Chapter 6
Cognition, Complexity and the City

One of the main conclusions from the previous chapter is the need for "a cognitive approach to urban dynamics"; more specifically, the need to add to CTC an explicit consideration of the cognitive dimension of cities and urban agents' behavior as developed in cognitive science. Several preliminary and preparatory steps toward this aim were made in previous papers (Portugali 2000, 2004, 2006a). Part II of this book that we now open attempts to integrate the previous studies and to provide a more comprehensive view on *Complexity, Cognition and the City*; the present chapter can be seen as an introduction to Part II. The discussion below develops by binding together the three elements of this project: cognition, the city and complexity. It starts with a concise introduction to cognition and cognitive science (Sect. 6.1). It then looks at the relations between cognition and the city (Sect. 6.2); next, at the relations between cognition and complexity (Sect. 6.3) and finally, at the implications thereof to the relations between cognition, complexity, and the city (Sect. 6.4).

6.1 Cognition

Similarly to "complexity" the notion *cognition* is not unequivocal, as different people in relation to different contexts and processes use it differently. In this chapter I'll use cognition as interpreted in Gardner's (1987) book *The Mind's New Science: A history of the cognitive revolution.* In this book Gardner describes the history of cognitive science as an interdisciplinary research domain that emerged in the mid-1950s when researchers in several fields began to develop theories of mind based on complex representations and computational procedures. According to Gardner, the disciplines involved in this interdisciplinary study of mind and intelligence embrace philosophy, psychology, artificial intelligence, neuroscience, linguistics and anthropology; however, as we shall see below, the study cities and urbanism should be included in this science, too.

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6.1.1 Cognitive Science – A Concise Introduction

Cognitive science – *the mind's new science* – started according to Gardner (ibid) in the mid-1950 as a rebellion against the paradigm of *behaviorism* that dominated the study of cognition and behavior in the first half of the 20th century. This rebellion gave rise to a new paradigm about the relations between environment, mind and behavior – the *information processing approach* – that nowadays in retrospect is called also *classical cognitivism*. As we shall see below, the notion of *cognitive map* (Tolman 1948) played an important role in this paradigmatic revolution – a fact that immediately connects the science of cognition to the study and science of cities. However, since its emergence in the mid-1950s the new science of cognition underwent several changes that have challenged the classical view. This section introduces behaviorism and classical cognitivism and then discusses some of the above-noted changes and the implications thereof to the notion of cognitive map and the study of cities.

6.1.2 The Black Box

The black box (BB) is often described as the model of behaviorism – the approach that dominated the study of cognition and behavior in the first half of the 20th century. This view which is mainly due to Skinner (1953) suggests that animals' and humans' behavior can be fully explained my means of the relations between stimulus and response (S-R) as they take place in the observable external environment. Behaviorism further suggests that the various phenomena that are commonly attributed to the notion Mind (e.g., perception, imagination, thinking, emotions) cannot be subject to scientific inquiry for the simple reason that they are not observable: one cannot see pain, happiness, images, thoughts, and the other products of Mind – neither in the observable behavior of organisms nor in the inner structure of the brain. Most importantly, behaviorism claims that the mind with its many faculties, while very interesting, is simply not needed in order to explain behavior. One can thus treat Mind as a black box (Fig. 6.1) and explain all behavior on the basis of stimulus-response (S-R) relations. Pavlov's (1927) *classical conditioning* is the classical and most famous set of experiments that illustrate this point of view. At a more philosophical level according to behaviorism behavior is essentially an adaptation to changing environmental conditions: when dealing with a short time scale we are thus dealing with conditioning, while when in long time scale with biological evolution.

6.1.3 Classical Cognitivism

Cognitive science, as noted, originated in the 1950s as a reaction and rebellion against behaviorism that dominated the field in the first half of the 20th century. Three persons were specifically important in this scientific revolution: Alan Turing

(1936), Noam Chomsky (1957) and Edward Tolman (1948). Turing, for his influential contribution to computer science, and concepts such as ‘algorithm’ and ‘computation’ that have become metaphors for the very process of cognition and cognitive science. Chomsky for demonstrating that the BB model of the mind cannot explain linguistic behavior; and finally, Tolman who in a set of experiments showed that the BB models fails also in the case of animals’ and humans’ way-finding behavior: in order to explain rats’ and humans’ way-finding behavior, a *cognitive map* must first be created and internally represented in the BB.

The scientific revolution that gave rise to the cognitive science was associated with what today in retrospect is called *classical cognitivism* and its *information processing approach (IPA)*. According to this view, there is a clear-cut separation between the mind as the cognitive system in the brain, the body within which the brain is located and of which it is part and the world outside. Cognition, according to this view is essentially the manipulation of symbols on the hardware of the brain. These symbols are essentially static entities – *internal representations* of the external extended environment (Fig. 6.1 *center* and Fig. 6.2 *top*). A typical cognitive process thus starts when in response to a certain need, task or environmental cue, the person’s mind/brain consults this internal representation and on the basis of this consultation takes decisions and sends instructions to the body how to act. According to classical cognitivism, a cognitive map is essentially an internal representation stored in the mind/brain and being consulted in processes of navigation and way-finding, location in space, way directions and the like. This view that dominated the studies of cognitive maps in the 1960s and 1970s is still influential today.

6.1.4 Embodied Cognition

Classical cognitivism and its information processing approach are not as dominant as they used to be in the past. New paradigms, such as PDP (*Parallel Distributed Processing*) and *neo-connectionism* (Rumelhart et al. 1986), pragmatist environmental cognition (Freeman 1999), *experiential realism* (Johnson 1987; Lakoff 1987), *situated cognition* (Calencey 1997) and *embodied cognition* (Varela et al. 1994), seem to seriously challenge the classical view. The notion of *embodied cognition* (ibid) commonly serves also as an umbrella term to these challenging views and so it will be used here.

According to these views (Figs. 6.1 *bottom*, 6.2 *bottom*), cognition is *embodied* in the sense that mind and body are not independent from each other but form a single integrated cognitive system, and in the sense that many cognitive capabilities are derived from the bodily experiences in the environment. The notion *affordance* as developed by Gibson (1979a) in his article “the theory of affordances” and in his *The Ecological Approach to Visual Perception* (Gibson 1979b) captures these relations between mind, body and environment in an innovative way. It suggests that the mind/brain of organisms do not perceive the environment objectively as it is, but rather the bodily “action possibilities” it affords to that kind of organism

