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Juval Portugali

Complexity, Cognition and the City

With a Foreword by
Hermann Haken

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Understanding Complex Systems

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Including three chapters in collaboration with Hermann Haken, a chapter in collaboration with Andreas Daffertshofer and Herman Haken, and a chapter in collaboration with Roni Sela

Foreword

After his highly successful book *Self-Organization and the City*, Juval Portugali now presents his new book *Complexity, Cognition and the City*. I have had the opportunity of reading his manuscript and I must say, I am deeply impressed with both its depth and breadth. Surely, it will provide theoreticians as well as practitioners with remarkable insights. Why is this so? Let me start with practitioners, e.g., regional or city planners. As Portugali has early observed and studied, the phenomena of self-organization play a very important role in the development of cities, regions etc. In how far can planners deal with these processes? Can planners avoid them, steer them, utilize them? Clearly, insights gained at this level may have (or at least should have) considerable impact on the decision making of governmental agencies. (Actually, Portugali devotes a whole section to decision making including the fundamental results of Kahneman and Tversky).

Portugali's book, however, goes far beyond questions concerning the development of settlements starting several thousands of years ago till our age. As the title of this new book indicates, Portugali applies complexity (theory) to problems of cognition where he touches upon questions such as pattern recognition but also categorization etc. He also incorporates concepts such as Dawkin's memes, to mention just another example of the breadth of his book. Thus, this book offers many important stimuli and results to researchers and students in cognitive science and to a broad audience interested in Complexity. I am sure the readers will be as delighted as me when reading this work either systematically, or just browsing through chapters that are of particular interest to the respective reader.

Finally, I want to make a few rather personal comments on "Complexity" or "Complexity Science." A scientific discipline as complex as Complexity Science itself has, of course, not only many facets, but also many fathers. Among them are, for instance, members of the Russian school with names such as Kolmogorov, Lev Landau, Yuri Klimontovich to mention but a few of them. Other scientists, for instance the Frenchman Poincaré or the American Ed. Lorenz have certainly been equally influential. Clearly, complexity science is an international enterprise. My own contribution to the development of complexity science has been my efforts to deal with the phenomena of self-organization from a unifying point of view, an endeavor that I called “Synergetics”.

I was delighted that Juval Portugali got interested in the field of Synergetics, which has led to a series of highly stimulating discussions (and eventually to joint papers) into which Juval Portugali time and again injected intriguing new ideas.

A few still more personal remarks might be added. In science, we may observe two different trends. On the one hand, the desire to bring order into the often perplexing world of phenomena. This has led to unifying theories in physics, such as Einstein’s theory of general relativity on space, time and matter, or in chemistry to Mendeleyev’s periodic table of elements. On the other hand, scientific work means acquisition of more and more knowledge on all kinds of phenomena that seem of scientific importance. I think it is fair to say that presently complexity science mainly belongs to this class of efforts, which is witnessed, e.g., by the “Complexity Digest” founded by the late Gottfried Meyer (actually a former Ph.D. student of mine).

An interesting discussion on what “Complexity” is about and even if it is a science at all can be found in a little book edited by Carlos Gershenson (who is also the new editor of the “Complexity Digest”). Portugali’s book is a highly valuable contribution also to this discussion where, indeed, he opens new vistas, last but not least, on the complex system called “a city”. I use this foreword to thank Juval Portugali for his friendship all over the years, and I am looking forward to our further fruitful cooperation.

Stuttgart, December 2010 Hermann Haken

Preface

The last four decades have witnessed the emergence of two interrelated domains of research: the first – *complexity science*, is a collection of theories that deal with open and complex systems that exhibit phenomena such as self-organization, chaos, or nonlinearity. The second domain, that emerged some 10 years later, applies the various theories of complexity to the study of cities; in this book I want to refer to it as *CTC – complexity theories of cities*.

This is my second book on CTC. The first – *Self-Organization and the city (SOCity)* – published some 10 years ago, had two main aims: one, to link complexity theories with cities by means of the conceptual and methodological tools of complexity theories; two, to link CTC with urban theory as developed throughout the 20th century. The present book still follows the above aims but adds a third one: to create a triple link between complexity, the city, and *cognition* as developed in cognitive science – hence the title of the book *Complexity, Cognition and the City*.

Complexity theories have developed in the "hard" sciences in order to deal with a special kind of systems that are open and complex in which local interactions between the parts give rise to an emerging global structure. In the classical prototypical complex systems the local entities have usually been molecules, atoms, and the like, that is, entities that by their nature are simple. Complexity has thus been seen as the property of the global emerging system alone but not of its elementary parts. This conception has characterized also the various applications of complexity theories to systems studied in the life sciences, sociology, and also to the study of cities. In the latter case while it was recognized that each of the social or urban "parts" is a complex system, too, it was further assumed that this property could methodologically be ignored. The notion of *agents* as currently used in urban simulation models is a good example: it is a kind of automaton that mimics the behavior of urban agents in a predetermined way.

The central thesis of this book is that this is not sufficient: that we have to treat each urban agent as a complex self-organizing system too. The implication is that in the city (as in society at large) we deal with *dual complex systems* in which the city and each of its parts (the urban agents) is a complex system. The science that deals with the complexity of agents in general and of the human agents in particular is cognitive science. The central thesis of this book thus further suggests that in order to appreciate the complexity of the human-urban agents one has to consult the science that explicitly deals with this issue, namely, with human spatial behavior as revealed by cognitive science.

Of all complexity theories, Haken's theory of *synergetics* is the one that best fits to the above aim of treating the city as a dual, complex, cognitive system. This is due, firstly, to the fact that synergetics was intensively applied to the domains of cognition and brain functioning, secondly, to its notions of *order parameter*, *enslavement*, and *circular causality*. Thus, similarly to my previous book, this one too is strongly and directly inspired by synergetics; however, not only by the elegance and beauty of the theory, but also, probably mainly, by the personality of its founder Hermann Haken – a great scientist, a marvelous person, a friend, and a colleague. Hermann Haken's encouragement and support, the many conversations we had during our many years of fruitful collaboration, and his detailed comments on an early draft of the present text, were seminal in the production of this book.

Several chapters in the book were written in collaboration with colleagues: Chapters 8 and 9 on information theory as well as Chap. 19 on decision making were written with Hermann Haken; Chap. 20, that further elaborates on decision making, was written by Andreas Daffertshofer, Herman Haken, and myself; while Chap. 13 that links complexity, cognition and planning, was written in collaboration with Roni Sela. And while I bear full responsibility for any mistakes that might be found in the text, I would like to emphasize that without these collaborations the project of writing this book would not be complete.

As implied by the above discussion, this book can be seen as a continuation to SOCity that was published some ten years ago and indeed, few of its chapters are extended or revised versions of chapters in the previous book: Chapters 2–4 and 10 extend and revise Chaps. 2, 3 and 1 in SOCity; Chap. 17 is a reinterpretation of my collaborative Chaps. 7 and 8 in SOCity, with Izhak Benenson and Itzhak Omer. Finally, Chap. 19 is a nonmathematical version of my collaborative Chap. 14 in SOCity with Hermann Haken. The book has further benefited from several of my studies in the last decade. Some prominent cases are Chap. 7 that closely follows my paper from 2002 on "The Seven Basic Propositions of SIRN (Synergetic Inter-Representation Networks)", in *Nonlinear Phenomena in Complex Systems* 5(4): 428–444. Chapters 8 and 9 are based on Haken and Portugali's (2003) paper "The face of the city is its information" (2003) in *Journal of Environmental Psychology* 23: 385–408, and, on our (Haken and Portugali) not-yet published paper "Information adaptation". Part III on planning has greatly benefited from my collaborative work with Nurit Alfasi; in particular Sect. 13.5.2 of Chap. 13 makes use of our collaborative paper "An approach to planning discourse analysis": Portugali and Alfasi (2008) *Urban Studies* 45(2): 251–272; while Chap. 16 is based on our collaborative Chap. 11 in SOCity and on our (Alfasi and Portugali) paper "Planning rules for a self-planned city" (2007) *Planning Theory* 6(2): 164–182. Finally, Chap. 18 is based on my paper "Toward a cognitive approach to urban dynamics" (2004) *Environment and Planning B: Planning and Design* 31: 589–613, and Chap. 20 is a nonmathematical version of Daffertshofer, Haken, Portugali (2001)

Self-Organized settlements. *Planning and Design: Environment and Planning B* 28(1): 89–102.

Last but not least, I would like to thank Anat Goldman and Efrat Blumenfeld-lieberthal who made many of the drawings and gave all of them their good final touch – and many appreciative thanks to the Springer team, in particular to Dr. Christian Caron, Executive Editor of Physics, and his editorial assistant Gabriele Hakuba. Dr. Caron was the driving force encouraging me to write this book.

Tel Aviv, December 2010 Juval Portugali

Contents

Abbreviations

AB	Agent base
CA	Cellular automata
CCCity	Complexity, cognition and the city
C-cognitive map	cognitive Map (conceptual/categorical)
CPA	Collaborative (or collective) planning approach
CTC	Complexity theories of cities
DSS	Decision support systems
E-languages	External languages
FACS	Free agents on a cellular space
GIS	Geographical information systems
I-language	Internal language
IPA	Information processing approach
IRN	Inter-representation networks
M-code	Memetic code
NU	New urbanism
PSS	Planning support systems
S-cognitive Maps	Specific cognitive maps
SIRN	Synergetic inter-representation networks
SMH	structuralist, Marxist and humanistic approaches
SO	Self-organization
SOC	Self-organized criticality
SOCity	Self-organization and the city
SUP	Strategic urban planning
TK	Tversky and Kahneman
USM	Urban simulation models
VR	Virtual reality

Introduction

As the title testifies, this book suggests a conjunction between three components: *Complexity, Cognition and the City*. The first two – complexity theory and cognitive science – refer to relatively young scientific domains, while the third – the city – is an old, or rather ancient, entity and artifact.

The first component – Complexity – refers to Complexity theory or rather *theories*, that is, to several theories that originated in the 1960s when physicists such as Hermann Haken and Ilya Prigogine became aware of, and started to study, physical-material systems that exhibit phenomena such as emergence, self-organization, history and the like; phenomena that previously were regarded as typifying organic or even socio-cultural systems, but not material systems. These resemblances between phenomena in the animate and inanimate domains were one of the reasons that soon after its emergence complexity theory became a general paradigm that was applied to a variety of domains ranging from physics, to life sciences, social sciences and the study of cities, too.

The second component – Cognition – refers to cognition as perceived by cognitive science, that is, the science of mind that emerged in the mid-1950s as a rebellion against the paradigm of behaviorism that dominated the study of animals and human behavior in the first half of the 20th century. At the core of this rebellion was the demonstration that behaviorism's postulation that all behavior can be explained by externally observed factors fails and that in order to explain behavior one has to take into consideration the role of the mind.

The third component is the city. Cities and urban society exist with us for more than 5000 years; however, the academic study of cities is not as old. It started mainly in the early 20th century, on the one hand, out of the recognition that the cities that entailed the industrial revolution are qualitatively different from older cities; while on the other, by the emergence of scientific world view, namely, by the view that science provides the key for the understanding of the dynamics of cities as well as for the appropriate handling of cities. The result was the domains of urban studies, planning and design that started as branches of established disciplines such as economics, sociology, geography, engineering or architecture, but gradually became disciplines in their own sake.

While the conjunction suggested in this book between complexity theories, cognitive science and cities is novel, links between pairs of these three entities do

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exist. There are already strong links between complexity theories and cognitive science as well as between complexity theories and cities; there are also weak links between cognitive science and cities. The strong links between complexity theories and cognitive science are not surprising: the brain as a network of billions of neurons connected in complex feedforward and feedback loops is regarded by many as the ultimate complex system, and the answer to the question of *How Brains Make Up Their Minds* (which is the title of Freeman's book from 1999) is often answered: 'by means of the property that brain and cognition are complex systems capable of self organization'.

There are also strong links between complexity theories and the study of cities and urbanism. These links started when Prigogine, one of the founding fathers of the complexity paradigm, was referring to the city as a metaphoric example by which to convey his notion of dissipative structures to his fellow physicists; it continued when physicist Peter Allen took this city metaphor seriously and reformulated the central place theory of cities in terms of complexity; studies of cities as complex self-organizing systems then grew exponentially when students of cities and urbanism became attracted by the new paradigm of complexity and self organization. The result is that we now have a whole domain to which I'll refer below as *complexity theories of cities*, or in short: *CTC*.

And what about the links between cognitive science and cities? According to Gardner's (1987) historical account of *The Mind's New Science*, six disciplines were specifically active in building cognitive science as the new science of mind: psychology, philosophy, linguistics, anthropology, neurosciences and AI (artificial intelligence). The study of cities was not among them. The links developed in the 1960s when students of cities became interested in the *Image of the City* (Lynch 1960) and students of cognitive science in "cognitive maps of rats and man" (Tolman 1948), spatial cognition and behavior. For the latter cognitive scientists the city was mainly a convenient environment and arena within which one can study the various aspects of spatial cognition and behavior; the dynamics of the city was not and is still not in their research agenda.

Why to link complexity, cognition and the city? The answer to this question follows my personal impression is that CTC has reached a state in which it becomes subject to the 'law of diminishing marginal utility', and, that in order to further grow and develop it needs to create new links; one such promising link is the link between CTC and cognitive science. Let me explain.

This book is my second attempt to look into the domain of CTC. The first was *Self-Organization and the City* that was published some ten years ago (Portugali 2000). In these ten years the domain of CTC has flourished: the number of practitioners grew dramatically and with them the number of studies on the various aspects of cities as complex self organizing systems, the field became recognized and even fashionable, it has become a permanent and popular topic in many international conferences that directly or indirectly deal with cities (a situation that typifies many other disciplines in the social sciences and the humanities). Looking deeper into the developments of the last decade, a change of emphasis can be observed in both complexity theories and CTC: from long-term complexity theories and CTC that explore the whole life path of complex systems (fast *emergence* → long *steady state* → short *chaos*/collapse → and back again), to short-term approaches that emphasize and explore the process of emergence. One sign of this shift of interest, in the domain of CTC, is the growing popularity and use of cellular automata and agent-based urban simulation models. The relative mathematical simplicity of these models made the field of CTC accessible to many urban scholars that previously were refrained from this field because of the complexity of its mathematical models and argumentations.

My impression is, as noted, that we are approaching a situation by which the current influx of studies becomes subject to the law of diminishing marginal utility. The reason is that so far CTC have been fully applicative in their structure, that is, they have applied complexity and self-organization to cities by studying the various cases in which cities behave like complex systems in physics and life sciences. The benefit from this is the influx of studies noted above; the cost, however, is twofold: Firstly, CTC have almost lost their connection with the core of urban studies, that is, they have become more a branch of complexity theories as studied in the sciences and less a partner in the overall study and discourse on cities in general and on the cities of the 21st century in particular. Secondly, by treating cities as inanimate physical complex systems, CTC can verify existing complexity theories but cannot add to them new dimension that might typify human complex systems but not inanimate physical systems.

The aim of this book is to show how can CTC become a full partner in the discourse on cities and how it can contribute to mainstream complexity theory. The key to both as we'll see below is to link complexity, cognition and the city.

The Structure of the Book

The book contains 20 chapters grouped into four parts. Part I provides the context. Looking at the domain of cities from the perspective of Snow's thesis regarding science's two cultures, it portrays the history and evolution of urban studies in terms of a tension between two urban cultures: *culture one* that attempts to create a science of cities inspired by the hard sciences, and *culture two* that promotes a study of cities inspired by social theory and philosophy (Chap. 1). The next two chapters describe in some detail the shifts between these two cultures. Chapter 2 starts with the *quantitative revolution* that gave rise to the first culture of cities that during the 1950s and 1960s attempted to build a science of cities, while Chap. 3 commences with a second paradigmatic revolution promoted by people who have criticized the first culture of cities from Marxist, structuralist and humanistic points of view thus building the second culture of cities as social theory oriented urban studies.

The first entry of complexity theories to the domain of cities was made by physicists who applied notions of complexity and self-organization to urban theories of the first culture of cities. Chapter 4 that describes this process serves two purposes: on the one hand, it introduces the various complexity theories as they evolved since the mid-1960s, while on the other, it surveys in some detail the history and evolution of the domain of CTC. Finally, Chap. 5 concludes Part I by looking at what has been achieved by CTC in the last three decades. It does so with a lot of appreciation but also with sober criticism. Based on the latter, the chapter concludes by looking ahead at potentials that have yet to be realized – in particular at the possibility and necessity to link complexity, cognition and the city.

