warehouse urban element in the creative way described as above? The answer is simple: urban agents are influenced by a combination of imagination, pressing needs and, often, precedents —such as remembering reading or hearing that someone did something similar. More specifically, urban agents can perceive the potential of an urban element as a consequence of chronesthesia—the property that our artist, like every other urban agent, *cannot not* mentally travel in time. Because the artist travels back to the past to "see" precedents, and forward to the future to "see" urban states that do not yet exist, s/he can act accordingly. In short, subjective semantic information is created as a consequence of the fact that urban agents are cognitive planners and designers.

1.6 Lofts, Balconies and Butterfly Effects

The creative planning described above is, of course, the story of lofts in New York, London and other big cities around the world. As described by Kwartler (1998), in New York City, *ad hoc conversion of lofts in SoHo by individuals began in the 1960s, illegally and in contravention of both the New York City Zoning Resolution and Multiple Dwelling Law. Subsequently, this ad hoc activity was legitimized by revisions to both sets of regulations in 1982.*

A similar scenario unfolded in Tel Aviv (and subsequently across Israel) in what has been described as the "butterfly effect of Tel Aviv balconies" (Portugali 2011; Portugali and Stolk 2014). Here, back in the late 1950s or early 1960s, an anonymous urban agent perceived the future state of his/her open balcony as a half room, planned a set of activities for it, designed the specific form of this half room and implemented his plan and design. As in the case of lofts, it took several decades before the planning authorities legitimized closed balconies; in fact in Israel (and by extension Tel Aviv) this happened very recently—during the year 2010.

However, what made the New York and Tel Aviv planning authorities change the planning laws of their cities was not the lofts or closed balconies in themselves, but rather the processes of mass self-organization that followed the innovative actions of the heroes of our stories—the two anonymous pioneering urban agents. From the perspective of the city as a complex system, these self-organizing and legitimization processes are the really interesting stories: Following the first loft conversion and closed balcony, the neighbors and friends of our two heroes could see, appreciate and in time imitate the new creative invention. From that moment on a self-organized process of space-time diffusion of the innovative urban element started, very much in line with Hägerstrand's theory of *Innovation Diffusion as a Spatial Process* (1967).

In terms of information adaptation I would add that the first lofts in New York City and the first closed balconies in Tel Aviv have altered the semantic information of the urban landscapes of the two cities: urban agents no longer see an industrial district with warehouses or residential buildings with balconies, but potential lofts and half rooms. These alterations in the potential (not yet existing) semantic and Shannonian information content of the urban landscape affected the location decisions and actions of a growing number of urban agents who started to build lofts and to close balconies; as a consequence land and property prices went up, and the whole urban dynamic changed. The legalization of lofts in New York two decades after they first emerged and of closed balconies in Tel Aviv four decades after their first appearance, was a consequence of these complex, collective, self-organized effects—of the fact that they became integrative components of their cities' *order parameter*, that is, dominant and dominating urban form. (For a formal definition of 'order parameter' see Portugali 2011).

My suggestion is that this chronesthetic tension between Shannonian and semantic information—between the existing state of urban elements and their semantically determined Shannonian information—is the *generative order* of the city as a complex, cognitive self-organizing system; that there are many other, less prominent or well-known urban events than the conversion of lofts and balconies, involved in continually changing urban dynamics; that the above tension is the generator of the common saying in CTC that cities emerge and change from the bottom up, out of the interaction between their agents; that as complex systems, cities are always in a far-from-equilibrium state, and that they change by means of self organization.

1.7 Planners and Designers versus the Planned and Designed

If, as a consequence of chronesthesia and cognitive planning and design, urban agents are natural planners and designers, resulting in the kind of self-organizing cities discussed above, we need to rethink the definition of 'urban planner': What are we to do with the prevalent distinction drawn between professional city planners and designers and the rest of the city's inhabitants? Theories of urbanism, planning and design as developed since the early twentieth century tend to treat planning and design as external interventions in an otherwise spontaneous urban process. The structure of cities, according to this view, is seen as an outcome of bottom-up spontaneous processes, on the one hand, and top-down planning and design interventions, on the other. Bottom-up planning or design processes in cities are rarely qualified as 'design' or 'planning'. Notions such as "organic cities" or "unplanned cities" thus refer to exceptions that in fact prove the rule. This perception of planning and design typifies also most CTC, for which the central question is how to plan and design cities in light of their nature as self-organizing systems.

Our own studies about the complexity of cities in relations to planning and design take a different view. We propose that, due to the property of nonlinearity that characterizes the city as a complex system, the planning or design action of a single non-professional urban agent, planner or designer (such as any inhabitant of the city) often affects the city much more than the plans and designs of professional planners—the city's official planning team. The cases of lofts and closed balconies discussed above are prominent examples. Taken in conjunction with the view that urban agents are natural planner and designers, we see each urban agent as a planner or designer at a certain scale, while the urban dynamics as a whole are essentially the product of ongoing interaction between a large number of urban agents at various scales (for further discussion see: Portugali 2011, Chap. 15). This non-linear view of how the complexity of the city is continually produced removes the distinction between bottom-up urban agents' behavior and top-down planning and design intervention.

1.8 Toward a Unified Field of Study

So, what makes cities complex? The answer to this question is simple: urban agents. These urban agents have specific cognitive capabilities—they are mental time travelers—and thus natural planners and designers, making cities complex, or rather, dually complex environments. The conjunction between complexity, cognition, planning and design discussed in this paper indicates a potential for the emergence of a new field of study in which planning and design are not external interventions in an otherwise spontaneous and complex urban process, but rather integral elements in its dynamics.

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