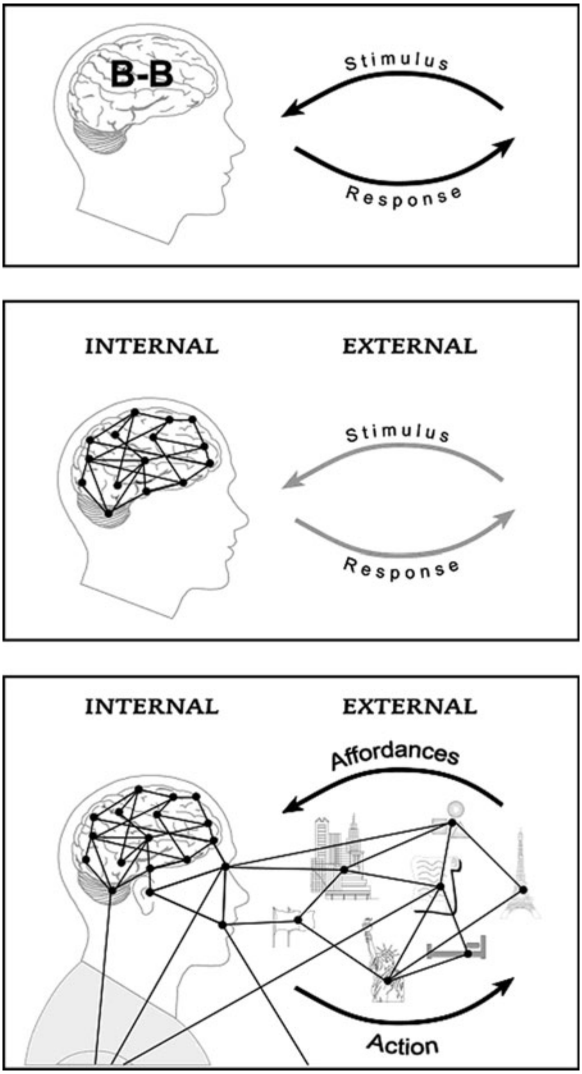

Fig. 6.1 *Top:* The BB model of behaviorism. *Center*: The model of classical cognitivism. *Bottom*: Embodied cognition

Fig. 6.2 Two approaches to the interrelationships between perception and action: (a) classical cognitivism in which perception is independent from action; (b) embodied cognition in which perception and action form a single system

Fig. 6.3 The barrel affords climbing (is "climbable") to the cats but not to the dog

(Fig. 6.3). It further suggests that a lot of perception is implemented by practically acting on the environment or on elements in it. Thus, in Fig. 6.4 the person perceives the properties of the paper by cutting it when the intermediate artifact (in this case scissors) is functioning as an extension of the body. Accordingly, perception and action are not two independent faculties, but two facets of a single *action-perception* integrated system, and cognition is *situated* (Calensey 1997), that is, intimately related to the environment within which it takes place. A cognitive map according to this view is an ad-hoc entity – an event created in the brain in relation to a certain bodily action situated in a specific environment.

6.2 Cognition and the City

The history of the relations between the study of cognition and the study of cities can be described by reference to three main disciplines: psychology, architecture and human geography. It started in psychology with Tolman (1932, 1948) who, in his papers on "Cognitive Maps in Rats and Men", has coined the term *cognitive map*. It has later originated once again, independently of Tolman, in architecture and town planning with Lynch's (1960) *The Image of the City*, and a short while

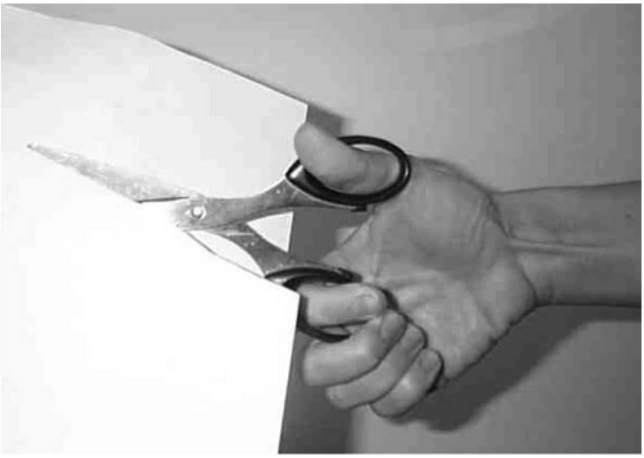

Fig. 6.4 An artifact often functions as an extension of the body. This figure follows Gibson's (1979b) Fig. 3.1, on which he writes: "A tool is a sort of extension of the hand. This object in use affords a special kind of cutting, and one can actually feel the cutting action of the blades"

afterwards appeared in human-urban geography. While it is hard to pinpoint a single starter in geography, David Lowenthal's seminal paper from 1961 might be a candidate, even though his specific approach was not followed.

The interests of the various partners in this interdisciplinary project varied. The psychologists were interested mainly in processes inside the mind/brain; the architects in the ways the architectural structure of buildings and cities are imagined – such knowledge they believed will enable them to design better cities. The urban geographers were looking for an improved behavioral model to location theory; the study of mental or cognitive maps, they maintained, was to provide a psychologically sound alternative to the unsatisfactory *Homo Economicus* model that was assumed as the behavioral model of the economically oriented location theory and spatial analysis that dominated human geography in the 1950s and 1960s. Lowenthal's interest in geographical epistemology that concerns "all geographical thought, scientific and other: how it is acquired, transmitted, altered and integrated into conceptual systems . . ." had no continuation in cognitive map studies, nor in alternative approaches of humanistic geography.

6.2.1 Cognitive Maps

The notion cognitive map (CM) is due to Tolman (1948), as noted, who in a set of experiments conducted during the 1930s and 1940s has shown that animals and humans have the capability to construct in their minds a representation of the external extended environment they experience (Fig. 6.5). Tolman's work had no connection to cities of course. It was originally directed to psychologists and as

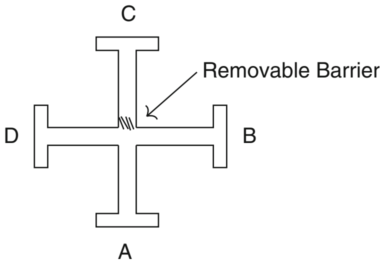

Fig. 6.5 Tolman's maze experiment. First, the rats were placed at A when B was the goal (food). Second, the rats learned several times to run to B to get the food. In doing so, they would have to turn right to get to point B. Third, the rats were placed at point C. Now, if the rats turned right and went to point D, then they were not using cognitive maps; however, Tolman found they turned left and went to section B thus proving the use of cognitive maps

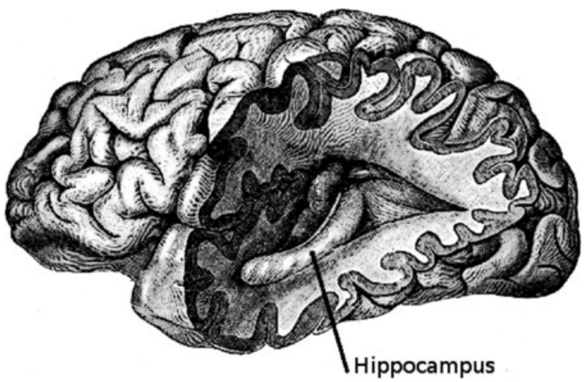

Fig. 6.6 The hippocampus, according to Okeef and Nadel's (1978), functions as a cognitive map

we've seen above, it played an important role in creating cognitive science and its specialized subdomain of *spatial cognition*. Some subsequent landmarks are Okeef and Nadel's (1978) *The hippocampus as a cognitive map* in which they establish the fact that the part of the brain known as *hippocampus* is of special importance in various cognitive tasks associated with space such as spatial behavior, navigation, way-finding and the like. An interesting notion in their book is the so-called *place cells* originally described by O'Keefe and Dostrovsky (1971). These are neurons in the hippocampus that become activated and fire in high rates when the animal gets close to the cells' *place field*, that is, the specific locations in the environment that correspond to the place cells.

6.2.2 The Image of the City

In *The Image of the City*, Lynch (1960) suggests five elements that according to him are specifically significant in shaping people's images of the city and in making the city *legible*. These five elements are *landmarks*, *nodes*, *paths*, *districts* and *edges* (Fig. 6.7). Examples of famous landmarks are the *Eiffel tower* in Paris or the '*leaning tower*' of Pisa, famous nodes are *Piazza San Marco* in Venice and *Tiananmen square* in Beijing, for paths *Fifth Avenue* in New York and *Oxford Street* in London are well-known examples while Paris' *Quartier Latin* and *Copacabana* in Rio de Janeiro are examples of a district and an edge, respectively. These are famous examples but each city in the world has its own nonfamous elements that make it legible.