Part II, is the theoretical heart of the book. It starts, in Chap. 6, with an overview on the existing and potential links between Cognition, Complexity and the City. It continues in Chap. 7 that introduces the notion of SIRN (synergetic inter-representation networks), which is at once an approach to cognition and cognitive mapping at the level of individual agents, and a cognitive theory of cities as complex self-organizing systems. According to SIRN the city is an artifact that comes into being out of the interaction between internal representations constructed by, and in, the mind/brain of people and external representations produced by them in the world. This view in its turn raised a question as to the nature of external representations. Commencing from a distinction between *Shannonian information* (Shannon 1948) and Haken's (1988) *semantic information*, Chap. 8 demonstrates that external representations such as cities and the various elements of which they are composed convey and transmit information that can be measured by means Shannon's information *bits*, while Chap. 9 further demonstrates that this ability is preconditioned by the city semantic information that comes into being by means of self-organization. Chap. 10 further looks at the city from the perspective of cognitive science's discourse on categories and categorization, while Chap. 11 concludes Part II by considering the various aspects of the city as a *complex artificial environment*.

Part III entitled *Complexity, Cognition and Planning*, explores the implications of CTC to the domain of urban, regional and environmental planning, which has evolved as the applicative facet of urban studies. This shows up in Chap. 12 that locates the CTC implications and approach to planning in the context of *the two cultures of planning* that developed hand in hand with the two cultures of cities as described in Chap. 1 above. Chap. 13 approaches planning from the perspective of cognition demonstrating that planning is on the one hand a basic cognitive capability of humans while on the other, a profession and academic discipline. It then makes a distinction between solitary planning and collective planning that provides the link to the academic-professional process of planning. Chap. 14 uses paradoxes as means by which to learn about the limitation of planning predictions in cities as complex self-organizing system. This finding is significant as the study and practice of planning are heavily based on the assumption that the ability of prediction is almost unlimited. Chap. 15 makes a link between CTC and social theory oriented planning theory, specifically communicative and strategic planning that currently dominates critical urban studies, while Chap. 16 concludes Part III by illustrating SPCity (self-planned city) as a city the planning system of which is built on the principles of complexity and self-organization. That is, a planning system in which every urban agent is a planner at a certain scale and whose planning process is not based on predictions but rather on planning rules.

Urban simulation models provide an important medium by which to study complex systems. This shows up very clearly in the domain of CTC in which many, probably most, studies are based on pedagogic, abstract and/or empirical urban simulation models (USM). Part IV studies the implications of the link between complexity, cognition and the city to USM. Two kinds of cognitive USM are presented and discussed: agent based (Chaps. 17, 18) and synergetic (Chaps. 19, 20). Chapter 17 is, in fact, a revisit in two models that have already been described in SOCity (*Self-Organization and the City* – Portugali 2000). They are revisited in order to explicate the cognitive dimension that in the past was essentially implicit. The first makes use of the notion of Festinger's (1957) *cognitive dissonance* while the second on Dawkins' (1986) notion of *memes* as memory units. Both models illustrate the way cognitive properties revealed by cognitive science can be employed in, enrich and improve, standard USM. Chapter 18 goes one step further and presents CogCity (cognitive city), which is an explicitly complex and cognitive urban simulation model. The next two chapters model the process of decision making in the context of cities from the perspective of synergetics and SIRN. Chapter 19, which is a descriptive account of quantitative Chap. 14 in SOCity, makes a link to Tversky and Kahneman's (1981) notion of decision *heuristics* and reformulates SIRN as a decision-making model. Chapter 20 continues this line of thinking by presenting an USM model that is novel in two respects: it explicitly considers the competition between decision-making agents, and, the role of time in that competition. The discussion in the book closes with concluding notes regarding the research directions that are implied by the present study.

Part I
The Cultures of Cities

Chapter 1
The Two Cultures of Cities

1.1 The Two Cultures

One of the most famous observations in the history of science is Snow's thesis about *The Two Cultures* – the culture of the sciences and scientists and the culture of the arts, humanities and the "literary intellectuals" as Snow referred to the proponents of this second culture. According to Snow the breakdown of communication between the "two cultures" is a major hindrance to solving the world's problems. C. P. Snow – a British scientist and novelist – delivered this thesis on May 7, 1959, as the Rade Lecture in the Senate House, at the University of Cambridge, England. The thesis was reformulated and extended by him a few years later in his *The Two Cultures and a Second Look* (Snow 1964). "It is hard to see", writes Yee in a review to a 1993 new addition of Snow's *The Two Cultures*, "why quite such a fuss was made over Snow's lecture at the time; as he himself was the first to admit . . . [that] nothing he said was particularly original" (Yee 1993).

But there is something original, I think, in Snow's thesis: the interpretation and perception of scientific differences not in terms of differences of logic, method or opinion, but in terms of cultural differences – a view that will later appear in studies about the history, philosophy and sociology of science. For example, in *The Structure of Scientific Revolutions* Kuhn (1962) develops the notion of 'normal science' – a period during which scientists conform to the dominant paradigm partly because they are convinced by it and partly because conservative tendencies make it much safer and convenient to conform to the group, that is, to the dominant scientific culture.

Cultures come into existence by emphasizing common values, norms and material goods shared by their members and by emphasizing and often exaggerating the differences between their common elements and those of other groups. Cultures survive by the process of *cultural reproduction* – the process that routinely and daily produces and reproduces the common (often exaggerated) elements that unite the group's members as well as the differences between them and other groups (Bourdieu 1993; Giddens 1997).

Snow's usage of the term 'culture' to refer to a certain grouping among the scientific community implies that scientists are no exception in this respect – they

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are first and foremost human beings and as such tend to form cultural groups by emphasizing and often exaggerating the common elements that unite them and those that separate them from other groups, by forming stereotypes of themselves and of the others and so on.

The above-noted similarity between Snow and Kuhn is not accidental: Historians of science indicate that Kuhn "was deeply impressed by Snow's thesis" (Andresen 1999, p 55) and that "Kuhn constitutes his theory about scientific revolutions as a version of the 'two cultures'" (Westman 1994, p 81).

Kuhn added to the notion of science as a culture his famous *The Structure of Scientific Revolution* (Kuhn 1962) – the view that science evolves not linearly and gradually, but by means of revolutions – a view that reminds one of Eldredge and Gould's (1972) "punctuated equilibrium" and of course of complexity theory's central notions such as bifurcation, phase transition and self-organization.

In what follows, I describe the study of cities in the last 60 years in terms of a conjunction between Snow's and Kuhn's theses, that is, as a pendulum that is moving between two poles that roughly correspond to Snow's two cultures when the moves from one pole to the other take the form of what Kuhn has termed "paradigm shifts" and what students of complexity call *phase transition*. At one pole, we see scholars that approach the city from the perspective of the sciences with their scientific methods, attempting to develop *a science of cities*, while at the other, studies that approach cities from the perspective of the humanities and social philosophy with hermeneutics as their major methodological tool.

1.2 The Two Cultures of Cities

The movement of this pendulum starts to be strongly felt in the 1950s with the so-called *quantitative revolution* (Burton 1963). Before that event, during the first half of the 20th century, the two streams developed in parallel: On the one hand, we see "soft" humanistic studies such as Mumford's (1961) *The City in History*, or Wirth's (1938) "Urbanism as a way of life" or the notion of *regional geography* as developed in urban geography (MacLeod and Jones 2001), while on the other, quantitative studies such as Auerbach's (1913) inductive study of the size distribution of cities, Christaller's (1933/1966) and Lösch's (1954) central place theories, Reilly's (1931) "Law of Retail Gravitation", gravity/spatial interaction models and the like (see further details below in Chap. 2)

In the 1950s, we see a split – a *quantitative revolution*. It was a revolution not because the proponents of this move invented the scientific approach to cities but because as part of their effort to convey their quantitative message they have strongly criticized and even de-legitimized the scientific validity of what they have referred to as descriptive approaches. This criticism entailed an almost unbridgeable gap between the quantitative vs. the descriptive studies – very much in line with Snow's two cultures.

The quantitative paradigm dominated the field of urban research during most of the 1950s and 1960s just to be replaced, in the early 1970s, by social theory oriented urban studies. As in the days of the quantitative revolution here too, this move took the form of a "revolution" when proponents of the new paradigm started to strongly criticize the positivistic-quantitative approach. They did so from two main points of view: from a Structuralist Marxist perspective and from a phenomenological idealistic perspective (Chap. 3 below). The result of this second revolution was that the gap between the two cultures of urban studies further widened.

The field was now divided into two distinct cultures – Structuralist, Marxist and Humanistic (SMH) approaches versus Positivist/Quantitative approaches to cities – with all the ingredients indicated by Snow and by cultures in general: a breakdown of communication, emphasis and exaggeration of differences between the cultures, stereotypic images of the other and a process of cultural reproduction that reinforces and safeguards the differences in a variety of ways, including: scientific journals that due to their specialized nature could easily exclude the views of the other – a process that was practically executed by an army of referees, "guardians of the wall", that protected the minds of the groups' members from intruding ideas; general introduction textbooks that, by their very nature, tend to stereotype complex relations; specialized conferences that naturally exclude the other side; and endless number of lectures and university courses that followed and reproduced the two cultures.

The above story about studies of cities and urbanism is well recorded (Chaps. 2–4). However, it is usually told in terms of a paradigm shift between science and humanities and social studies, or in terms of a tension between analysis and hermeneutics, but not in terms of cultures. Looking at this story from our perspective of the Snow-Kuhn conjunction adds two important components. The first component is a link to theories of complexity and self-organization. It is a twofold link in the sense, firstly, that cultures come into being spontaneously, that is to say, by means of self-organization (see Harton and Latane 1997, on this issue); and secondly, in that complexity theories of cities (CTC) have the potential to link the two cultures of cities – a point I've elaborated in the article "Complexity Theory as a Link Between Space and Place" (Portugali 2006) and will further elaborate below.

The second component is a sensitivity to cultural biases: For example, it is interesting to note that the very negation 'sciences' vs. 'humanities' is culturally biased – it is typical of the English speaking cultures. In other cultures and languages – in German, French and Hebrew, for example – there is no parallel to the term 'humanities'. Instead in German it is *Geisteswissenschaften*, in French the term is *sciences humaines*, while in Hebrew we use the term "mada'ei ha'ruach' – literally meaning the 'sciences of the human spirit'.

The events that led to, and the story of, the quantitative revolution that was then followed by the SMH qualitative revolution, were specifically dominant in the English speaking countries. In Europe as well as in other parts of the world it was much less prominent. However, due to the general prevalence in the use of the English language (and culture) in science as in other domains of life, it is not surprising that the "English narrative" became the canonical story of the field. I mention it here because as implied from what has been said above and as will be further elaborated below my view is that the gap between the two cultures of cities is not as wide as some tend to describe it. My view is that the two cultures of cities are related to each other as the two bordering edges of an almost-closed circle: The solid line that separates them is very long but the distance between them is rather short. As just illustrated, CTC have the potential to bridge this gap.

1.3 Parallel Currents

In the last two-and-a-half decades we have seen two parallel developments: The social theory oriented SMH urban studies followed general social theory by adopting postmodern, poststructuralist and deconstruction (PPD) approaches, while the quantitative spatial regional sciences were strongly influenced by theories of complexity and self-organization. These parallel developments, discussed in some detail in Chaps. 3 and 4, are interesting and significant in several respects:

First, there are several similarities between complexity theories and PPD in their perception of reality, for instance, both emphasize change, chaos and instability: PPD approaches by claiming that these properties are typical of postindustrial globalized society, that is to say, of the age of postmodernity and the new postmodern condition, while complexity theories by claiming that change, chaos and instability are some of the properties that characterize a certain type of natural and artificial systems, namely, open, complex, self-organizing systems which are far from equilibrium. As we shall see below, these similarities have led several authors to claim that complexity theories support, or are, a version of, postmodernism. My view about these similarities is different – I think that the links between complexity theories and PPD are superficial; that the more genuine links are between complexity theories and modernist social theory and that, as a consequence, CTC has the potential to, and should, link the two cultures of cities. This is one of the main themes of this book.

Second, cities have a special position in both complexity theories and PPD. In complexity theories cities were used from the start as metaphors for complex dissipative systems – e.g., by Ilya Prigogine, one of the founding fathers of the paradigm of complexity (Chap. 4). In PPD the current state of cities and urban society is regarded as one of the signs of postmodern society. More specifically, it is common in PPD to distinguish between two interrelated notions: *Postmodernity* that refers to the state of postindustrial society and *Postmodernism* that refers to a social philosophy about art, architecture and urban design in the age of postmodernity. The properties that are often mentioned as marking the present era and the move from the modern age to postmodernity are globalization, glocalization[1], the rise of civil society, and … cities and urbanism. The new nature of cities and

[1]A term combining the words 'globalization' and 'localization'. It comes to indicate that the emergence of globalization was associated with the rise of localization in culture, society and economy. See Wellman (2002) and further bibliography there.

urbanism – the rise of *global* or *world cities* and the fact that for the first time in human history more than half of the world population lives in cities – are often cited as phenomena that distinguish modernism from postmodernism. Henri Lefebvre (1970) has referred to this transition as *The Urban Revolution* – a view that I've adopted and further elaborated in connection with complexity theories of cities (Portugali 2000, 2006).

Third, there are similarities in the image of the city as it emerges out of the writings of both CTC and social theory oriented urbanists. Both describe the city as highly dynamic, hardly controlled, and unpredictable. It is therefore not surprising that proponents of both PPD and complexity theories are often using the same language: complexity, chaos, network . . . However, when PPD writers use these terms they refer to the literal meaning of the words whereas when employed by practitioners of complexity theories, to a formal theory with its specific mathematics. Thus, when a proponent of PPD says 'chaos' what is meant usually is the opposite of 'order', whereas when a complexity theorist uses the term chaos, in fact it means "deterministic chaos". In a similar way, when Castells (1996) writes about *The Rise of Network Society* he refers to the impact of information technologies – to the fact that society has become highly connected; whereas when CTC authors use the term 'network', they refer to the formalism of the new science of networks as defined by people like Barabasi and Watts (see Chap. 4). Or, when Healey (2007) entitled her book *Urban Complexity and Spatial Strategy* she meant that cities have become literally complex – very complicated; while when Batty (2007) named his book *Cities and Complexity* he meant 'complex' in the sense of complexity theory and its mathematical formalism, namely, *Understanding Cities with Cellular Automata, Agent-Based Models, and Fractals* (which is the subtitle of his book).

1.4 CTC – One Medium with Two Messages

So far, there have been very few attempts by proponents of CTC and PPD to cross the boundaries of their respective cultures. One such attempt was made by Thrift (1999) who, from the perspective of social theory oriented urban studies, wrote an article on "The place of complexity". His account appears like a tango: a small step forward and then two steps backward. "First", he states (p 33), "I want to take . . . complexity theory seriously. It *does* have . . . important things to say." But then he retreats: "But second, I want to recognize that complexity theory is just another business opportunity. It is up for sale. . . . So, third, . . . my account . . . is tinged with irony and is more than a little ambivalent."

On the other side of the barricade, in the CTC culture, there is very little discussion about the relation of the CTC approaches to the wider domain of urban studies, SMH and PPD included. The reason is, to my mind, again cultural: Many of the practitioners of CTC are scientists (such as mathematicians and physicists) who were attracted to cities not so much by interest in cities and urbanism as by the possibility to test and apply their models in yet another domain.

Others are quantitative geographers and urbanists who consider CTC as the second, more advanced theoretically and more sophisticated technologically, science of cities and themselves as the new generation of scientists of cities.

My view is different. I think CTC have two messages to deliver to general urban studies, planning and design of cities: The first message starts from the notion that similarly to many complex natural systems, the artifact cities are complex self-organizing systems too. Similarly to natural complex systems they come into being by the process of emergence out of the interaction between the many parts of the systems, and similarly to many natural complex systems, they are far from equilibrium systems typified by phenomena such as fractals, self-organized criticality, chaos, and nonlinearity. An important consequence of this resemblance is that many of the models developed in order to study "how nature works" [the title of Bak's (1996) book about self-organized criticality] are readily applicable and available to cities and students of cities. This is the main message delivered so far by CTC to the general study and research of cities.

The second message starts from exactly the other direction: indeed there are significant resemblances between natural complex systems and cities, but beyond the similarities there are also significant differences that cannot be ignored. Firstly, cities are *dual complex systems* in the sense that each of their elementary parts – the urban agents (individuals, households, firms, or public agencies) – is a complex system, too. Secondly, and related to the above, cities are artifacts, that is to say, the product of humans' intentions, aims, politics, learning, and hopes. The significance of this view is twofold: on the one hand, it gives CTC an opportunity to feedback and contribute to the general theory of complexity, for example, about the similarities and differences between phenomena of complexity and self-organization as they take place in the natural and artificial domains; on the other, it has the potential to develop links between the two cultures of cities.

I'll elaborate this potential in some detail below (Chap. 5); here let me emphasize its core: One of the main issues that separates the two cultures, the two cultures of cities included, concerns methodology – in order "to do science" one has to adopt the principle of parsimony that implies reductionism and thus enables quantification and mathematical formalism. Social theory and with it SMH and PPD urban theories, suggest that when applied to the human domain, the scientific method with its reductionism implies overlooking and thus loosing the essence of being human. As a consequence, in the human domain, to which cities and urban societies belong, one has to adopt hermeneutics as the preferred methodology. As I'll show below, complexity theory can be at once scientific and nonreductionist and thus link the two cultures of science and the two cultures of cities.

I've started to develop this view in *Self-Organization and the City* (Portugali 2000) and in a paper on "Complexity Theory as a Link Between Space and Place" (Portugali 2006); this is also a central theme in this book and I'll come to it again in Part II. In this first part, however, my aim is preparatory, namely, to describe in some detail what has been described in brief above and thus provide the context to the discussions in Parts II-IV that follow. Thus, Chap. 2 deals with the first culture of cities, which was the first attempt at developing a science of cities; Chap. 3 deals with the second culture of cities that suggests a social theory-oriented urban study; while Chap. 4 introduces in some detail CTC. I close Part I with Chap. 5 that looks back at CTC with appreciation at what has been achieved but also with sober criticism and finally by indicating potentials that have yet to be realized.

Chapter 2
The First Culture of Cities

The *quantitative revolution* was an attempt made in the 1950s by a new generation of urbanists to transform the "soft" descriptive study of cities into a "hard" analytical science (Burton 1963). These urbanists have revolutionized the field mainly by adopting location theory – a group of theories developed since the mid-19th century, mainly by economists who added *space* into the otherwise 'spaceless' economic models, and settlement geographers who employed economic consideration and physical analogies as means to explaining settlement patterns. The "founding father" of location theory and by implication of the quantitative revolution, was the 19th century German economist Johann Heinrich von Thünen with his *Isolated State* and our story begins with him. I write "founding father" in brackets because economist Thünen will never know that some 120 years after publishing his *Isolated State*, his work has become the foundation for a new theory of cities and settlements.

2.1 Thünen's Isolated State

> Imagine a very large town at the centre of a fertile plain, which is crossed by no navigable river or canal. Throughout the plain the soil is capable of cultivation and of the same fertility. Far from the town, the plain turns into an uncultivated wilderness, which cuts off all communication between this State and the outside world.
>
> There are no other towns on the plain. The central town must therefore supply the rural areas with all manufactured products, and in return it will obtain all its provisions from the surrounding countryside.
>
> The mines that provide the State with salt and metals are near the central town which, as it is the only one, we shall in future call simply "the Town" (Thünen's *The Isolated State*, Chap. 1, Hypotheses.)
>
> The problem we want to solve is this: What pattern of cultivation will take shape in these conditions, and how will the farming system of different districts be affected by their distance from the Town? We assume throughout that farming is conducted absolutely rationally.
>
> It is on the whole obvious that near the Town will be grown those products, which are heavy or bulky in relation to their value, and hence so expensive to transport that the remoter

J. Portugali, *Complexity, Cognition and the City*, Understanding Complex Systems,
DOI 10.1007/978-3-642-19451-1_2,

> districts are unable to supply them. Here too we shall find the highly perishable products, which must be used very quickly. With increasing distance from the Town, the land will progressively be given up to products cheap to transport in relation to their value.
>
> For this reason alone, fairly sharply differentiated concentric rings or belts will form around the Town, each with its own particular staple product.
>
> From ring to ring the staple product, and with it the entire farming system, will change; and in the various rings we shall find completely different farming systems. (Thünen's *The Isolated State*, Chap. 2, The Problem.)

These two short chapters that open von Thünen's *The Isolated State in relations to agriculture and political economy* is a verbal description of *The Isolated State* – the model which provides the foundation to all his economic work. "This method of analysis", he writes:

> has illuminated and solved so many problems in my life, and appears to me capable of such widespread application, that I regard it as the most important matter contained in all my work" (Hall, introduction to Thünen 1996, XXII).

At a later stage, so writes Thünen in an appendix to his book, this model was translated by a friend into the diagrams presented in Fig. 2.1. And despite Thünen's

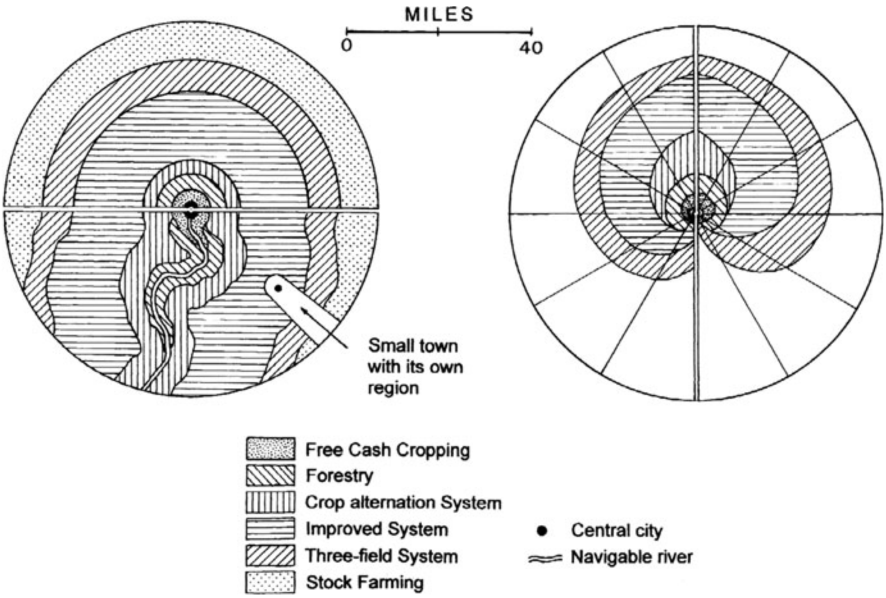

Fig. 2.1 "*These diagrams*", writes Thünen (Par. 384), "*drawn by a friend of mine, are not essential to an understanding of the problem under discussion–and nowhere in the work have I referred to them. But since they afford a simple and survey, . . . I feel they might be welcome to the student . . .*" (*Top, Left*) "*This shows the Isolated State in the shape it must take from the assumptions made in Section One . . .*". (*Bottom, Left*) "*Here we see the Isolated State crossed by a navigable river. Here the ring of crop alternation become very much larger, stretching along the river . . . The effect of constructing a highway is similar, . . .* " (Par. 385). (*Right*) "*The diagram illustrates the effect of the Town grain price on the extention of the cultivated plain*" (Par. 386)

comment that these diagrams "are not essential to an understanding of the problem under discussion – and nowhere in the work I have referred to them", they have since become the symbol/icon of his work – at least among students of geography, location and urbanism (especially Fig. 2.1a). Due to his *The Isolated State*, Thünen is regarded as the most important German economist of the 19th century; first, because it is the first formal economic model, and second, since Thünen has unconsciously invented here the economic principle of *marginalism*, some 50 years before Léon Walras, Carl Menger and William S. Jevons have made it the basis for modern economic theory (see Portugali 1984, for further discussion and bibliography).

2.1.1 The "Isolated City"

As noted above, due to his *The Isolated State*, Thünen is also regarded as the founding father of modern location theory; first, because his model enfolds all the ingredients of this theory – isotropic plane, spatial competition between land uses and the principle of marginal spatial utility – and second, and as a consequence of the above, since by changing a few key words in his verbal model, one can get the standard urban land-use model as formulated some 100 years later by the economic land use theorists of the city:

> *Imagine a very large CBD (Central Business District) at the center of an urban plain, which is crossed by no navigable river, road or canal. Throughout the plain the urban land is capable of all land uses and with the same utility. Far from the CBD, the plain turns into wilderness, which cuts off all communication between this metropolis and the outside world.*
>
> *There are no other centers on the plain. The city center must therefore supply the other urban areas with all urban products and services, and in return it will obtain all its labor force from the surroundings.*
>
> *The mines and factories that provide the Metropolis with raw materials and industrial products are near the CBD which, as it is the only one, we shall in future simply call "the Center".*
>
> *The problem we want to solve is this: What pattern of land use will take shape in these conditions?; and how will the urban system of different districts be affected by their distance from the Center? We assume throughout that decision-making is conducted absolutely rationally.*
>
> *It is on the whole obvious that near the Center will be allocated those land uses which are sensitive to the distance from the Center to the extent that they will not be supplied if located far from it. Here too we shall find services and products, which require an exposure to a very high threshold of potential customers in order to be supplied. With increasing distance from the Center, the land will progressively be given up to land uses cheap to transport in relation to their value.*
>
> *For this reason alone, fairly sharply differentiated concentric rings or belts will form around the Center, each with its own particular land use.*
>
> *From ring to ring the land use, and with it the entire metropolitan or urban system, will change; and in the various rings we shall find completely different land use systems.*

Similarly to von Thünen's friend, we too, can transform this verbal model into a visible diagrammatic model. All we have to do for this purpose it to take

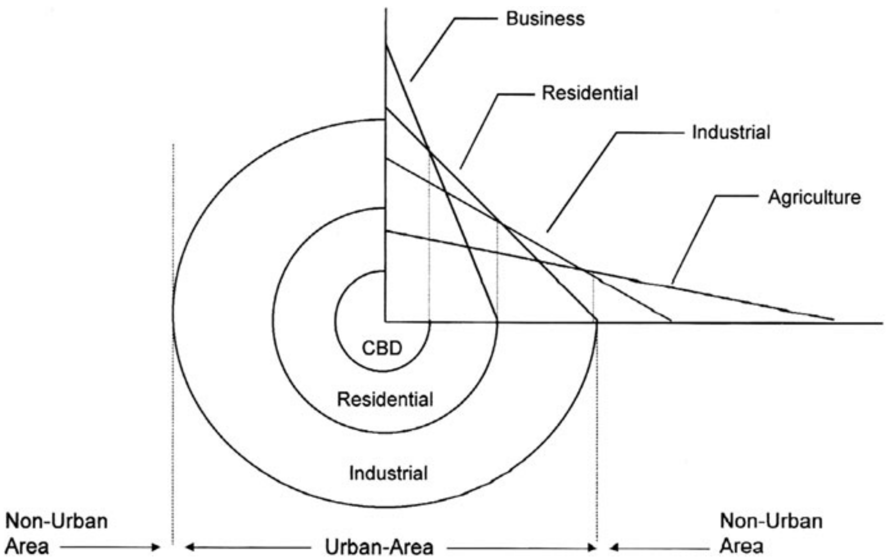

Fig. 2.2 Thünen's type urban land-use system as derived 100 years later in location theory by Alonso (1964). Businesses are prepared to pay high rent at the center of the city, but are reluctant to "live" far from it. Their spatial demand curves (or rbc – rent-bid curves) are thus the highest and steepest. Industrialists, in this exposition, are exactly the opposite and residents are in between: they cannot afford to pay the high prices at the center, but are prepared to live far from it, and so on. Each land use thus occupies a ring were it can pay (bid for) the highest rent. Note that the principle of marginal utility which is implicit in Thünen's landscape, here appears explicitly as the central economic principle. The resulting spatial pattern is as in Thünen's, however

the standard image and model of a city as formulated in location theory. The latter is usually derived not verbally, as in Thünen's, but by means of interplay between spatial demand curves and rent-bid curves as in Fig. 2.2. This play between spatial rent-bid curves was suggested by Alonso (1964) and is often termed *bid-rent theory*.

2.2 The Best Location

Unlike Thünen who unintentionally and unconsciously became the founding father of location theory, Alfred Weber, the young brother of the famous Max Weber, was the first to produce an explicit theory of location for its own sake. In the introduction to his major work *Theory of the Location of Industries* (Weber 1929/1971) he writes the following:

> "We *have a theory of the location of agricultural production by Thünen, . . . But we do not as yet have any theory of the location of industries . . .*" (p 5–6)

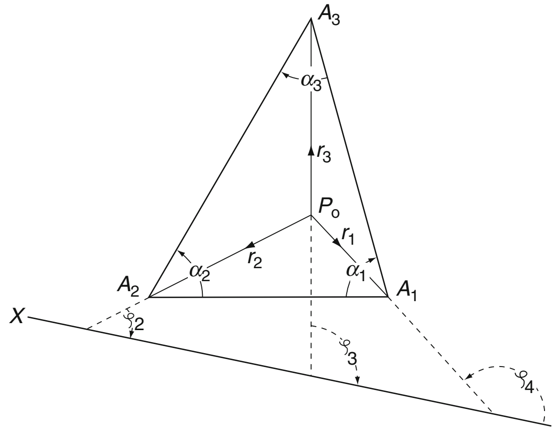

Fig. 2.3 Weber's (ibid Fig. 44) locational triangle. A1 and A2 indicate the location of the two raw materials (e.g. mines) needed to produce a given product; A3 is the location of the city where the end product must be sold/consumed. P is the location of the production point (e.g., a factory), while r1, r2, and r3 are the distances from P to A1, A2, and A3, respectively

Similarly to Thünen, he starts to formulate his theory with an imaginary uniform plain isolated from the rest of the world. "Methodologically", he writes, "we shall always proceed by isolation" (p 10). However, unlike Thünen who starts from a single point in space ("imagine an isolated town . . ."), Weber starts with an isolated region within which there are three points/locations that are essential to the production of a certain industrial product: Two points (e.g., mines) that supply the raw materials needed to produce the product and a city where the end product must be sold/consumed. These three points define what Weber (p 49) calls the *locational figure* and *locational triangle* (Fig. 2.3). Given the locational figure, the

> "*. . . problem to be solved is how transportation costs influence the distribution of industries, assuming that no other factors influencing the location of industries exist.*" (Weber, ibid, p 41).

It is clear that in such circumstances the production point must be located within the location triangle; the question is where? Weber answers in two steps: First he says, the production point must be in a location that minimizes transportation costs of the raw materials from the mines to the production point and the end product to the market. Metaphorically this can be likened to "an old apparatus invented by Varignon . . ." (ibid 229) that is shown in Fig. 2.4.

Second and at a more general level, the location of the production point is determined by means of what Weber has termed the *material index*, which is the ratio of weight of intermediate products (raw materials) to finished product. The material index gives indication as to whether the optimal location point will be close to the sources of raw material or close to the market, that is, to the city.