Despite the intuitive nature of Lynch's elements their influence was very strong, so much so that subsequent suggestions to improve them or reconsider them never took off; not when Golledge (1999) suggested looking at urban elements in a more general way, namely in terms of *points*, *lines*, *areas*, and *surfaces*; and not even

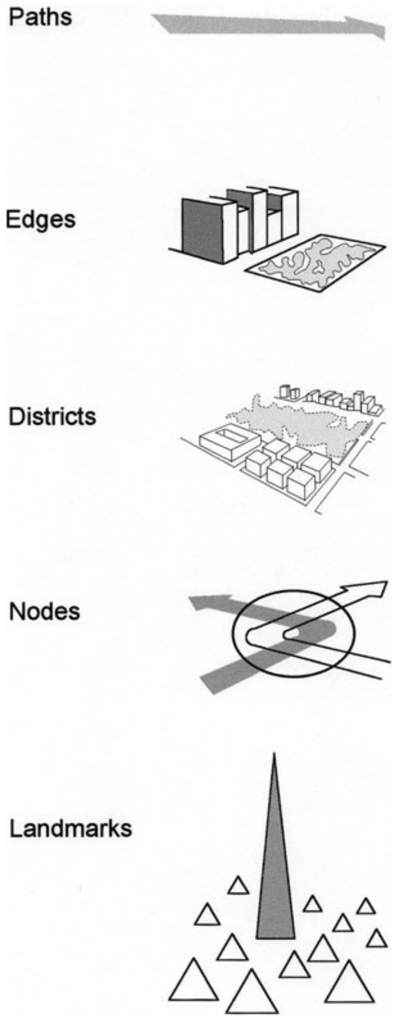

Fig. 6.7 Lynch's (1960, p. 47-8) five elements are specifically significant in shaping people's images of the city and in making the city *legible*

when Lynch himself, in a paper from 1985 "Reconsidering the image of the city", justified some of the criticisms and added a few more critical points of himself (too small sample size, for instance). In the 1980s, Lynch's *Image* was already moving in its own trajectory irrespective of the critics including Lynch himself.

The five elements according to Lynch are means to create (and find out) the target of Lynch's study – "the external look of cities" and the way this external look makes the city legible in a way similar to "the page you are now reading". By *legibility* he means

> *. . .one particular visual quality: the apparent clarity or "legibility" of the cityscape. . . The ease with which its parts can be recognized . . . a legible city would be one whose districts or landmarks or pathways are easily identifiable and are easily grouped into an over-all pattern* (Lynch, ibid 2–3).

6.3 Cognitive Cities

Despite the obvious similarity between the notion *cognitive map* and the notion *Image* and the fact that Tolman's work was well known when Lynch conducted his experiments, Lynch never made a connection to the work of Tolman; neither in his original book from 1960 nor 25 years later in the above-noted paper "Reconsidering the image of the city" (Lynch 1985). The name "Tolman" and the term "cognitive map" are not in the subject index and bibliography of these studies and not even in the collection *City Sense and City Design* (Banerjee and Southworth 1990) that was edited by Lynch's students and contains studies by himself and his coworkers. In fact, the link was never properly made. Writing on this issue in the late 1990s Allen (1999) expresses hope that Kosslyn's (1980) *Image and Mind* can provide an entrance for Lynch's Image into the domain of cognitive science. The difficulty of linking Lynch's images to Tolman's cognitive maps and to Kosslyn's cognitive images is that cognitive scientists Tolman and Kosslyn were concerned mainly with images as an internal representation constructed in the mind/brain, whereas the architect Lynch with properties of the externally represented/constructed environment that made (images of) cities legible. The theory of SIRN (synergetic inter-representation networks) presented in the next chapter enables a simultaneous treatment of these internal and external representations.

While Lynch's project never made contact with Tolman's, it nevertheless catalyzed the emergence of a specialized research domain on the interface between cognitive science and the study of cities termed 'environmental cognition', spatial behavior or 'cognitive geography'. Since its emergence in the 1960s/1970s the central focus of this research domain moved away from Lynch's Image with its focus on cities and their external appearance toward Tolman's cognitive map with its focus on spatial cognitive capabilities such as spatial behavior, navigation, reasoning, wayfinding and so on. Subsequent studies in this research domain have further elaborated on cognitive maps showing their various properties and also, often by implication, the differences between cognitive maps and the real structure of cities. Two aspects of these differences that are relevant to subsequent chapters – ‘systematic distortions in cognitive maps’ and ‘kinds of cognitive maps’ – are discussed next.

6.3.1 Systematic Distortions in Cognitive Maps

One important (and entertaining) research tactics in cognitive science is the use of ambivalent patterns, pictures or sentences; that is, patterns that deceive the mind/brain to the extent that it fails to recognize the offered pattern. Examples are the Muller-Lyer and checker-shadow illusions that are shown in Fig. 6.8. The research domain on systematic distortions in cognitive maps applies this method to the study of cognitive maps. It shows several cases in which cognitive maps as internal representation in the mind of subjects systematically differ from the real map and real environment (Tversky 1992). The notion *systematic* comes to indicate that such distortions are typical to every normal person and they result not because of some malfunction of the mind/brain but because of the exact opposite – because it works perfectly.

One well-known systematic distortion is Stevens and Coupe’s (1978), distortion due to *hierarchical organization*; another is Tversky’s (1981, 1992) distortion due to *rotation*; a third one is Holyoak and Mah’s (1982) distortion due to cognitive *perspective*. Figure 6.9 illustrates the first of these distortions. In our own studies (Portugali 1993; Portugali and Omer 2003) we’ve found distortions due to *attention*

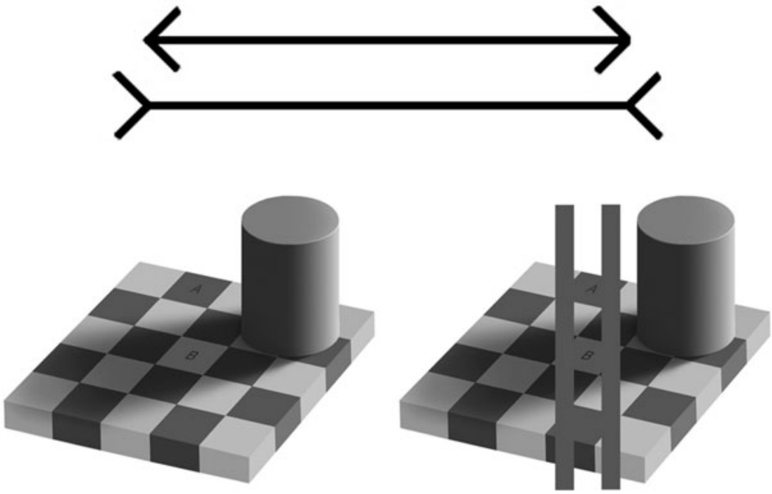

Fig. 6.8 *Top*: The Müller-Lyer illusion devised by him in 1889. Viewers invariably “see” that the lower line is longer than the upper one; yet the two are identical in their length. *Bottom*: The Checker-shadow illusion. The squares marked A and B are the same shade of gray, yet they appear different (*left*). By joining the squares marked A and B with two vertical stripes of the same shade of gray, it becomes apparent that both squares are the same (*right*)

Fig. 6.9 In a paper entitled "Distortions in judged spatial relations", Stevens and Coupe (1978) reported on an experiment in which subjects in San Diego, California were asked to indicate from memory the direction to Reno Nevada. Most subjects have indicated that Reno is northeast of San Diego, while from the map it can be seen that it is, in fact, northwest. Stevens and Coupe's interpretation is that this distortion is due to *hierarchical organization* of spatial knowledge. That is, people tend to store in memory not the exact, or relative, location of all cities, but rather the relative location of states. Thus, when asked to make judgment about directions between cities, subjects infer the direction between cities from the spatial relations between the states

or *situation* and distortions due to *nonlinearity*. They are presented in Figs. 6.10 and 6.11, respectively, with further details in the captions to these figures.