Equipped with these locational tools Weber turned to study several phenomena, in particular the phenomenon of agglomeration and the impact of labor. In both, the basic question is the same: in what circumstances the industry (i.e. the production point) will move from its optimal location inside the location triangle toward other industrial installations (agglomeration) or toward another location (e.g., a city or

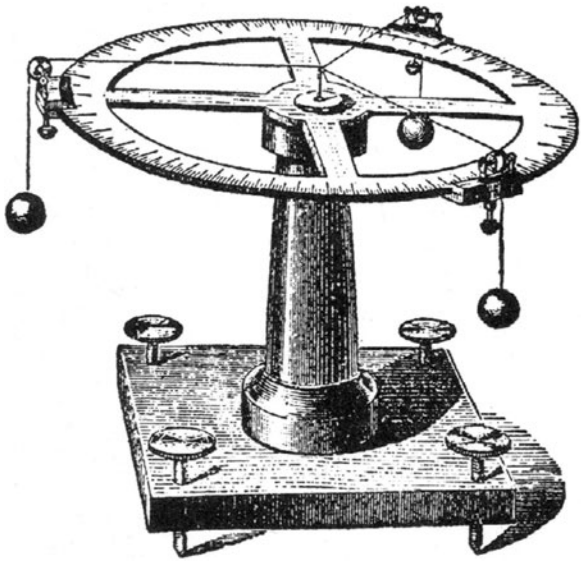

Fig. 2.4 Pierre Varington (1654–1722), a French mathematician, played a role in elaborating Newton's law of gravitation. His studies paved the way for the discovery that moments of forces are axial vectors. He illustrated this, among other things, by means of what became known as the *Varignon's apparatus*

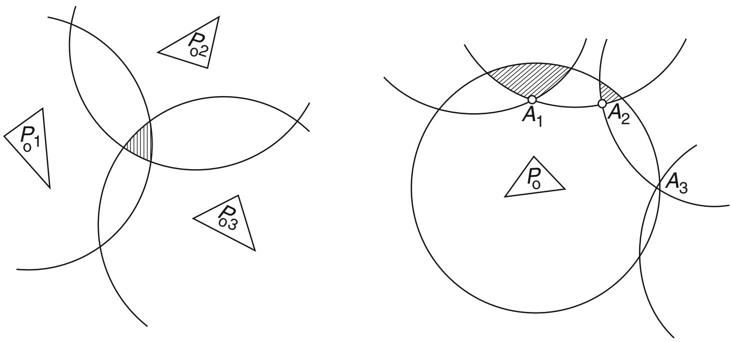

Fig. 2.5 Weber's (ibid Figs. 20, 21) illustration of agglomeration. As can be seen, it occurs when due to internal and external economies, industries prefer to move away from their optimal location (as determined by their location triangle) and to spatially concentrate in an intermediate locale. "The center of agglomeration must obviously lie within the common segments of the critical isopadanes [lines indicating the cost of moving the production point away from it optimal location] . . . It will be located at the one of several possible points.. which has the lowest transportation costs in relation to the total agglomerated output" (Weber 1929/1971, p 138). Thus, the intersection between the three isopadanes will entail agglomeration (Fig. 2.5, *left*), while the two intersections in Fig. 2.5, *right* will not

country) that provides cheaper labor. The principle answer to both is identical (see Figs. 2.5): Movement from the optimal location entails increase in transportation costs. Consequently, the move will be implemented if the increase of transportation costs is less than the benefits from the new location – economies of scale in the case of agglomeration and the saving on labor costs in the case of labor.

Similarly to Thünen's agricultural land-use theory, Weber's industrial location theory was not formulated as an explicit urban theory and similarly to Thünen's theory, the urban component was from the start implicit in it. Firstly, in the sense that following the industrial revolution, the location of industries and the phenomena of agglomeration were one of the attractors to the process of urbanization. Secondly, since the processes of labor migration to industrial countries, regions and cities and the migration of industries to locations of cheap labor are major urban phenomena and forces, specifically so today, at the age of globalization.

But there is a third property of Weber's theory that makes it urban and was not given attention, and it is this: Weber, as we've seen above, considered his theory as complementary to Thünen by adding industry to agriculture. However, Weber is complementary to Thünen in yet another and more general locational respect. Thünen's basic question was this: given a locational point in space (the city) how do we arrange the various land-uses around it? Weber's is the symmetric mirror image of Thünen's: given an area within which various elements are spatially distributed, where is the best locational point? Weber in his theory considered the best location for an industry, but the question and the answers are in principle more general and can refer to the best location for a shopping center, an airport, a neighborhood, and of course, a new town or a city.

2.3 Cities as Central Places

Thünen's concentric rings image of the city was a source also to another image of the city, or rather of cities: cities as central places for their agricultural hinterlands, cities as mediators between their hinterlands and other cities, and cities as hierarchical systems of central places. *Central Place Theory* was developed independently by two persons: Christaller (1933/1966) in his work on *The Central Places of Southern Germany*, and August Lösch (1954) in his *The Economics of Location*. If Thünen has "invented" the notion of marginal utility some five decades before its time, then Christaller and Lösch have suggested a genuine system theory several decades before Bertallanfy (1968) published his *General System Theory*.

Both Christaller and Lösch start with an "isolated city" of a sort. Christaller starts with a kind of an isolated state, which includes a geometrically central city and its dependent peripheral towns. From this starting point he then derives three basic hierarchies of central places (the $k = 3$ market, $k = 4$ transportation, and $k = 7$ administrative principles) from which the population of this imaginary state can consume goods and services and in which they can sell the products they produce. This is illustrated in Fig. 2.6. Lösch, on the other hand, starts with several independent isolated states, or cities, floating on an isotropic plane. He then assumes an increase of population and economic activities which bring in more isolated cities, then by means of competition and general spatial equilibrium, the whole region becomes full and at a later stage as the process continues it reaches a spatial equilibrium in the form of a complex system of central places. Figure 2.7 describes the main stages in the process.

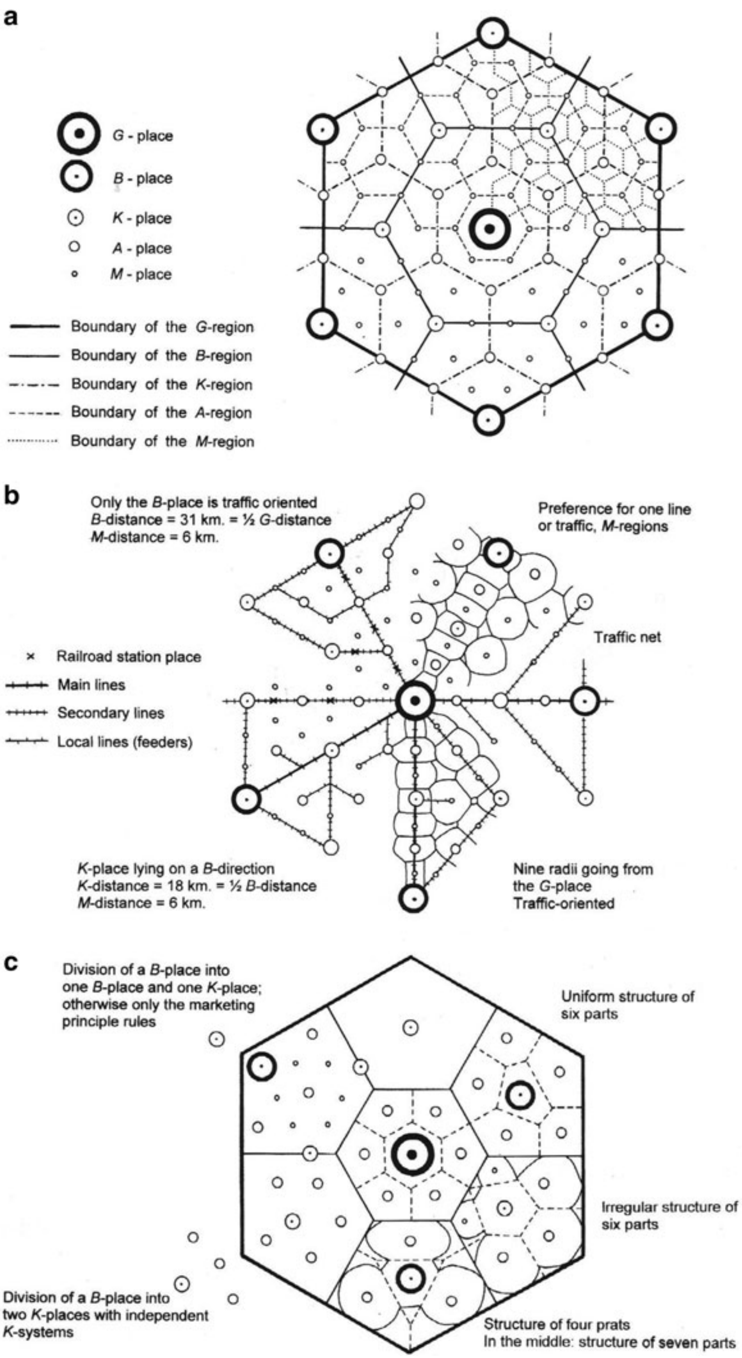

Fig. 2.6 Christaller's systems of central places according to the three locational principles. (**a**) The marketing regions in a system of central places. (**b**) A system of central places developed according to the traffic principle. (**c**) A system of central places developed according to the separation principle (*Source*: Christaller 1966, Figs. 2, 4, 6)

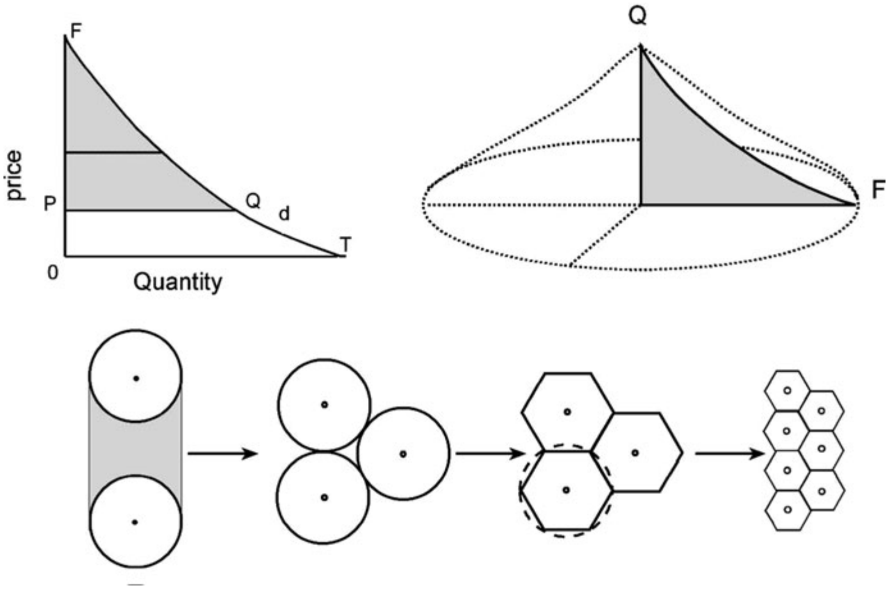

Fig. 2.7 The derivation of Lösch's system of central places. *Top*: The derivation of a spatial demand cone with its market area (*right*) out of an "ordinary" demand curve (*left*). In the words of Lösch (1945, pp 105–6 and Figs. 20-22): "Let *d* (*top, left*) be an individual demand curve for beer. If *OP* is the price at the brewery, . . . those living at *P* will buy *PQ* bottles.. Further away the price will . . . be higher . . . and the demand . . . smaller. . . . at *F* . . . no beer can be sold. Thus *PF* will be the extreme sale radius for beer, and the total sales . . . will be equal to the volume of the cone that would result from rotating the triangle *PQF* on *PQ* as an axis" (*top, right*). *Bottom*: Development of market areas from the large circle to the final small hexagon. The above deduction (*top*) "would be relevant if economic regions were circular. But they are not. . . . because all the corners between the circles would not yet have been fully turned to account . . . the corners can be utilized by pressing the circles together until a honeycomb results. As a consequence . . . the total demand curve will be shifted downward. But the hexagon can be made smaller, until the total demand curve . . . touches the supply curve. Then the market is full." (Lösch 1945, pp 109–110, fig. 23)

Lösch's theory is more ambitious and complex than Christaller's. While the latter's aim was confined to *tertiary activities*, that is to say to services, Lösch's aim was a general theory of location. As a consequence, his urban landscape is more complex, first with respect to the levels of the hierarchy and second, with respect to what he has termed as *city-poor* vs. *city-rich* sectors, that is to say, sectors in his theoretical economic landscape, which because of the spatial distribution of cities in them, are better and/or worse served. The original model of Lösch is shown in Fig. 2.8, whereas Fig. 2.9 is a refinement of Lösch as suggested by Isard (1956).

2.4 Rank-Size Cities

In 1913, German geographer Felix Auerbach published an article in which he demonstrated regularity in the size distribution of cities in several countries (Germany, GB, USA France, Austria, Russia). The basic finding is that the size distribution of cities

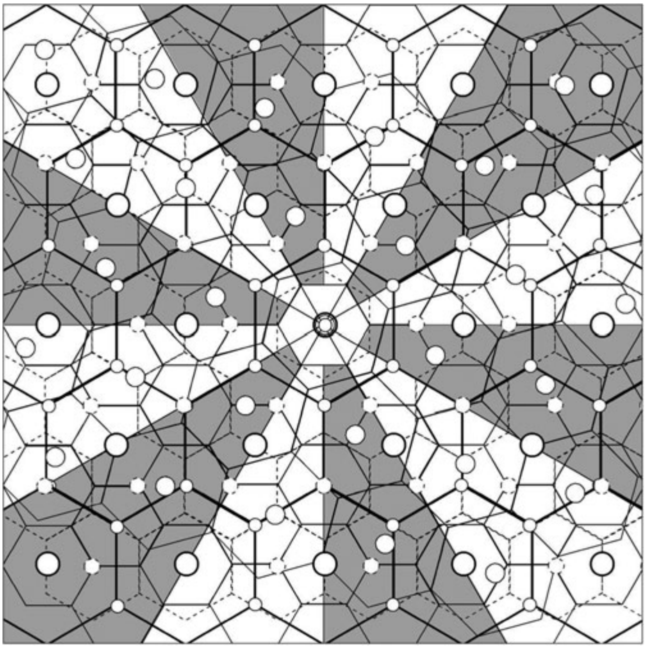

Fig. 2.8 Lösch's derived system of central places with their market areas, divided into city-poor, city-rich sectors (*Source*: Lösch 1945, Fig. 28)

is hierarchical in the sense that there is one/few big city/cities, more medium-size cities and so on, and finally a relatively large number of the very small cities. About a decade later, the statistician Lotka (1924) introduced the rank-size distribution of city populations on a double logarithmic paper. Pumain (2006, p 190) who surveys the early beginnings of the rank-size rule further mentions other scholars and in particular Gibrat (1936) who suggested the lognormal distribution. Following the above pioneering studies of the rank-size rule, this regularity in the size distribution of cities was found time and again in different countries. A few recent examples are given in Fig. 2.10. Such examples must be taken with caution, however, as a recent empirical study indicates that this is not always the case (Soo 2005). Using new data on 73 countries and two different estimation methods this study concludes that the Zipf's Law is rejected for many of the countries.

The notion of hierarchy enfolded by Auerbach and the other pioneering studies reminds one of Christaller's central place hierarchy and indeed he has not ignored his predecessor: The observation regarding the size distribution of cities and towns, he notes,

> ... *has already led to the statement of a most incredible law.* (Christaller 1933/1966, p 59).

And in a footnote he leaves no doubt regarding his view on this "incredible law":

> *"Auerbach's Law", (Size of place = Size of largest city/Rank of place) is not much more than playing with numbers.* (ibid, f.n 19).