From the point of view of urban dynamics the lesson from the above studies is twofold: first, humans behave in space not according to the real structure of the environment, but rather according to their cognitive maps of it. Second, cognitive maps and other images of the city according to which humans behave in space are often systematically distorted.

6.3.2 Kinds of Cognitive Maps of Cities

Despite its attraction, the term cognitive map was never fully and clearly defined with the consequence that different scholars mean different things when referring to it. Thus, for O'Keef and Nadel (1978) a cognitive map is a certain part of the brain – the hippocampus, place-cells and the like, while for cognitive geographers and psychologists it is a metaphor for internally represented information about the external extended environment. The obscured nature of the concept cognitive map (Tversky 1992; Kitchin and Blades 2002) has led Roberts (2001, p 16) to argue "that the term cognitive map may have lived its usefulness", but now it is time for it to go.

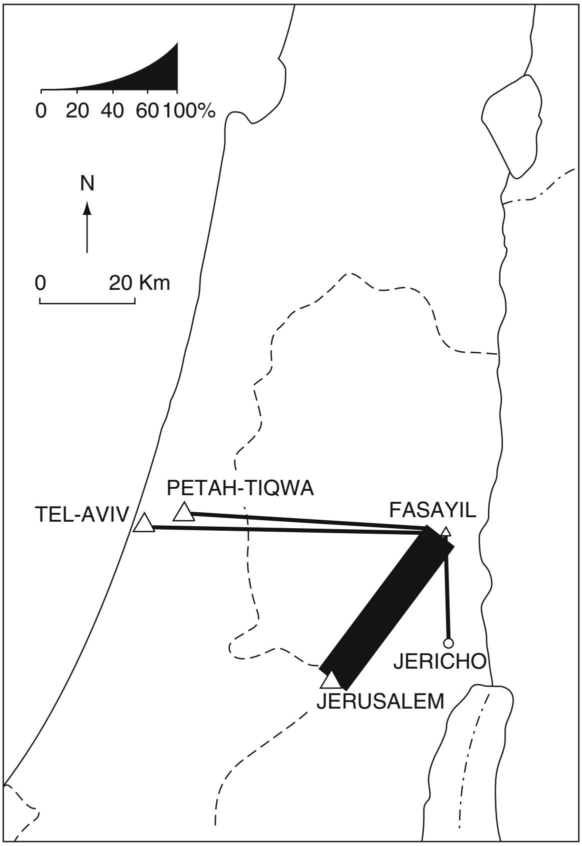

Fig. 6.10 Situated distortion. In an experiment conducted by Portugali (1993) inhabitants in the settlement Fazael were asked to indicate the nearest city to their own settlement. Most respondents indicated Jerusalem, while from the map it can be seen that it is, in fact, Jericho. Unlike the above distortion due to hierarchy, here all respondents inevitably knew the geographically correct relations as the road to Jerusalem goes via Jericho. However, their situation (Israelis living in the occupied territories interviewed in Hebrew by an Israeli) drew their attention to Israeli towns/cities only

In a subsequent paper “Cognitive maps are over 60” (Portugali 2005) it has been claimed that “the rumors about the death of cognitive maps are rather pre-mature”. That its many possible meanings and forms suggest, in fact, a new research agenda. More specifically, that the obscurity of the notion is, among other things, a consequence of (1) the development of ontologies in cognitive science with respect to the very nature of cognition and cognitive processes (above Sects. 6.1.4); (2) the related development of research about kinds of memory and (3) the fuzzy boundary between the notion cognitive map and the cognitive process of categorization. The paper has further suggested that it would be useful to treat the notion cognitive map not in terms of a single meaning entity, but in terms of *kinds of cognitive maps*. As an illustration the paper then introduces several kinds of cognitive maps that result from: (1) different

Fig. 6.11 In an experiment conducted by Portugali and Omer (2003) subjects were asked to indicate from memory the direction from Haifa to Tel Aviv, Ashkelon and Beer Sheva. In the case of Tel Aviv and Ashkelon most responses were accurate (southwest); on the other hand, however, most subjects have indicated that Beer Sheva is southeast of Haifa, while from the map it can be seen that it is, in fact, southwest. Portugali and Omer's interpretation is that most subjects underestimated the cumulative effect of a bending edge, namely, that the Israeli coastline bends westward "exponentially" in a nonlinear fashion with the implication that what to the eye looks as a slight inclination of the coastline westward, off the N-S axis, near Haifa, might accumulate to some 60 km at the south part of the country. Nonlinear relations are counter-intuitive and hard to perceive and judge

ontologies – classical, embodied and SIRN cognitive maps; (2) different kinds of memory such as autobiographic, prospective, short-term and long-term cognitive maps; and (3) conceptual vs. specific, that is, c- vs. s-cognitive maps.

In what follows I suggest that this conception of cognitive maps implies a new view on Lynch's thesis: In place of his "The image of ***a*** city" the suggestion here is to think in terms of *Images of cities* resulting from different ontologies, kinds of memory and processes of categorization. The following are examples for different images of cities:

Classical cities. These are the result of the ontology of classical cognitivism. These cities are perceived as essentially static symbols, internal representations of the external real cities. In response to a certain need or task, the person consults this internal representation and on the basis of this consultation takes decision and sends instructions to the body how to act. This view that has dominated cognitive maps studies in the 1960s and 1970s is still dominant today as noted.

Embodied cities. These cities are implied by the pragmatist ontology of embodied cognition as described above. An image of a city according to this view is an ad-hoc entity – an event created in the brain in relation to a certain bodily action situated in a specific environment.

SIRN cities. The SIRN (synergetic inter-representation networks) view will be presented in full in the next chapter. Here it can be said that SIRN views the image of cities in a way similar to the embodied view, that is, an ad-hoc entity – an event created in the brain in relation to a certain bodily action situated in a specific environment. However, it emphasizes that this event evolves as a play between internal representations that are 'subevents' constructed by the mind, and external representations that are events constructed in the world. Such a play gives rise to an inter-representation network that in a process of circular causality constructs the world outside and inside.