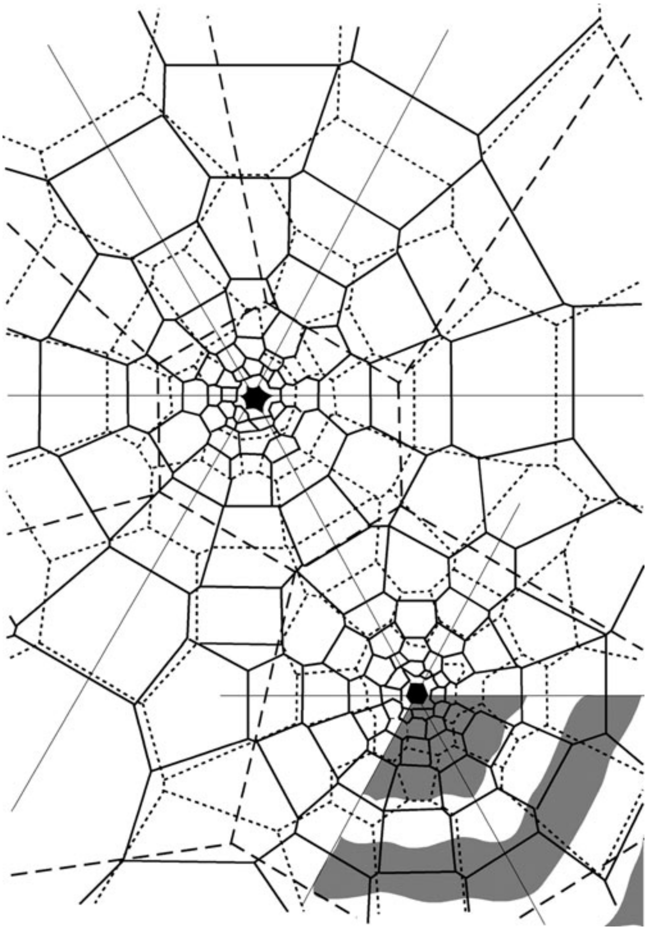

Fig. 2.9 A Lösch system of central places modified by Isard (1956) so as to be consistent with the resulting population distribution

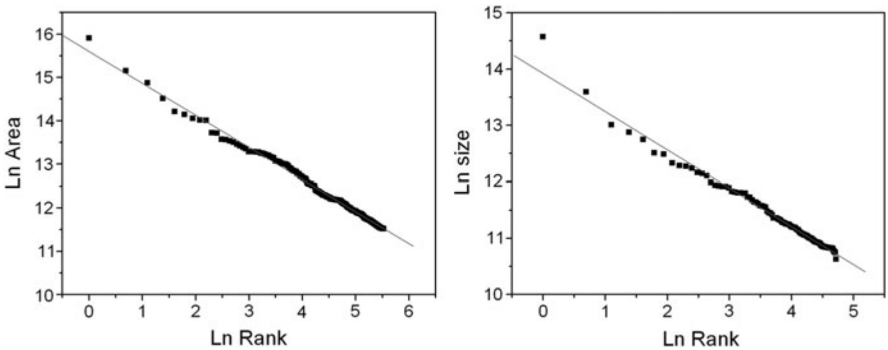

Fig. 2.10 Typical examples of the rank-size rule. The rank-size distribution of cities in the USA (*left*) and in France (*right*)

After dismissing Auerbach's inductive approach to the observed hierarchical regularity of cities he turned to develop his own deductive central place theory as presented above.

But despite of Chistaller's dismissing criticism, Auerbach's idea didn't die. In 1949 Harvard linguist George Kingsley Zipf showed that this rank-size distribution typifies not only cities, but a whole range of phenomena (Zipf 1949) and by so doing he got all the fame so much so that this distribution is commonly called *Zipf's law*. Zipf's work provided a source of inspiration to a long list of subsequent studies on systems of cities (Bourne and Simmons 1978). Once again in the 1970s the idea was criticized for being a statistical observation devoid of sound theoretical basis and once again like the mythical phoenix it re-emerged this time in the context of complexity theories of cities: first as a property of fractal structures in general, then as a central property of fractal cities (Batty and Longely 1994), next in Bak's self-organized criticality cities and as we'll see below, in the new science of networks and in network cities, as a genuine sign for self-organization (Batty 2005). As we shall see in Chap. 4, the two properties that typify rank-size cities as complex self-organization systems are the *scale-free* and *power law* distributions.

2.5 Ecological Cities

Imagine an ecological system with a relatively high population density. The population is composed of several spatially segregated communities, each in its specific territorial niche, the individuals of which are motivated by a simple aim – survival. For this purpose they have to form communities and interact among themselves, as individuals and collectivities, in various forms of symbiosis, competition, domination, invasion, succession, and the like. This ongoing complex interaction, between individuals and communities, is the engine behind the dynamics of our ecological system. The latter might be a small water pool created after the rain, it might be a desert, a jungle, and also, so claim proponents of social and urban ecology, a city.

The ecological image of the city originated out of the Chicago school of *social ecology* and its product *urban ecology*. To be sure, social and urban ecology were not a direct, one to one, application of biological ecology to society and the city. In his seminal book *The City*, Park (1925) builds on top of the *biotic level* that describes the city in universal terms of symbiosis, competition, invasion etc., a *cultural level* that describes the city in unique human terms of social and moral norms, politics and religion. In a paper on "Urbanism as a way of life", his student and follower L. Wirth (1938) has further elaborated Park's view. He has, first, described society in terms of three orders: the ecological-biotic and on top, the cultural order and the political order. Then, from this general social order, he has delineated the urban form on the basis of three ecological principles of *size, density* and *heterogeneity*.

As in biological ecology, were morphological analyses provide the basis to theorize about underlining mechanisms, here too, the formulation of general

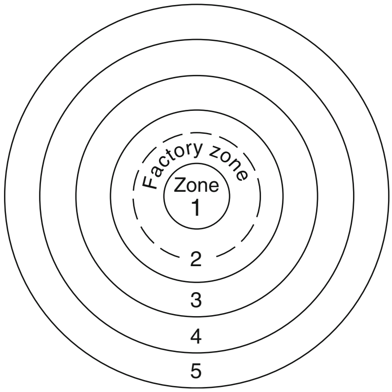

Fig. 2.11 Burgess' concentric zone model: (1) central business district, (2) zone in transition, (3) zone of working men's homes, (4) residential zone, (5) commuters' zone

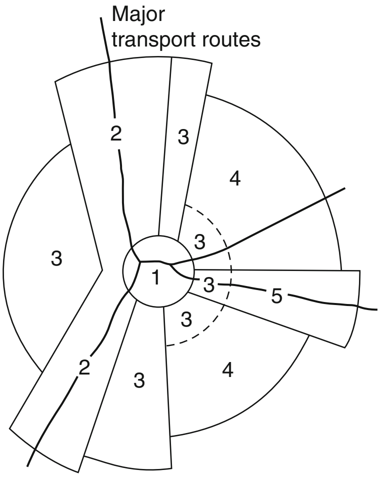

Fig. 2.12 Hoyt's sectoral model: (1) central business district, (2) wholesale and light manufacturing, (3) low-class residential, (4) medium-class residential, (5) high-class residential

principles of urban ecology was associated with several detailed studies of *urban morphology*. The first and probably most influential ecological image/model was put forward by Burgess (1927) who, on the basis of his empirical studies in Chicago, has described the city as an entity that expands radially from its center and in the process forms a series of concentric zones (Fig. 2.11): a CBD zone, surrounded by a zone of transition characterized by high residential and business turnover, a working class zone, a middle-class zone and an outer zone of suburban population-commuters.

Burgess' model was followed by Hoyt (1939) who, on the basis of empirical studies on rent gradients in American cities, suggested a sectoral morphology of the city. In the latter, relatively homogeneous residential and nonresidential areas grow outward from the city center probably along transportation routes, and in the process produce a sectoral pattern as in Fig. 2.12. Burgess and Hoyt's models were integrated by Mann (Fig. 2.13) and at a later stage by Ullman and Harris (1945) in

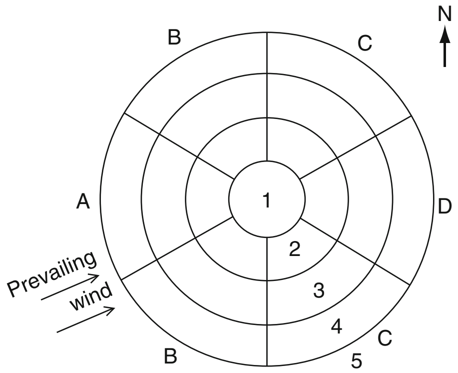

Fig. 2.13 Mann's model of urban structure: (1) central business district, (2) transitional zone, (3) zone of small terrace houses in sector C and D; large bye-law hosing in sector B, large old houses in sector A, (4) post-1918 residential area, with post-1945 development mainly on the periphery, (5) commuting distance 'dormitory'towns, (A) middlle-class sector, (B) lower-middle class sector, (C) working-class sector (and main council estates), (D) industry and lowest working-class sector

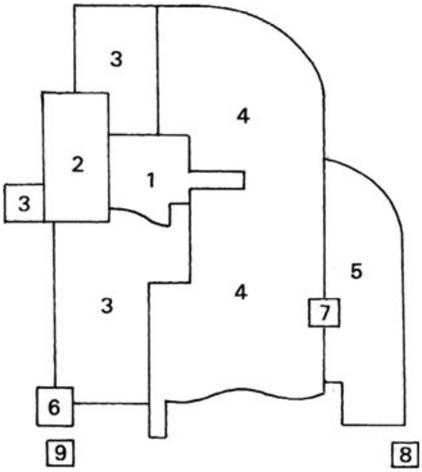

Fig. 2.14 Ullman and Harris's multiple nuclei model: (1) central business district, (2) wholesale light manufacturing, (3) low-class residential, (4) medium-class residential, (5) high-class residential, (6) heavy manufacturing, (7) outlying business district, (8) residential district, (9) residential suburb

their *multiple nuclei model* in which urban growth starts not in one, but in several nuclei thus producing the morphology presented in Fig. 2.14.

The whole of the ecological approach is strongly linked to Chicago. Not only to the Chicago School, but to the very metropolitan field of Chicago which has become the ideal type (in Max Weber's sense) of the city of the fifties and sixties: Its land use rings, spatially segregated ethnic groups, rent-bid curves, and distance decaying population densities appeared in most textbooks (e.g., Fig. 2.15, which is taken from Haggett et al. 1972) and were forced on almost every student of urbanism, planning and social geography. And when a certain instance of urbanism did not conform to the ideal type, as in the case of so many "third world" cites,

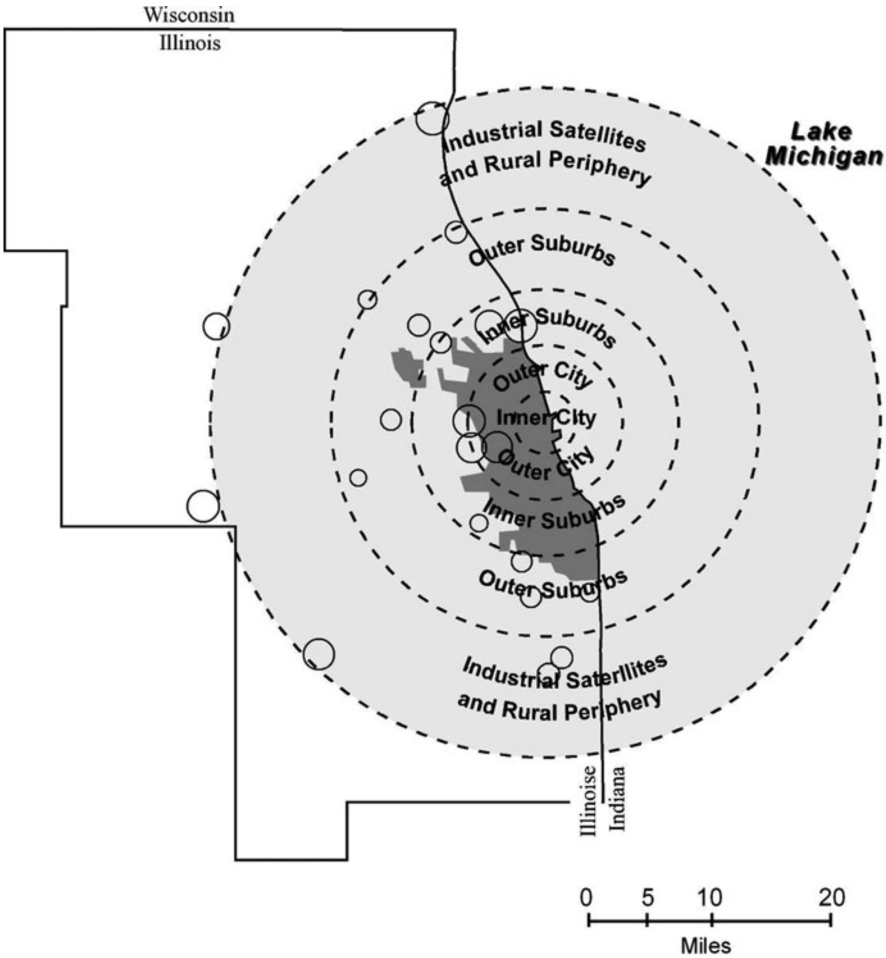

Fig. 2.15 Regional differentiation of Chicago as presented in several geographical textbooks (see, for example, Haggett's (1972, p 263) textbook *Geography: A Modern Synthesis*)

it was treated as exceptional, needing special explanatory maneuvers. The fact that the majority of world population lives in exceptional cities whose structure and nature depart from Chicago never mattered much.

2.6 The Eco-City

It is hard not to see the morphological similarity between the **eco**logical cities just described and the **eco**nomic cities of Thünen, Christaller, Lösch and the others discussed above. The ecological city of Burgess is almost identical in its form to the

Thünen-type concentric economic cities – a similarity that was noted by many. To this I would add that Lösch's city-rich/city-poor sectors are not very different from Hoyt's sectors, especially in light of our comment above that Christaller's and Lösch's central place theories were applied to the study of the internal structure of cities.

But the two eco-cities are not only similar visually and morphologically, but also with respect to their underlying mechanism. For both, reality is an arena where plants, animals, individuals and collectivities, compete and fight for survival, and in a similar way, for both the city is the arena for the urban process – the process by which people as individuals and collectivities compete over the urban land(use), either by means of an interplay of spatio-economic rbc's, or by means of ecological invasion and succession processes identified by means of Chicago-type factorial ecologies (Berry and Horton 1970).

These similarities between the two types of "eco-": the economic and the ecological, are hardly surprising in light of the symbiotic relations that characterized the origin of the theory of economics and the theory of evolution when they first emerged in the first half of the 19th century. In his *Science, Ideology and World View*, Greene (1981) follows in some detail the way several ideas about 'free', 'natural', competition and 'survival of the fittest', among individuals and collectivities, first appeared in liberal political economy and social philosophy in the writing of figures such as Malthus, Adam Smith and Herbert Spencer, and only at a later stage have inspired Darwin. The impact of Darwin's biological Origin of Species was so strong, however, that it pushed to the shade its early historical origins in the human domain.

Despite the apparent similarity and links between the two eco-cities – the ecological and the economic – throughout most of the 20th century the two research domains were kept distinct from each other with no explicit connection. As I'll argue below (Chaps. 4 and 5), the appearance of complexity theories as theories of complex adaptive systems and their application to cities, paved the way for a more general urban theory that explicitly links the ecological and economic interpretation of cities.

2.7 Gravity Cities

Sir Isaac Newton's law of universal gravitation from 1687 states that two bodies in the universe attract each other in proportion to the product of their masses and inversely as the square of their distance. In direct analogy to Newton's law, several social scientists in domains such as economics, geography, demography and sociology (e.g., Stewart 1948; Isard 1956; Hansen 1959) suggested that two countries, regions, cities, or districts in a city, interact with each other in proportion to the product of their masses and inversely according to some function of the distance which separates them, that is:

$$I_{ij} = kM_iM_j/f(d_{ij})$$

When interaction (I_{ij}) between two locations *i* and *j* might refer to the flow of immigrants, goods, traffic, telephone calls, etc.; M_i, M_j masses of cities *i* and *j* to population, size of shopping centers; whereas d_{ij} might refer to geographical distance, economic distance (travel cost), social distance and so on, while *k* is a normalizing constant. An interesting application of the gravitation/interaction logic is Reilly's (1929/1931) *Law of retail gravitation* that attempts to determine the boundaries between different markets or cities in the following way:

$$BP = Da, b/1 + \sqrt{}P_a/P_b$$

where *PB* is the distance from a given city *a* to the breaking point, that is to say, to its boundary with adjacent city *b*; *Da,b* is the distance between cities *a* and *b*, while P_a and P_b are the population of cities *a* and *b*, respectively.

The first interaction/gravity urban models were formulated by a direct analogy to Newton's gravitation, with $f = 1/d^2{}_{ij}$, then, as a consequence of empirical studies it was realized that the power function is not always 2, and the model was thus generalized to $f = 1/d^a{}_{ij}$, when power *a* is determined empirically. Still at a later stage, to a larger extent as a consequence of Wilson's (1970) work on *Entropy in Urban and Regional Modeling*, the model took the form

$$I_{ij} = A_i B_j M_i M_j exp(-bd_{ij})$$

where *Ai* and *Bj* are balancing factors, interpreted also as *accessibility* and *potential* terms. These two terms are interesting as they allow one to envision the city, on the one hand, as an accessibility surface, describing the accessibility of the inhabitants to the city's spatial distribution of goods and services, on the other, as a potential surface, describing the population potential of the city (i.e. spatial demand) to various commercial or service centers of the city. Figure 2.16 is a typical example.