Autobiographic cities (ABCities). Such images of cities are part of each person's *autobiographic memory* and as such refer to the way memory for everyday personal experiences in space is influenced by the passage of time. In light of research on this kind of memory (Schacter 1996) one can propose, first, that ABCities are dynamic entities, that is, they change in time and are sensitive to the specific cues that generate them. Figure 6.12 illustrates two ABCities drawn by an Ethiopian Jew

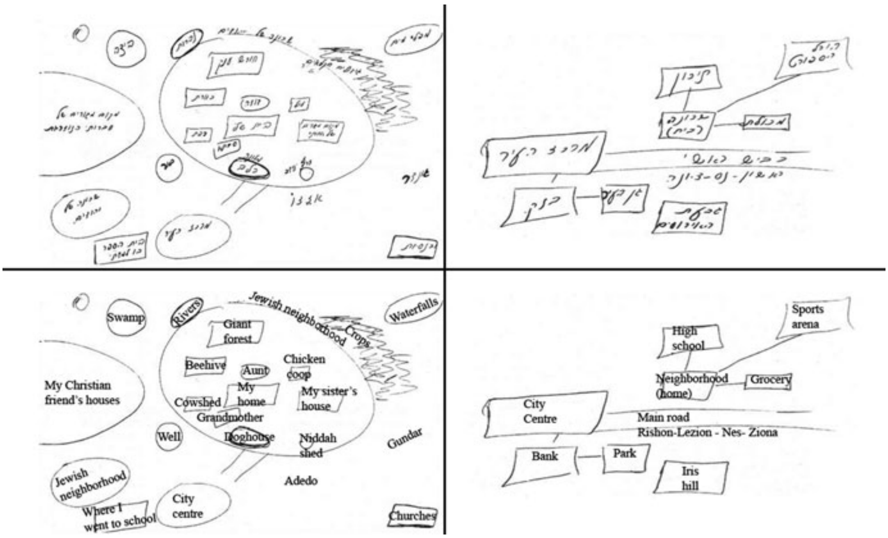

Fig. 6.12 ABCities drawn by an Ethiopian Jew living in Israel. *Top* (*left* and *right*): The original drawings with their Hebrew text; *bottom* (*left* and *right*): the same drawings with their text translated to English. The differences are dramatic: the drawing of the home left in Ethiopia is full of details, affection, and nostalgia (*left*); it is what humanistic geographers (e.g., Relph 1976) would call *place*. The drawing of the current home is rather alienated with very few details and no signs of affection (*right*); it provides a good example to what Relph (ibid) has defined as *placelessness*

living in Israel. These two figures are taken from a study in which Ethiopian Jews who immigrated to Israel during the 1990s were asked to produce two drawings: one describing the neighborhood and home left in Ethiopia (Fig. 6.12 *top*) and another (Fig. 6.12 *bottom*) describing the current neighborhood and home in Israel (Fenster 2000; Portugali, in preparation).

Prospective cities. These images of cities are the product of a certain kind of memory termed *prospective memory* (PM) that refers to the future use of memory – one "remembers to remember" and then to perform (Sellen et al. 1997). Cases of PM are commonly divided into *time-dependent* and *cue-dependent* PM (Brandimonte et al. 1996; Marsh & Hicks 1998). In a paper entitled "A synergetic approach to cue-dependent prospective memory" Haken and Portugali (2005) indicate possible links between the notions of PM and cognitive maps of cities and in a subsequent paper two forms of prospective CMs have been elaborated (Portugali 2005). Prospective cities thus refer to images of cities we expect to visit or images of future cities. As we'll see below, images of prospective cities affect human behavior and decision making in existing cities.

C- vs. S-cities. Due to the cognitive capability for categorization, each person has images of specific cities (s-city) and also an image(s) that refer to the category 'city', that is, to a city in general (c-city) (Portugali 2004). The significance of this distinction is that in the absence of specific information about *the* city one can still behave successfully in the city by using one's information about *a city*, namely about the category city. Or, put differently, in the absence of an s-cognitive map of a certain city one can still function successfully in the city by using one's c-cognitive map of a city.

Studies about memory and categorization indicate that people employ different kinds of memory in different circumstances and for different cognitive tasks. The same applies to cognitive maps and to the above kinds of cognitive maps. For example, short-term cognitive maps of cities are used when someone asks you how to get from here to there (Couclelis 1996); autobiographic cognitive cities might be employed when you return to, or describe, your home town/village/neighborhood; c-cognitive maps are employed, for instance, when you arrive to a new city you've never visited before.

What are these cognitive cities? Are they fixed entities as suggested by the classical ontology, or, ad-hoc entities as suggested by the embodied ontology? How do they emerge? How and when do people use different cognitive cities? To answer these and similar questions we shall first look at the relations between cognition and complexity and then at the implications to cognitive maps, spatial behavior and the dynamics of cities.

6.4 Cognition and Complexity

The title 'cognition and complexity' comes to indicate that I see cognition as a complex system and the various cognitive processes, ranging from perception to behavior, as processes exhibiting the properties of emergence, self-organization and the like. Still more specifically the text below is strongly influenced by Haken's theory of synergetics which is to my mind the complexity theory that has contributed most to the study of brain functioning and cognition (Haken 1996, 2002).

Complexity enters cognitive science in four ways: first, through neurology and neurobiology – the brain with its about 10^{11} (100 billion) neurons each with about 10^4 connections is often mentioned as the ultimate example of a complex system. Second, the various cognitive processes are typical examples of emergent properties: cognitive phenomena such as perception, thinking, speech, writing, emotions, behavior, and action of all kinds involve a huge number of interacting parts (ranging from neurons to muscles) and exhibit macroscopic properties that are absent at the microscopic level of individual cells. Third is the puzzle of the homunculus: In their *The Self and its Brain* Popper and Eccles (1977) portray the entity *Self* as a kind of programmer on the hardware (computer) of the brain. This interpretation raises the question of how the Self is created in the first place (Fig. 6.13). The logical answer would be by means of a program programmed by another Self (e.g., homunculus) smaller than the first one, and so on, until infinitum. Complexity theory solves this problem by the notion of self-organization, namely by suggesting that a central property of complex systems is the process of emergence in which the interaction between parts at the microscopic level entails emerging properties at the macroscopic level.

Finally, the view of embodied cognition comes close to complexity: unlike classical cognitivism that sees cognition in terms of interaction between two independent systems (brain versus environment) or even three (mind, body, environment), embodied-situated cognition sees cognition in terms of an interactive

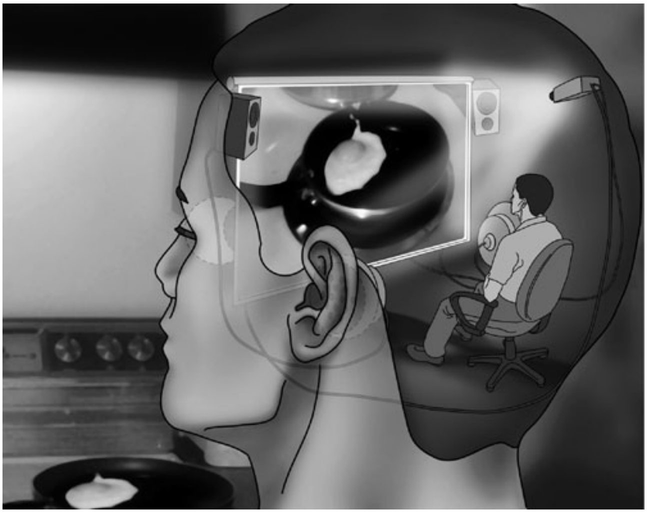

Fig. 6.13 The paradox of the homunculus (Latin for 'little man'). Poper and Eccles (ibid) portrey the entity *Self* as a kind of programmer (i.e. homunculus) on the hardware (computer) of the brain. But who/where is the homunuclus of the programmer's mind/brain and the homunculus of the homunuculus's homunuculus' mind/brain . . .?

system that includes the brain, the body and the environment as its subsystems. The weakness of the embodied cognition view was the question of how such a subsystem comes into being. The answer comes from complexity theories: by means of self-organization! This view was elaborated by Haken's synergetics studies on brain and cognition (see below) and also by people such as Edelman (1992), for example, in his *Bright Air, Brilliant Fire – On the Matter of the Mind* and Freeman (1999), for example in his *How Brains Make Up Their Minds*.

6.4.1 Synergetics and Cognition

Of the various theories of complexity synergetics has the most direct and intimate relations with brain and cognition. Since he started to develop the theory of synergetic in the late 1960s Haken with his coworkers have devoted a major proportion of their research energy to the study of cognition and brain functioning. These studies were integrated in several books such as *Synergetics of Cognition* (Haken and Studler 1990), *Synergetic Computers and Cognition* (Haken 1991/2004), *Principles of Brain Functioning: A Synergtic Approach to Brain Activity, Behavior and Cognition* (Haken 1996).

As we've seen above (Chap. 4, Sect. 4.2.2) the theory of synergetics was developed by reference to several paradigmatic case studies. In Chap. 4 above we've introduced two – the laser paradigm and the pattern-recognition paradigm; in Chap. 7 below we apply the pattern recognition paradigm to the study of cognitive maps. In order to complement the picture we now introduce the third – the finger movement paradigm.

6.4.1.1 The Finger Movement Paradigm

The finger movement experiment was first conducted by Kelso (1984) and further interpreted by Haken, Kelso, and Bunz (1985). The physiologist Kelso asked test persons to move their index fingers in parallel at the tempo of a metronome. At the beginning when the tempo of the metronome and the frequency of the finger movement were small this behavioral task could be performed quite well. Gradually the experimenter increased the speed of the metronome and the finger movement. Then suddenly, quite involuntarily, a switch to another kind of movement occurred, namely, to a symmetric movement (Fig. 6.14). The control parameter here was only the speed of the finger movement. This behavioral phase transition has been modeled by means of synergetics in all details, including the so-called critical fluctuations and critical slowing-down.

As can be seen, this experiment illustrates self-organized behavior of an individual person. Another experiment conducted by Schmidt, Carello and Turvey (1990) indicates that the same happens in the case of two persons (Fig. 6.15). In the latter, two seated persons were asked to move their lower legs in an antiparallel fashion and to watch each other closely while doing so. As the speed of the leg movement

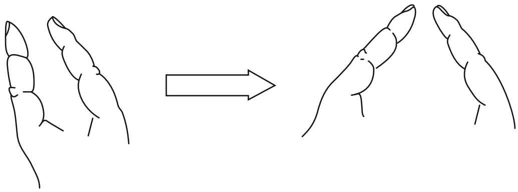

Fig. 6.14 Kelso's finger movement experiment. While initially people can move their index fingers in parallel, beyond a critical speed of the finger movements the relative position of the fingers switches involuntarily to the antiparallel, i.e., symmetric, position

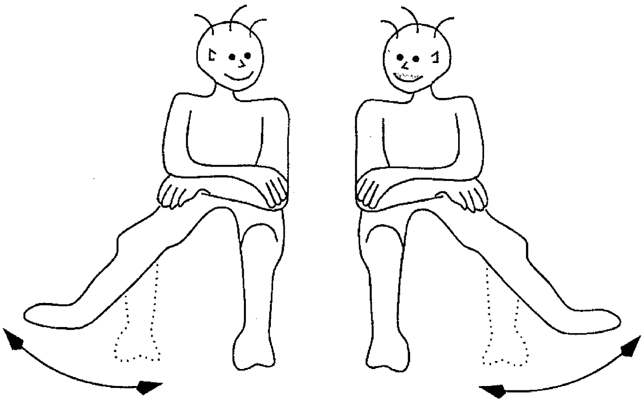

Fig. 6.15 The Schmidt, Carello, and Turvey (1990) leg movement experiment with results identical to the above Kelso's experiment

was increased, an involuntary transition to the in-phase motion suddenly occurred, in line with the Haken-Kelso-Bunz (ibid) phase transition model (Haken 1996, p 87–90). This experiment is of special significance because it implies collective behavior – a phenomenon that plays an important role in urban dynamics and has yet to be fully analyzed from this perspective.

6.4.2 Self-Organizing (Cognitive) Maps

The notion of *Self-Organizing Maps* (SOM) as developed by Kohonen (1995/2001) is a mathematical model that converts the nonlinear relationships between high-dimensional data into a simple two-dimensional grid of nodes thus enabling the visualization of high-dimensional data. According to Kohonen, a SOM is a two-facet entity: On the one hand, it is a model of *brain maps* while, on the other, a mathematical tool that compresses information while preserving the most important topological and/or metric relationships of the primary data (ibid 106) – similar to *multi-dimensional scaling*, for instance (Borg and Groenen 2005). As a model for

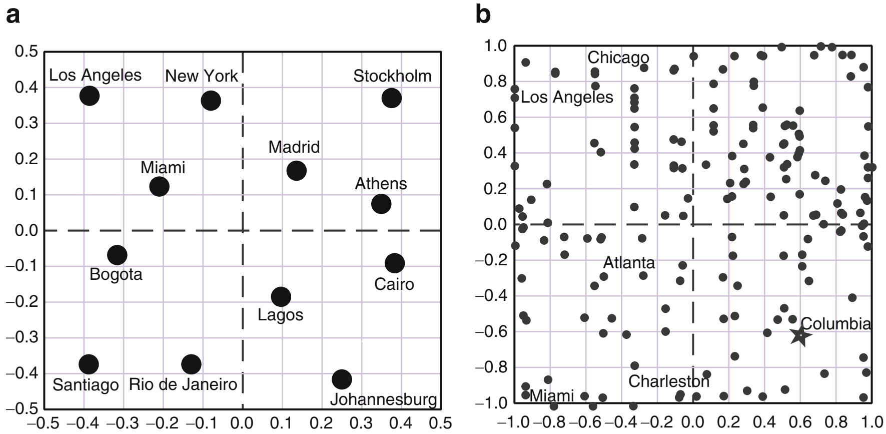

Fig. 6.16 Lloyd's (2000, Figs. 3 and 7) SOCM. Plots of the location of 12 world cities (*left*) and 232 US cities (*right*) simulated by the Kohonen neural network. In both cases the SOCM are systematically distorted

brain maps, SOM refer to a long history of brain mapping studies that have revealed several kinds of brain maps, ranging from genetically determined maps to maps affected by experience. Examples of the latter kind are 2D brain maps that correspond to a specific geographical location in the environment or abstract brain maps that correspond to the spatial relations between the elements of certain categories. As an information compression tool, the SOM methodology has been applied to a very wide range of studies such as speech recognition, image analysis, the visualization of financial records, processes of categorization and more (see Kohonon 2001, p 104 for further details), and also to cognitive mapping.

In a paper from 2000, Lloyd has coined the notion of *self-organized cognitive maps* (SOCM). In that study he applied Kohonon's SOM to two sets of data about cities in continents that rim the Atlantic Ocean and cities in the USA. Lloyd's findings are interesting in that the resultant 2D SOCMs are systematically distorted, thus indicating that the process model authentically simulates the way systematic distortions are created in real minds/brains of humans (Fig. 6.16). In the last decade there were several other studies that employed the SOM model (e.g., Skupin and Hagelman 2005).

6.5 Complexity, Cognition and the Dynamics of Cities

As we have just seen, cognition and the city are strongly connected via studies on cognitive maps, spatial behavior and the like. On the other hand, complexity and cognition are strongly connected due to the complexity of the mind/brain. We've further seen that few studies started to approach cognitive maps of, and spatial behavior in, cities from the perspective of complexity theories. The focus in these studies as in cognitive science in general is on the individual agent. Can one go one step further and link complexity and cognition with the dynamics of cities? The answer to my mind is positive. However, in order to do so one has first to cross three boundaries that stand in the way of this link: the boundary of 'the city as an arena', the boundary of 'the city as a derivation-representation' and the boundary of 'reductionism'. They are discussed next.