The family of gravity/interaction models is probably the most prominent form of "physicalism" in the study of cities and their planning. At a more basic level,

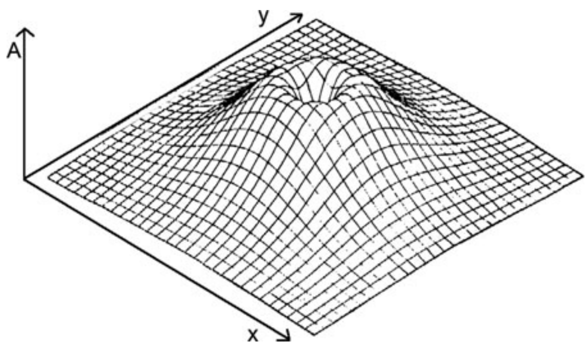

Fig. 2.16 The city of Manchester as an accessibility surface. The city map is decomposed into a cellular space with X and Y coordinates, where A is the level of accessibility. Note that accessibility from the periphery to the city center first increases, then drops toward the very center (due to traffic congestion) (*Source*: Angel and Hyman 1972)

however, physicalism is but one aspect of the Newtonian-mechanistic world view which forms the foundations for all positivist sciences (Portugali 1985).

The family of gravity/interaction models is the most prominent form of "physicalism" but not the only one. As discussed by Ollson (1975), and exemplified in Figs. 2.2 and 2.5, *exp(-bd*$_{ij}$*)*, the negative exponential distance term, is at the roots of the economic cities of location theory just described, as well as of simulation models such as Hägerstrand's (1967) innovation diffusion (below) and Morrill's (1965) ethnic segregation dynamics. Hägerstrand's contribution is discussed next.

2.8 Spatial Diffusion and the City

If the gravity model measures the intensity of the interaction between locations (neighborhoods, shopping centers, or cities), then the theory of spatial diffusion studies the outcome of interaction: the spatial diffusion of cultural traits, of economic innovations, of diseases such as AIDS and SARS, of riots, of the human race, of agriculture (Fig. 2.17) and of cities (Fig. 2.18).

The notion *diffusion* (the full term being *Molecular diffusion*) originally refers to the process by which molecules spread from an area of high concentration

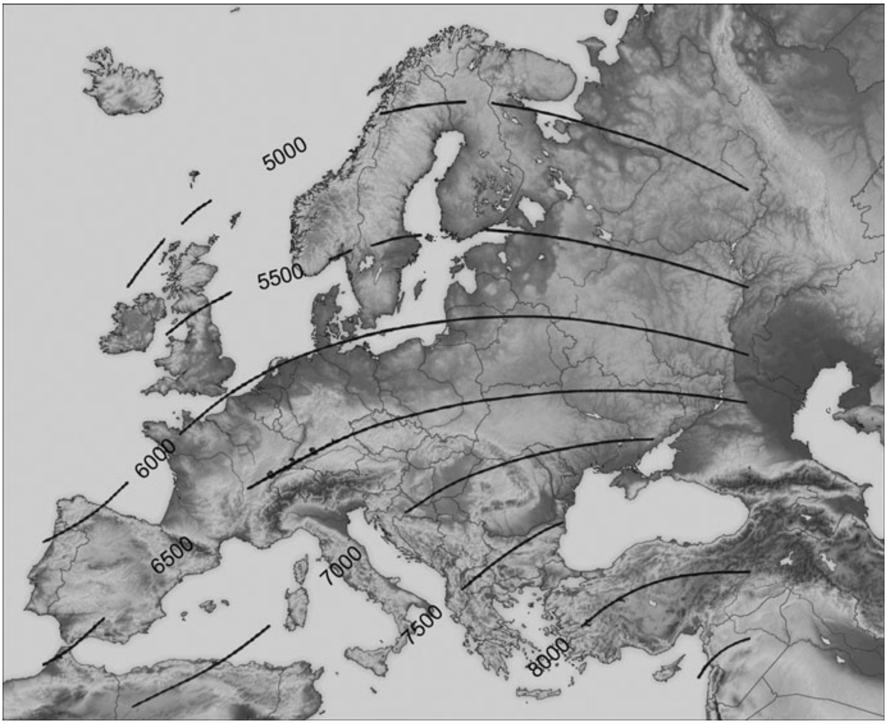

Fig. 2.17 The diffusion of agriculture from its core of origin in the Middle East westward (The numbers indicate years before present)

Fig. 2.18 The diffusion of cities and urbanism from the urban core in the Middle East westward

to area(s) of low concentration. The process is of fundamental importance in disciplines such as physics and chemistry, however, similarly to gravitation it was applied by means of analogy to the human domain in relation to the diffusion of phenomena mentioned above.

While the usage of the notion of diffusion in the human context goes back to the beginnings of the 20th century, the formal theory of innovation diffusion is due to the work of a single person – the Swedish geographer Torsten Hägerstrand (1967) in his book *Innovation Diffusion as a Spatial Process*.

Hägerstrand has used a cellular space as a means to simulate the process (Fig. 2.19). This cellular space is, in fact, Hägerstrand's version of the "classical" uniform plain of most location theories. The process starts when a certain innovation is introduced at time t_0 at a certain cell of the cellular space (Fig. 2.19 *left*). This cell becomes the core of the innovation. As a consequence, a *mean information field* (MIF) emerges around the core (Fig. 2.19 *center*). The MIF is a field of probabilities that indicates the probability of cells (or rather of agents living in the cells) to adopt the innovation. Two processes are crucial in determining these probabilities: one is spatial and the other temporal. The spatial process is the "classical" distance decay function according to which the probability to adopt an innovation at a certain cell is inversely proportional to its distance from the core(s). The temporal process

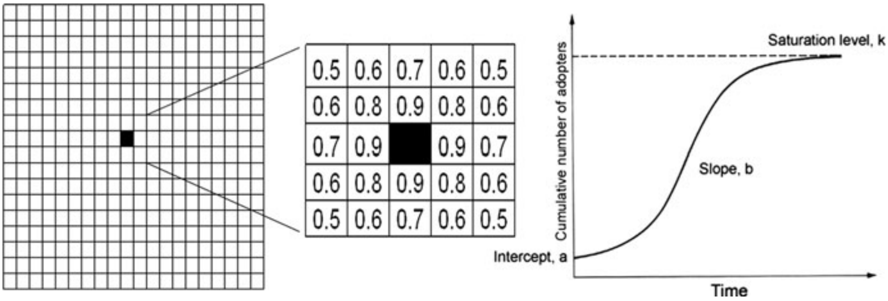

Fig. 2.19 *Left*: An innovation is introduced at time t_0 at a certain cell of the cellular space, simulating a geographical space (e.g., a city, a region) where the ordinate and abscissa are its geographical coordinates. *Center*: A *mean information field* (MIF) emerges around this cell. *Right*: The temporal build-up in the number of adopters in the cellular space follows the logistic curve

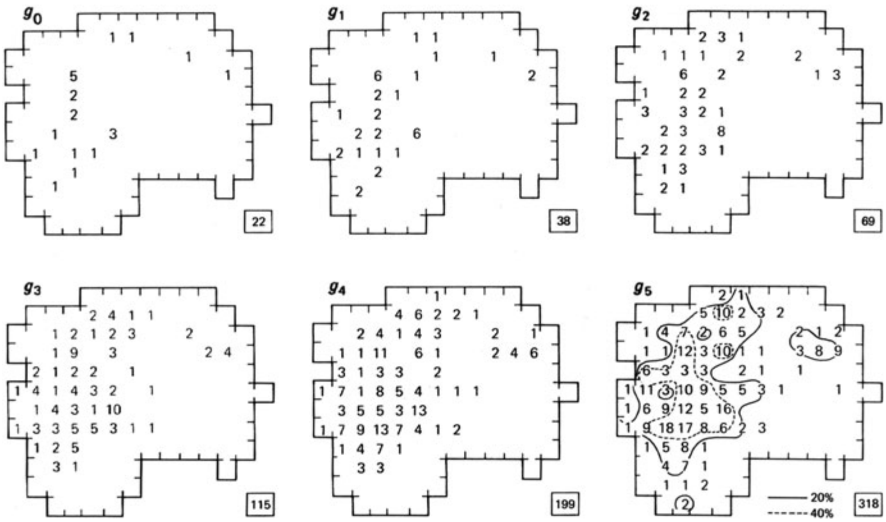

Fig. 2.20 The evolving pattern of adopters of an agricultural innovation as simulated by Hägerstrand (1967, p 23). The numbers in the squares indicate the total number of adopters in the corresponding map

followed empirical observations that the time evolution of the adoption process takes the S-shape form of the logistic curve, namely, at the beginning very few adopt the innovation and the process is slow, then when the innovation becomes popular the number of adopters is growing exponentially and finally the process levels off again (Fig. 2.19 *right*). Fig. 2.20 shows the evolving pattern of adopters of an agricultural innovation as simulated by Hägerstrand (1967, p 23).

While Hägerstrand's theory was not formulated as an explicit urban theory, it is nevertheless related to cities and to the first science of cities in several ways. Firstly, Hägerstrand's theory of spatial diffusion was used by several writers as means to simulate diffusion of cities and urban society from their cores of origin in the Near East and East Asia to other parts of the world (Fig. 2.18 above). Similarly to other grand innovations and revolutions in human evolution – the domestication of plants and animals that gave rise to agriculture, for instance – urban society started at one or a few cores (and this is a matter of controversy) from which it then diffused in space and time, very much in line with Hägerstrand's theory.

Secondly, Hägerstrand and even more so subsequent researchers of the spatial diffusion phenomenon studied the way the morphology of the landscape affects the spatial diffusion process. One example is barriers and corridors (Fig. 2.21), while another is what Haggett, Cliff, and Frey (1977) call *central place diffusion*. By the latter they refer to "diffusion down the central place hierarchy" (ibid, p 240). That is, that in many cases the process starts at the largest city of the urban hierarchy, from which it then diffuses to other large cities, then to the next level cities in the hierarchy, then to lower level cities and so on. In this kind of process it is possible that an innovation at New York City, for instance, will be introduced in London and Paris before its introduction to cities and towns in the geographical proximity of New York.

Thirdly, methodologically, Hägerstrand's spatial diffusion theory and model added three innovative elements to the first science of cities: One is a stochastic view and approach to spatial processes and by implication to the dynamics of cities. This was an important innovation as all urban models described above were essentially deterministic in their structure. Two, is the use of simulation models as a theoretical device and as means for empirical analysis. Three, Hägerstrand has added *time* as an explicit parameter in the spatial process; all location theories, as we've seen above, ignore the role of time. These methodological elements, as we'll see below, come close to the methodologies of the CTC approaches to cities and as such form a natural link between these two domains of study (Portugali 1993, Chap. 4, Figs. 4.5–4.8).

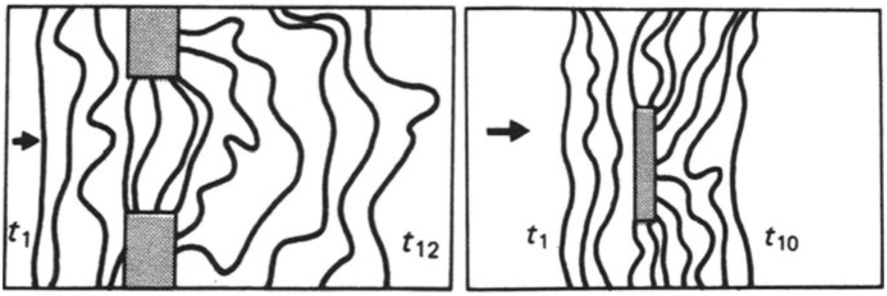

Fig. 2.21 Diffusion with barriers. Diffusion waves passing through opening in a bar barrier (*left*), and round a bar barrier (*right*). X and y are the geographical coordinates of this imaginary space, the arrows indicate the direction of the innovation wave, while *t* their time at the beginning of the process (t_1) and after the 10th and 12th time units (t_{10}, t_{12}) (after Haggett et al. 1977, Fig. 7.7)

2.9 Cities as Simple Systems

Complexity theory is a theory about systems that are complex in several respects: First, they are open to their environment and exchange with it information and material. Second, their parts are extremely numerous and are linked by a complex network with feedback and feed-forward loops. Due to their complexity there is no way to establish causal relations between the parts of such systems and thus to predict their behavior. Such systems typically exhibit phenomena of chaos, bifurcations, abrupt changes, phase transition, fractal structure and the like. The brain if often described as a typical complex system and cities, too.

None of these properties typify the cities we've described above – on the contrary: the number of their parts is relatively small, they are connected (or rather assumed to be connected) by well-defined rules and causal relations and as such these cities are assumed to be fully predictable; and when in practice this is not the case, the assumed reason is lack of sufficient data. And if the brain can be regarded a typical example of a complex system, then the machine is the metaphor for the cities of location theory.

Two bodies of urban theories suggest that the view of the cities as simple mechanistic systems is misleading and misses the very essence of cities: One such body derives its inspiration from social theory and philosophy, while the other from complexity theories; the first constitutes what we've termed above as the second science of cities, while the second, as we shall see below, has the potential to link the two cultures of cities. The next two chapters elaborate on these two different images of cities – Chap. 3 on the second culture of cities, while Chap. 4 on complexity theories of cities or in short on CTC.

Chapter 3
The Second Culture of Cities

3.1 Introduction

In the early 1970s we see a rather unusual development in the domain of urban studies: Some of the leading urbanists of the quantitative-positivistic "conviction" that dominated the discipline in the 1950s and 1960s started to question the scientific and social validity of their own project. The most prominent among them was David Harvey (1973) with his *Social Justice and the City* – a book that produced the most influential critique to date of positivist urban studies, that is to say, of the first culture of cities. Harvey's attack came from a Marxist-Structuralist standpoint. Others attacked positivistic geography and urbanism from phenomenological and idealistic positions that later came under the title of *humanistic geography*. Together these two lines of criticism formed what I'll refer to below as SMH (Structuralist-Marxist and Humanistic) urban studies. Sect. 3.2 surveys the field of SMH urban studies.

SMH urban studies dominated the field for about a decade and a half until the emergence in the mid-1980 of postmodernism as a leading approach in the humanities, social sciences, urban studies and most importantly, as a dominant style in architecture and urban design. As the name indicates, postmodernism is not a negation of modernism, but rather a twist of style and emphasis; the same applies to its two extensions – deconstruction and poststructuralism: In fact many postmodernists, deconstructivists and poststructuralists were ex-SMHians who, while becoming less committed to the grand SMH ideologies, still kept strong sentiments to the old ideas.

From the start postmodernism, poststructuralism and deconstructuvism – to which I'll refer to below as PPD – had special relations with urbanism, cities, and architecture. Architecture was employed, on the one hand, as a metaphor to convey PPD ideas, while on the other, PPD architecture demonstrated how abstract ideas could take form in concrete, iron and glass and forms of buildings. As for cities and urbanism, they became the arena in which the *postmodern condition* showed itself, namely, globalization, the decline of the welfare state, the rise of global/world cities, glocalization, and multiculturalism. Sect. 3.3 on 'PPD cities' elaborates on these issues.

J. Portugali, *Complexity, Cognition and the City*, Understanding Complex Systems,
DOI 10.1007/978-3-642-19451-1_3,

While the major tension in the domain of cities and urbanism has been the tension between the two cultures of cities as described above, there were other approaches that formed what I describe below as ‘the third way’ to cities and urbanism. Projects such as Jane Jacobs’, Christopher Alexander’s, and also Torsten Hägerstrand’s have suggested a third way that in retrospect can be regarded as forerunners of CTC. Their ideas are discussed in Sect. 3.4.

3.2 SMH (Structuralist-Marxist and Humanistic) Cities

The SMH (Structuralist-Marxist and Humanistic) attack entailed a split that divided urban studies into two parallel streams: On the one hand, we see Positivistic urban approaches that continued the first culture of cities and its attempt to develop a science of cities. The latter included the so-called *quantitative geography*, *regional analysis* with its orientation toward economic theory and system approaches, and *behavioral geography* that since the 1970s has developed more as a branch of cognitive science than of human geography and urban studies. On the other side of the barricade, we see SMH urban studies that have formed part of what we term here *the second culture of cities* that is strongly inspired by social theory and philosophy.

The abbreviation SMH does not indicate an identity between Marxism, structuralism, phenomenology and idealism. The differences between these approaches are significant and in some cases (see below) approximate the differences between each of them and positivism. The notion SMH indicates, first, the wider geo-historical context: the days of early 1970s were the aftermath of Vietnam and students’ upheavals of the 1960s in Europe and the USA. Secondly, in the specific history of urban studies the SMH approaches emerged more or less at the same time, united by their common positivistic “enemy”; by their self-image as the discipline’s intellectual, anti-capitalistic avant-garde; by social theory as their source of inspiration. In particular they became influenced by the Frankfurt School interpretation of social theory and philosophy with its emphasis on qualitative analysis and hermeneutics, and rejection of logical positivism and its quantitative analysis.

These uniting elements have obscured the differences between structuralism, Marxism and the humanistic approaches and more importantly, the similarities and potential links between them and various positivistic stands. For example, mathematical methods can be, and have been, employed in order to criticize “neoclassical economic geography and to develop a Marxian political economic alternative”, and “progressive human geography can take advantage of quantitative practices” (Sheppard 2001, pp 535–6). Furthermore, as we shall see below, systems theory had and has strong links to structuralism and Marxism, while the positivistic cognitive geography shares many common areas of interest with humanistic and postmodern urban studies. Given the differences between the various components of SMH, it is not surprising that their images of the city differed from each other. Some of these images are described below.

3.2.1 The City of Social Justice

David Harvey's (1973) *Social Justice and the City* pushed aside to the periphery the quantitative tools of the first science of cities and suddenly the surfaces of cities became transparent and through them one could clearly observe the deep structure of society, the ruling and the ruled classes and their relations of production as well as social relations of production. Suddenly one started to see the hidden structure of the Capitalist engine which is the real power responsible to all that takes place on the surface: the high-rises, the suburbs, the movement of people, the rich and the poor, their wants, dreams, hates and loves . . . all these, be they big and magnificent or small and ugly became secondary, peripheral, at best trivial surface representations, or a momentary configuration in a huge chess game played by the historical social forces and their relations of production.

Your efforts to tame the city, said Harvey, are Siziphean efforts; your scientific models are "incapable of saying anything of depth and profundity.." (Harvey 1973, p 129); not because you are bad guys or second-rate professionals, but because, like Don Quixote, you tilt at windmills, and by so doing not only that you do not harm the real beast – the Capitalist mode of production – but you actually participate in its reproduction; not only that your sophisticated plans do not reduce injustice in the city, but they reproduce it; create it anew again and again. Capitalism with its city of injustice is advancing and flourishing behind the ideological false consciousness of your liberal science and planning.

Had there been a subtitle to Harvey's book it might have read 'the transformation of a social urban geographer from a liberal positivist into a structuralist-Marxist Social Theorist'. David Harvey's personal story is, in a sense, the story of a whole generation. As a participant in the "quantitative revolution" of geography and urbanism of the 1950s he gradually became one of the authorities in positivist-quantitative geography. His book *Explanation in Geography*, published in 1969, is since one of the best, and most comprehensive, geographical synthesis of positivist theory, methodology and philosophy.

Harvey started to doubt his own "Explanation" already when it was in press (Harvey 1970), and his "Social Justice" is, an all-out Marxist-structuralist attack on his Liberal-capitalistic "Explanation". "Social Justice" has triggered a bombardment of anti-positivism, anti-quantification criticisms, mostly by the ex-leaders of the quantitative-first science of cities. Bunge the ex-theory and model builder, Gould the ex-behaviorist, King the ex-statistician, Smith the ex-neoclassical location theorist, to name but few of the prominent figures; one by one they stand up, criticize their positivist-quantitative past and promise a new, socially relevant, urban geography (AAAG 1979).

If the early 1970s have been the years of criticism, the late 70s were the years of re-formulations. The Journal *Antipode* became the major (though not the only) outlet for radical-Marxist geographers and urban planners in the U.S., while *International Journal for Urban and Regional Research* in Europe. Relph's humanistic-Heideggerian *Place and Placelessness* appeared in 1976, and a year later Yi-Fu

Tuan's (1977) phenomenological monograph on experiential *Place and Space*. In 1977, Peet's Marxist *Radical Geography* was published. Ley and Samuels (1978) have edited *Humanistic Geography* and texts of forgotten geographers, such as the anarchists Elisee Reclus (Dunbar 1981) and Prince Kropotkin (Breitbart 1981), reappeared on the stage as a starting point for a renewed, socially relevant geography and urbanism. In 1980, Kirk published *Urban Planning in a Capitalist Society*, while in 1981 Dear and Scott edited *Urbanization and Urban Planning in Capitalist Society* – a collection of essays attempting "to define a general theory of urbanization and planning ... a theory that generally insists upon the explicit derivation of contemporary urbanization processes out of the structure of the capitalist mode of production" (p XIII). In 1982, once again came David Harvey, now with *The Limits of Capital* in which he attempts to go beyond Marx's *Capital* in order to fill some "empty boxes" in the Marxist theory, especially those related to 'the urban process under capitalism'; a project which was completed three years later with the simultaneous appearance of his two new volumes *The Urbanization of Capital* (Harvey 1985a) and *Consciousness and the Urban Experience* (Harvey 1985b).

The above partial and by no means exhaustive list will suffice to transmit the spirit of the period – the fact that the "quotations" in the writings of Harvey, Peet, or Kirk come from Marx, Engels, Lefebvre, Thompson, Althusser, Levi-Strauss, or Habermas, while those of Tuan, Relph, and Battimer, from Schutz, Husserl, Sartre, Buber, Gadamer, and Heidegger. In short, SMH urbanists were inspired by 'social theory' or 'social philosophy' – that body of literature which takes the entity 'society' as its focal subject matter.

This is significant since social theory oriented urban studies were not a side-stream of social geographers and urbanists interested in the philosophy of science, but became the central current of the discipline affecting many planning schemes, almost every research, theoretical as well as empirical. This, I think, has no parallel in any other discipline not even in sociology whose source of origin was social theory itself. Twentieth century sociology, as noted by Frisby and Sayer (1986), has disentangled itself from social theory and from grandiose questions such as 'what is society' or 'how society is possible', or, what are the relations between the individual agent and the social structure. Contradictory as it may sound, urbanism, social geography and urban planning have done exactly this and became "applied social theory". Social theory has become a theoretical framework for studies on interregional migration, location of industries, regional or urban inequalities ... urban studies, geography and planning have taken social theory from the high spheres of philosophy 'down to earth', literally.

3.2.2 The Marxist City

Marx, as is well known, had very little to say about space and cities and yet the theory of cities and urbanism is intimately linked with his writing. This is so with respect to the discourse of ancient cities and urbanism which is strongly influenced by the Marxist interpretations of Childe's (1950) "urban revolution" and of Wittfogel's (1957) "oriental despotism" and "hydraulic civilization"; and this is so with respect to discourse of urbanism in modern capitalist society in which central figures are people like Lefebvre (1970) with his (once again) "urban revolution", Harvey (1985b) with *The Urbanization of Capital* and Castell (1977) with his *The Urban Question*.

The Marxist (image of the) city is a city of big forces, of modes and relations of production, of class struggle between the oppressing and the oppressed, of the capitalists versus the working class, of the economic infrastructure and the political-ideological superstructure, all obeying the laws of history as revealed by Marx and elaborated by Marxism. Two such images, one of Castell's and the other of Harvey's, will suffice to give you the spirit of this new Marxist city.

Castells (1977) constructs his Marxist city by translating Althusser's nonspatial structuralist-Marxist conception of social structure to a spatial urban structure. Here the city is the spatial expression, or representation, of the structure of society as Marx and Marxism have revealed and elaborated. This translation is shown in Fig. 3.1.

In *The Urbanization of Capital* Harvey (1985a) portrayed another image of a Marxist city. It is constructed by showing how the very laws of capitalism as formulated by Marx(ism) entail, as a logical consequence, the specific capitalist urban landscape as we know it today. Capitalism as the dominant mode of production of our age is characterized by structurally inherent inner tensions and contradictions and is thus chronically unstable. As a consequence, the landscape of capitalism is full of tensions. One very basic tension is between forces working toward spatial agglomeration and processes working toward dispersal over space (Fig. 3.2). The agglomeration processes pull clusters of economic activities into specific locations and regions, thus forming cities, and at the same time the inherently expansionary tendency of capitalism which demand that capital accumulation be also dependent upon time-space coordination between regions pushes toward spatial dispersion of economic activities. According to Harvey, this tension can be resolved only through 'the urbanization of capital' (Gregory 1994).

3.2.3 The Humanistic City: From Space to Place and Back Again

The criticism of the first culture of cities developed as noted in two heads: one was structralist-Marxist and the other phenomenological and idealistic. A central tenet in this second line of criticism was the tension between *place* and *space*. The notion of *place*, according to writers such as Tuan (1977) in *Place and Space*, and Relph (1976) in *Place and Placelessness*, refers to the intimate humane relations between people and their very homes, neighborhoods, cities, lands, countries; the positivistic *space*, they claimed, is an alienated, alienating and dehumanizing abstract concept – a *placelessness*. The notion of space as conceptualized by positivist approaches and theories, claimed both structuralist and humanistic geographers and urbanists,

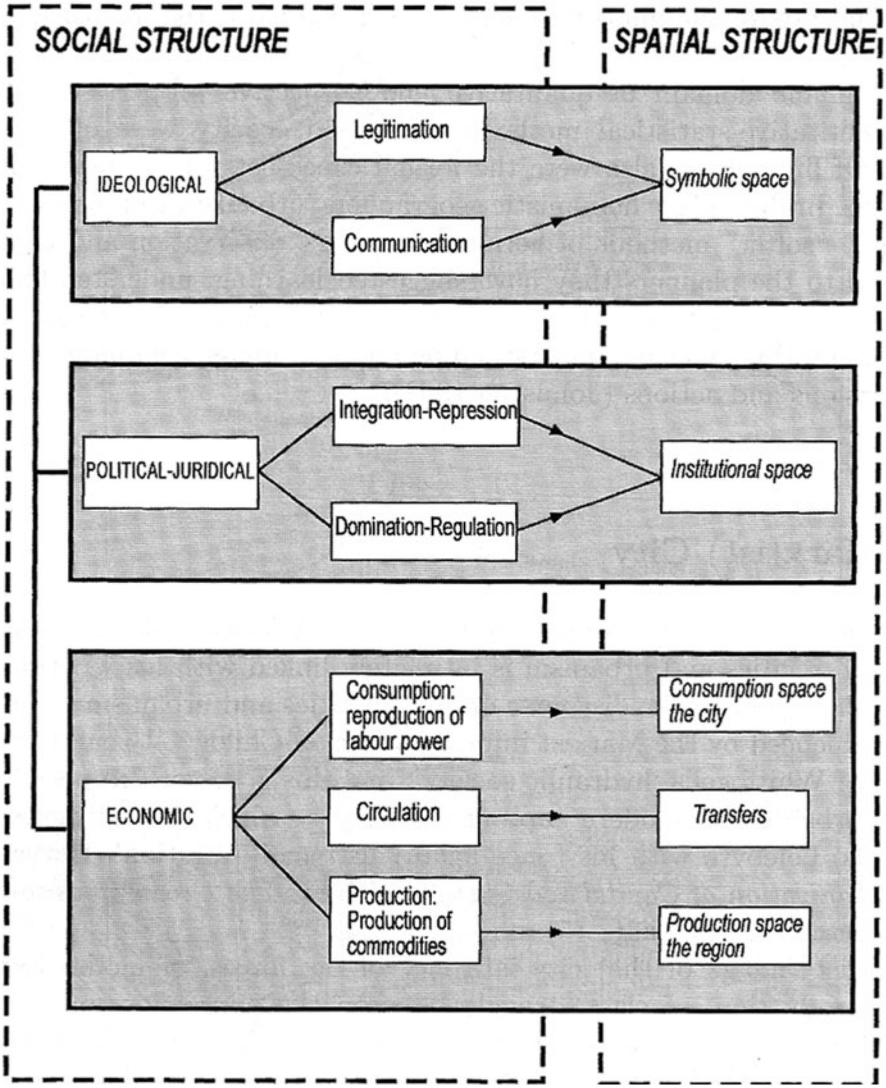

Fig. 3.1 The Marxist city as a spatial representation of social structure (*Source*: Gregory 1994)

is part of the ideological false consciousness that tends to obscure people's view at their real conditions of existence.

The humanistic image of a city that emerges out of this discourse is a city of places and spaces; a city as human individuals, subjectively and inter-subjectively, perceive, remember, cognize and imagine, it to be: the visual shape of the city with its neighborhoods, streets and parks, as well as its nonvisual properties of good/bad streets, prestigious buildings, safe, dangerous, pleasant, friendly, alienated, neighborhoods, and the like.

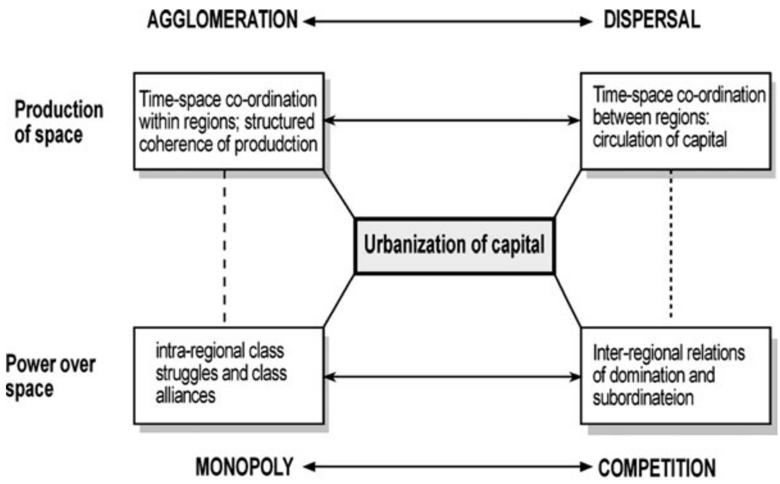

Fig. 3.2 The Marxist city as an outcome of basic tensions in the landscape of capitalism (*Source*: Gregory, ibid)

This is a city that is constantly shaping individuals' daily activities and routines, which in their turn construct the city, and individuals' cognitive maps of the city, and so on in an ongoing process of reproduction and structuration. The heroes of this ongoing play of urban dynamics, are human individuals with their subjective near and far, big and small, pleasant and ugly – elements and properties which have no role to play in the first culture of cities, but are the main actors of the humanistic city.

By looking at the city from within, from an *insider's view*, from the perspective of people, of the individual, the humanistic city attempts to capture the added existential, phenomenological, experiential, quality of the city; the *real* city as experienced by the people who actually create and construct the city. They try to capture not only the sense of *place* – those portions of the city which were created by people and thus directly transmit individuality, human scale and "peopleness"; but also the sense of *placelessness* – those impersonal and alienated parts of the city created not by the personal wishes and activities of people, but by the impersonal interests of the multi-national, the big company, the institution, the system.

In this humane domain of qualitative and subjective properties, the positivist-quantitative-statistical methods of the first culture of cities were of very limited use. In their place humanistic urbanists and planners had to turn to "softer" methods of hermeneutics, free observation and conversation; and to the planners they have suggested learning, understanding and awareness: learn, understand and be aware of, the place and placelessness of cities, and this knowing, understanding, and awareness will guide your planning decisions and actions (Johnston 1988).

The above dichotomy between place and space marks the usage of these terms in the discussions of the 1970s. Subsequent structuralist-Marxist and humanistic (SMH) urbanists as well as postmodernist, poststructuralists and deconstructivists (PPD – see below) have further elaborated both notions (Hubbard et al. 2002, pp 16–18) and have exposed their multidimensionality: instead of the place-space dichotomy of the 1970s, they now portray the two notions in terms of a continuum at one edge of which stands the humanistic *place* of the 1970, while at the other, a socially produced *space* as conceptualized, for example, by Lefebvre (1974/1995) in his *The Social Production of Space*. In between one finds a multiplicity of places and spaces that form the continuum. The gap now is between this place-space continuum and space as employed by positivist urbanists.