6.5.1 The Boundary of the City as an Arena

Since Lynch's (1960) *The Image of the City* and Tolman's (1948) "Cognitive maps in rats and men" the study of cognitive mapping, cognition and behavior in the city have become a genuine interdisciplinary research domain. The number of studies in this domain is very large and the spectrum of topics vast (for surveys see Golledge and Stimson 1997; Kitchin and Blades 2002). But one aspect is missing from these studies – the way human cognition affects the dynamics, evolution and change of cities. The vast majority simply ignores the issue. Occasionally there is a voice (e.g., Clark 1993) contending that cognitive scientists should relate spatial behavior to the dynamics of the urban structure, but by and large they do not. "Much of the work of behavioral geographers", write Golledge and Stimson (1997, p 486) "has focused more on why people move and less on the impacts . . . on the structure of urban areas".

For the majority of environmental psychologists and behavioral urban geographers the city is essentially an arena full with landmarks, paths and other Lynchian "elements" that effect people's image of the city, that function as cues for spatial behavior, decision making and the like, but not a dynamic entity that evolves and changes among other things as a result of agents' perception, decision making and spatial behavior. Urban dynamics is not a research topic in studies on spatial cognition, cognitive mapping and cognitive geography. Thus, in the various COSIT meetings that in the last decades provided the main forum for Spatial Information Theory (see http://www.cosit.info/home.html), the issue almost does not appear (a COSIT paper that does refer to urban dynamics is Benenson and Portugali 1995). And, in a recent comprehensive overview on *The Cognition of Geographic Space* (Kitchin and Blades 2002) the issue of urban dynamics is not mentioned. In fact, there is nothing unusual here – Kitchin and Blades simply follow the conventional division of labor in urban studies according to which urban dynamics is essentially the business of studies on urbanism, of social theory, of urban, social or economic geographies, of planning and urban design; but not of cognitive science, spatial cognition and cognitive geography.

As we've seen, Lynch's (1960) Image of the City acted as an impetus for cognitive scientists, urban designers and human geographers to develop environmental cognition and cognitive geography. We have further seen, that despite the intuitive closeness between the notions 'image of a city' and 'cognitive map', the link between them was never made: Lynch ignored Tolman's cognitive maps and students of cognitive maps have treated Lynch's elements as given – as fixed and not subject to change, evolution and design.

Moreover, there was an attractive and challenging potential in this link because Lynch wrote his *Image* from the perspective of an urban designer whose aim is to shape or design the externally represented world in order to create a legible city – *A Good City Form* (Lynch 1981), whereas cognitive maps are about the internally represented city and the way it affects spatial behavior. Integrating them could thus have produced a cognitive theory of urban dynamics. All that had to be done is to make one small step and cross the boundary between the *Image* and the cognitive map. But this step was never made and the boundary between Lynch's *Image* and Tolman's Map was never crossed. The question is why? The reason suggested below is that this is a consequence of the way the boundaries of cognitive science (to which Tolman's Maps belongs) and those of social theory, arts and humanities (to which Lynch's image belongs) evolved in a way that prevents cross-boundaries interactions.

6.5.2 The Boundary of the City as a Derivation and Representation

The mirror image of 'the city as an arena' is the fact that students of the dynamics of cities ignore cognition and cognitive mapping and their possible role in the urban process. Theories of urban dynamics have traditionally tended to treat the city as a derivation or a representation. In Chap. 2 we've seen that in the 1950s and 1960s, the city was treated as an *eco*nomic landscape derived from the basic principles of neo-classical economics, or as an *eco*logical city that obeys the rules of ecology (invasion, succession, ecological niche etc). In Chap. 3 we've further seen that in the 1970s the city was treated (mainly by structuralist-Marxists and humanistic urbanists and geographers) as a representation of society. A typical view here (e.g., Lefebvre 1970; Gregory 1994) is that in Antiquity, the city was a representation of the "ancient mode of production," while during the Middle Ages, the city represented the "feudal mode of production." Then came the Industrial Revolution and with it the "industrial city," which represented the early "capitalist mode of production" (Lefebvre 1970), and at a later stage the "city of modernity" as the landscape of 20th century capitalism or as an aspect of its social life. In this spirit Harvey (1989) claims that the "postmodern city" represents late capitalism, while Castells (1989) introduces *The Information City* as "a representation of society" – an important aspect of *The Rise of Network Society* (Castells 1996).

Cities are intimately related to society and as we've seen in Chaps. 2 and 3, their interpretation as derivations or representations of politics, economics, or different modes of production, of their respective societies, have been rather productive; a great deal of insight concerning cities and urbanism has been gained by looking at them in this way: location theory, urban ecology, SMH urban theories – to name but a few of the more prominent achievements of this line of thinking.

But how is a system of central places or of urban rings created? Classical location theory answers with the *Homo Economicus* – that imaginary, fully rational, decision maker that possesses complete information and can thus act with zero uncertainty. Recent developments in economics itself indicate that this answer is not sufficient – I'm referring to Simon's (1991) *bounded rationality* and its more recent reinterpretation by Nobel laureate Daniel Kahneman (2003). The fact that the cognitive psychologist Kahneman got a Nobel Price in Economics (for the studies he conducted in collaboration with Tversky) indicates that the conventional economic person is not sufficient an answer and that the answer must be searched in cognitive science.

A similar question might be leveled at the SMH urban studies: how a city becomes a representation of society? The standard answer is "by means of the process of space-time reproduction"! That is, people in their daily routines reproduce the structure of society. But how exactly daily routines of humans are created? How do people as individuals and collectivities behave in cities and in other domains; how and why they conduct routinized behavior? SMH urban studies have no answer – it is outside the context of their domain.

The notion "representation" is central also to cognitive science and as such to studies of cognitive maps. However, while in social theory the term refers to *external representation* (of society, economy . . .), in cognitive science and cognitive maps studies it refers to *internal representation*. According to this view a cognitive map of a city is an internal representation in the mind of individuals of the experiences they had in the city, the information they accumulated on it by means of these experiences, as well as by other means. How the various cognitive internal representations participate in the urban dynamics? This question was not asked nor explored. Why? Because the boundaries of cognitive science were defined in such a way that the answer is beyond its scope. The notion of SIRN suggested in the next chapter is an attempt to go beyond these boundaries.

6.5.3 The Boundary of Reductionism

Unlike the first culture of cities that perceives the city as a derivation from economic forces and the second culture of cities (the social theory oriented urban studies) that describe the city as a representation of society, CTC portray the city as a global system and structure that is *emerging* out of the local interaction between its many agents. On the other hand, however, CTC are similar to location theory and social theory oriented urban studies in that they too overlook the complexity of the parts. The vast majority of scientists in this domain ignore the implication from what has been demonstrated above, namely, that similarly to the city as a global complex system and structure, each of its local parts too is a complex system whose level of complexity doesn't fall from that of the global system. This view leads to the notion of cities as *dual complex systems* that is elaborated below.

The relation between the complexity of the local parts and the complexity of the global system is a general methodological problem of complexity theory. For example in his *Brain Dynamics* Haken (2002) writes that while each of the billions of neurons of which the brain is composed is itself complex, synergetics allows to treat the parts as simple and concentrate on the dynamics of the global system – the brain. This is in fact a basic tactics of synergetics and as we've seen above (Chap. 4) Weidlich applied it to the relations between complex urban and global regional systems and complex single local cities. Can it be justified in the case of cities? My view is that in some limited cases the answer is Yes! But as a general rule the answer is No! – In the case of cities the complexity of the urban agents cannot be ignored. There are two kinds of arguments in support of this view: arguments derived from complexity theory and an argument that is derived from the specific nature of human agent.

6.5.3.1 Complex Cities and Nonreductionism

On the one hand, the city is complex because it is an open system that has a very large number of interacting part. In this respect the city is not different from a tree or a colony of ants or termites. On the other hand, however, the city is not a tree because unlike a tree it is characterized by a semi-lattice network of connections (Chap. 5, above) and unlike a tree and colony of ants it is strongly affected by expectations and plans, that is to say, its network of connections extend to the future to events that haven't yet happened and in fact might never happen. Chapters 13, 14 below elaborate on this issue in detail. In other words the complexity of the city as a global system cannot be fully understood and defined independent of the complexity of the individual parts and their cognitive capabilities.

CTC portray the city as a global system that is *emerging*. Now, this notion of emergence implies two things: first, a bottom-up process in which the interaction between the parts gives rise to the global system – the city. Secondly, emergence implies also nonreductionism – that due to nonlinearity that typifies cities as complex systems, the properties of the global cannot be reduced to those of the parts. CTC were dominated by the first implication – this is evident in the popularity and extensive use of cellular automata urban simulation models. The problem is, however, that ignoring the nonreductionist implications of emergence leads CTC into a paradox and sets the boundaries of CTC in such a way that a link between cognition and cities will not be possible.

6.5.3.2 Dual Complex Systems

Following the above discussion I suggest that it will be useful to distinguish between two kinds of complex systems: *singularly complex systems* vs. *dually complex systems*. Singularly complex systems refer to situations in which complexity is a property of the global system but not of the local parts, or, to cases in which the complexity of the parts can be ignored. In dually complex systems complexity is a property of both the global emerging system and its local parts and in which the complexity of the parts cannot be ignored. A few examples might illustrate the rationale for this distinction:

Take for example the Bénard experiment (Fig. 4.1 in Chap. 4 above): as described above, it is composed of simple parts, namely atoms and molecules, that by means of their interaction give rise to an emerging complex global system. As we've further seen above, while the emerging complex global system affects the form of movement of the parts of the system (e.g., as a consequence of the synergetic slaving principle) it has no effect whatsoever on the *structure* of the atoms as the parts of the system. The relations in this dynamics thus take the form of

Simple → Complex

namely, simple cause (local interaction between simple agents) and complex effect (global complex system).

Now consider a flock of birds that is often cited as a typical example of self-organized collective behavior (Fig. 6.17). Each single bird in the flock has a complex brain and body and is by definition a complex, adaptive, self-organizing system by virtue of the fact that it is subject to the slow process of biological evolution. On the face of it, this is a dual complex system. However, due to the fact that biological evolution is slow, the feedback impact of the collective behavior of the flock on the genotypic structure of each single bird and its entailed phenotypic behavior can be ignored and the reductionist

Simple → Complex

relations that obey the principle of parsimony can be maintained.

The case is different with the *Homo sapiens sapiens*. This human agent is subject to two evolutionary self-organizing processes: The slow process of biological evolution and the fast process of cultural evolution. According to Dawkins (1986), the fast process of cultural evolution shows itself in the evolution of *memes* (see below Chaps. 7 and 18), which are essentially ideas; according to my view, cultural evolution comes into being by the evolution of memes and the simultaneous evolutionary process of the production of artifacts. This latter view comes close to the notion of *Homo faber* as suggested by Enri Bergson (1911/1998) in his *Creative Evolution*.

The city is often cited as the largest (collective) artifact produced by humans. Because cultural evolution is fast, the feedback effect of the artifact city as the

Fig. 6.17 Flocks of birds. Left and right flocks photos by Tianji Zhao

emerging global system on the human urban agents is often immediate (Fig. 6.18). As a consequence, the complexity of the urban agents cannot be ignored. The relation that typifies the city as a complex system is thus

$$\textbf{Complex} \rightarrow \textbf{Complex}$$

namely, complex ‘cause” (local interaction between complex agents) entails a complex “effect” (the city as a global complex system). The notion of SIRN (synergetic inter-representation networks) that is introduced in the next chapter, and the notion of *complex artificial environments* that is discussed in Chap. 11, attempt to capture this property.

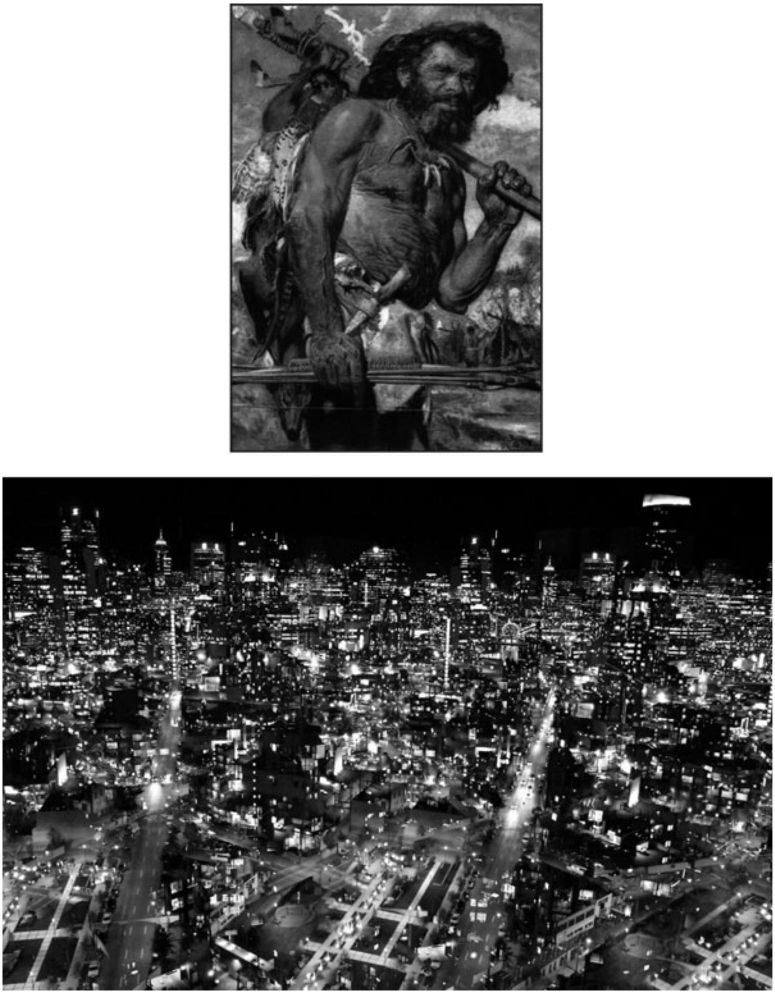

Fig. 6.18 The artifact city has an immediate effect on the human urban agent

6.6 A Concluding Note: SIRN (Synergetic Inter-Representation Networks)

At the bottom of the above three obstacles is the issue of the boundaries, namely, the boundaries of the entity city and the boundary of the cognitive and the fact that these boundaries are not crossed. The next chapter introduces SIRN (Synergetic Inter-Representation Networks) as a theory and approach that suggests crossing these boundaries.