3.3 PPD Cities (Postmodern, Poststructuralist, and Deconstruction)

It is common to see the origin of postmodernism, poststructuralism and deconstruction in the writing of personalities such as Foucault, Derrida, Lyotard and Jameson, among others and in precursors such as Nietzsche, Heidegger, Lacan, and Wittgenstein (Dear 2000, p 31). What is common to PPD writers is that they have turned their back on, and questioned, various positions that, following the appearance of 'postmodernism', are regarded as characteristics of 'modernism'. Among other things, they have exposed and criticized modernism's obsession with history, time and progress and have questioned the belief in an Archimedean point from which one can derive moral as well as scientific truth. In his *Time's Arrow & Archimedes' Point* Price (1996) writes that the attempt to find an Archimedian perspective on reality was one of the greatest efforts of modern science and philosophy. The belief in the possibility to define such a point was common not only to physicists and philosophers (to whom Price refers), but also to 'modernist' social theorists, be they Marxists, structuralists, humanists or liberals.

The rejection of any fixed point of departure shows up in the reluctance of PPD writers to say what postmodernism *is* and to concentrate instead on what it *is not*: "*I'll use the term* ***modern*** *to designate any science that legitimates itself with reference to a metadiscourse* ...", writes Lyotard (1984, xxiii) and then adds that postmodernism is the "incredulity towards metanarratives" (xxiv). "... *it is hard to know what postmodernism is*", writes Dear (2000, p 25) in his *The Postmodern Urban Condition*, and Cilliers (1998, p 113) argues: "The word 'postmodern' has acquired so many different meanings that it has become impossible to define it". The term postmodernity, says Luhmann (2000, p 40), "cannot say what it means, because this will lead to ... its deconstruction".

The doubts concerning the Archimedean point are directly related to the criticism of history and progress: if there is no Archimedean point, there is no clear end and neither truth nor possible notions of progress and direction toward them. In such a world and reality one is thus left with coexisting entities (cultures, aims, ideals, truths, ...) with no hierarchy among them, that is to say, with a multiplicity of spaces and places. "The great obsession of the nineteenth century", wrote Foucault (1986, p 22), "*was, as we know, history ... The present epoch will perhaps* *be above all the epoch of space* . . .". Thus, the subtitle of Soja's (1989) *Postmodern Geographies* reads: "The reassertion of space in critical social theory".

Proponents of PPD claim, with Lyotard (ibid), that the rejection of any Archimedean point allows a highly dynamic and creative interpretation of society, culture and science. Critics of postmodenism, namely physicists Sokal and Bricmont (1998) in their *Fashionable Nonsense*, argued that such a rejection leads to the "abuse of science". Modernist social theorists have claimed that the rejection of such a point, be it an objective truth or alternatively a social consensus in Habermas' (1984–7) sense of 'communicative action' (see Chap. 12), makes postmodernism unethical (Habermas 1992). In a similar manner, Gellner (1992, p 49) argued that postmodernism is essentially a form of extreme modernist relativism that in its turn "*does* entail nihilism". Postmodernists have responded by saying that PPD approaches are not nihilist in that they hold an ethical position that can be described as a "softer", context dependent, form of modernist ethical standpoints. Thus, in the concluding section to his book Dear (2000, p 318) writes: "I do not pretend to be a 'pure' postmodernist; my scholarly, personal and professional lives are too committed to social activism to be comfortable with extremes of relativism. But my . . . commitments to . . . Marxian epistemologies . . . have been radically undermined". On the other hand, deconstructivism in architecture (a notion that echoes and negates the Russian constructivism of the 1920s) goes hand in hand with capitalist-liberalist ideologies that typify the current global economy (for example, the architecture of Eisenman, Gehry, Tscumi or Hadid and the work and writing of Koolhaas 1995).

There is no place here to further elaborate on the debate concerning the various PPD positions. (For a detailed discussion of the various views and their relation to urban studies, see Dear 2000, in particular Chap. 2). However, regardless of what one's position on the above is, it would be fair to say that the various notions of PPD authentically reflect the experiential sensation of life and society at the end of the 20th and the beginning of the 21st centuries: a somewhat chaotic and unstable *Network Society* (Castells 1996), highly connected by complex channels of communication, constantly under a bombardment of information of all sorts, a fast changing world, with shrinking distances, loss of direction, and all the rest. Postmodernists tend to interpret these phenomena as markers of a genuine post-modern reality (Lyotard 1984), while others follow Harvey's (1989) view that these postmodern phenomena are in effect modernism in disguise – markers of the latest stage of capitalism and by implication of modernism.

3.3.1 The PPD City

The image of the city as emerging out of the various PPD writings is an image of an untamed, shrew, capricious and ever-changing city; actually it is not a city but a text; a text written by millions of unknown writers, unaware that they are writers, read by millions of readers, each reading his or her own personal and subjective story in this ever-changing chaotic text, thus changing and recreating and further complicating it. Today's urbanism is a big theatre at the center of whose stage we see a kaleidoscope of shapes and forms, high-tech science-fiction structures mixed with pharaonic lotus capitals from the second millennium B.C. Egypt (e.g., Sterling's Staatsgalerie in Stuttgart), and in and around it a similarly pluralistic kaleidoscope of cultures and subcultures of Italians, Chinese, Japanese, Jews, Indians, Gays, Lesbians ... Somewhere at the side of this second-millennium urban stage, way in the periphery, one can still observe the base and the superstructure, with their modes and relations of production, the capitalists versus the proletariat, talking, shouting in vain trying to be heard. In this PPD city nothing is stable, nothing is true nor does anything matter for more than a second, not the Marxist urban categories, nor any other grand theory or truth: all must go, must move, clear the way to the new next whatever it is.

For the pessimist positivist and SMH urbanist or planner this sounds chaotic; for optimists – highly desirable and creative: an ever-changing, ever-moving reality. Yet this is not what takes place in the currently emerging postmodern reality; at least not up till now. Take the emerging urban landscape and architecture, probably the most visible representation of PPD. Indeed, it started with free and creative quotations from the futurist high-tech Archigram architecture (Cook 1972) and 2nd millennium B.C. Egyptian columns. However, very quickly it turned into a uniform style with the double column, the gable and the circular window as its trademarks. Walk around in Tel Aviv and you'll see that you can't instantly not identify the uniform, postmodern, style. And yet, the words 'uniform' and 'style' are the very opposite of postmodernism.

As further elaborated below in connection with urban planning (Chap. 12), the postmodern trend toward plurality and coexistence, in art, science, urbanism, and society, is at least problematic – and this is indeed its deadlock: You can't tame, plan, engineer, the environment, since you are trapped in its chaos, and you cannot participate in its chaotic interplay since you are trapped in its structure, fashion, and style. This deadlock shows up in a debate in the geographical journal *Society and Space* (1987) on modern and postmodern geography and planning. Postmodern geographers accuse David Harvey that his Marxist-structuralist geography is totalitarian, and Harvey responds that there is nothing more totalitarian than such an accusation. Both are right, of course, since both are playing a zero-sum game: there is no room for chaos in the highly ordered Marxist world and there is no room for stable structures in the highly chaotic postmodern city.

3.4 The Third Way

The major tension in the study of cities has been described above as the tension between the two cultures of cities that correspond, as noted, to Snow's two cultures. That is to say, the tension between attempts toward a science of cities (first culture) versus attempts at a critical, socially relevant, study of cities (second culture). While this tension indeed gave the tone and dominated the field during the second half of the 20th century, there have been other approaches that did not conform with the two main parallel streams but nevertheless suggested an alternative way or rather ways of looking at the city. I'm referring to projects such as Jane Jacobs' (1961) *The Death and Life of Great American Cities*, Christopher Alexander's (1965, 1979, 2002–2004, Alexander et. al. 1979.) publications ranging from "A city is not a tree" and *Pattern Language* to his recent *On the Nature of Order*, and, Torsten Hägerstrand's (1969) *Time Geography*.

Similarly to the SMH second culture of cities, Jacobs and Alexander were and are critical of the first science of cities; however, their criticisms differ from the SMH's in several respects. First, unlike the SMH criticism that was essentially political and as such directed toward the entire liberal-capitalist system that dominates Western society, their criticism of the first culture of cities was directed toward the scientific method and its application to cities, city planning and urban design. Second and as an implication from the above, unlike SMH that started with the overall capitalist system and as a consequence saw the city as a representation or derivation from it, their criticism started with and from the nature of the city itself. Third, unlike SMH that focused mainly on the phenomenon of urbanism, their main concern was city planning and design. Something went wrong with our perception and understanding of cities, claimed Jacobs and Alexander, each in her/his own way, and as a consequence of this misunderstanding, something is wrong also in the way we intervene in the dynamics of cities by means of urban planning and design.

I'll describe the work of the above two in subsequent chapters: The work of Alexander in Part II that suggests a cognitive approach to the complexity of cities, and the ideas of Jacobs in Part III in the context of a discussion on complexity and planning. I bring theme here because of their close association with CTC (complexity theories of cities). In fact, I share with Batty (below Chap. 5) the view that these theories and views were forerunners of CTC. Jane Jacobs with her great intuition and penetrating observations into city-life was able to note already in the 1960s that cities emerge bottom-up out of the local interaction between their inhabitants and users and that the seemingly chaotic appearance of cities suits human life as a glove to an hand. A few years later Alexander (1965) drew attention to a fundamental property of the city, namely, that it is a complex network – a *semi lattice* network – and that this complexity arises out of the complexity of the human mind – a point he elaborated in his further works that showed that people perceive, behave in, and act on, the environment by means of patterns that exist in their minds and in the world.

A third exemplar of the third way is Torsten Hägerstrand (1969) with his project "*Time Geography*" that he initiated in a paper entitled "*What about people in regional science*". Hägerstrand never wrote explicitly on cities and their planning; however, I do include him in this group because like them he did not conform with the two cultures of cities and because his emphasis on time, daily routine and the individual touches some of the basic properties of complexity: bottom-up, local interaction and the power of daily routines that to my mind is the "weak force" of urban dynamics. His project and its connection with complexity theory are described next.

3.4.1 Hägerstrand's City of Daily Routines

SMH urban studies were indeed the most prominent critiques and the ones that had the most dominant impact on the subsequent evolution of the field. However, there was another line of criticism that at the time looked as promising as SMHs but at a later stage gradually evaporated for reasons that to my mind are essentially cultural. I'm referring to Hägerstrand's project *Time Geography*.

In 1969, Hägerstrand presented a paper entitled "What about people in regional science" to the European Congress of the Regional Science Association in Copenhagen and a year later published the paper in the journal of that association (Hägerstrand 1970). "What about people ..." became a seminal paper that started a new brand of geography and spatial analysis known as *time geography*. In this paper Hägerstrand puts forward several innovative suggestions. First, that in addition to the study of cities by means of representative statistical samples, we might as well benefit from studying single individuals. Second, that this can be done by mapping the movement of individuals not only in space, as is usual in urban studies, but in space and time simultaneously – hence, time geography. Third, when observing an individual's trajectories in space-time, one realizes that the individual is always in movement: when staying in a single location s/he is moving in time; when moving between locations, the individual is moving in space-time. Fourth, when observing the space-time movement of individuals in the city, one realizes that much of it is routinized (Fig. 3.3) – hence the notion of "dance" in this context. Fifth, that by observing individuals' space-time movement, or "dance", in the city, and by focusing mainly on their routinized movement, one can learn about the nature of the urban environment within which people are operating. The city of daily routines opens a window into the significance of the "weak force" of the city – the daily and the personal and the ordinary; not only as a methodology to identify and study the system of space-time constraints within which individuals are operating, but also into the way individuals by their normal day-to-day life create and construct the city as a humane place.

Hägerstrand's time geography was accepted with enthusiasm, several publications followed (Carlstein 1981; Carlstein et. al. 1978; May and Thrift 2001), and the new notion was also adopted by social theorist Giddens (1984) in his theory of *structuration*. But then it almost disappeared and was mentioned mainly in texts about the history of geography (Peet 1998). The reasons for this discontinuation in the space-time theory is to my mind the treatment given to it by Giddens whose work became influential in social geography. Giddens gave Hägerstrand's time geography a bear hug: On the one hand, he made remarks indicating that Hägerstrand's time geography made significant contribution to social theory by stressing (Peet, ibid, 158-9)

> "*the routinized character of daily life connected with the basic features of the human body, its mobility and means of communication ... According to Giddens ... Hägerstrand identified sources of constraint over human activity ...*

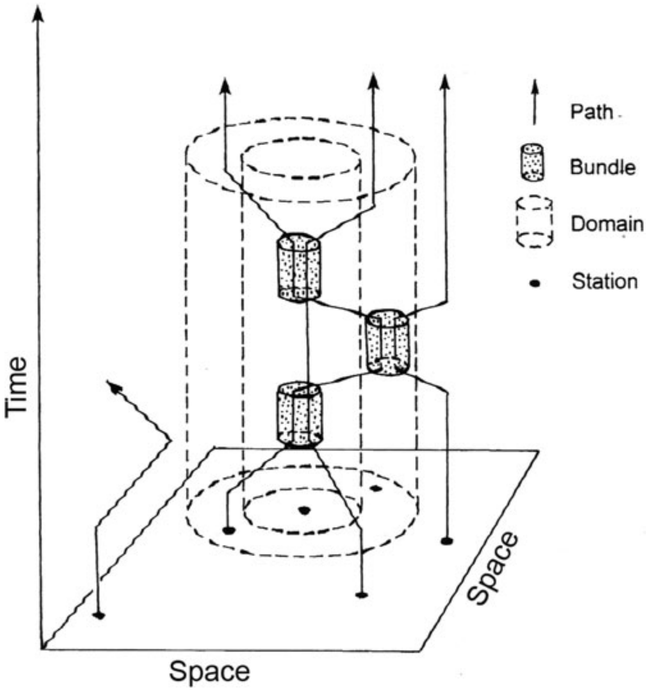

Fig. 3.3 Hägerstrand's web model of time geography. The *path* represents the daily movement in space-time of an individual; the *bundle* is the space-time place/cylinder where the individual congregates with other individuals (e.g., home, work, school, etc.), while the *domain* describes the space-time area/cylinder within which the individual's daily movement takes place

On the other hand, however,

> *Giddens (1984, p 116–18) expresses reservations about Hägerstrand's time geography: he thinks that it operates with a naive and defective conception of the human agent; it recapitulates the dualism of action and structure; it focuses on constraint but does not see this also as an opportunity; it has a weakly developed theory of power ... " (Peet 1998, p 158–9).*

Hägerstand has formulated his time geography at a bifurcation point – at a period during which the major tension in the study of cities was between positivism and SMH urban studies that eventually split into two parallel currents. In such a cultural climate there was no room for ideas that do not conform to one of the main conflicting streams. As a consequence, at such a period a criticism from Giddens that at the time was very influential in SMH urban studies, simply put an end to the attempt to further develop time geography and realize its full potential. This was unfortunate because, firstly, Hägerstrand's time geography is simple, beautiful and elegant theory; secondly, it can be linked, on the one hand, to quantitative approaches while, on the other, to SMH approaches, with the implication that it could have linked the two; thirdly, as we shall see below, it can also be naturally related to complexity theory.

3.5 CTC as a Link Between the Two Cultures of Cities

CTC is in an interesting position: On the one hand, as a theoretical body that originated in the sciences, mainly in physics, it came with a whole arsenal of mathematical formalisms; in this respect it is close to the first culture of cities. And indeed, many of the proponents of CTC see it as the new and more sophisticated science of cities. On the other hand, complexity theory and CTC have many similarities to PPD so much so that several scholars have interpreted complexity theory as the scientific counterpart of PPD or even as a "scientific proof" of the PPD world views. My personal view is that the similarity to PPD is somewhat superficial and that the more profound similarity is with the early forerunners described above and with "modern" social theory oriented views of the city.

This association of CTC with the first culture of cities with its quantitative approaches, and at the same time with qualitative-hermeneutic approaches of the second culture of cities, makes complexity and self-organization a paradigm which has the potential to provide a common integrative ground for the various cities described above and below and thus to reconcile their seemingly irreconcilable nature. To see how, we first need to have a deeper look into CTC. This is the task of the next chapter.

Chapter 4
Complexity Theories of Cities (CTC)

4.1 Introduction

4.1.1 Bénard Cells

Henri Bénard, a French physicist working at the beginning of the 20th century, found the following about a liquid in a round vessel heated from below: At the beginning of the process, when the temperature difference between the heated bottom and the cool top is low, the heat is being transferred by conduction and no macro-motion can be observed in the liquid. However, as the temperature difference increases and a certain threshold is reached, the movement in the liquid becomes instable, chaotic and then a strikingly ordered pattern appears: The molecules of the liquid which at the beginning were moving in random, suddenly exhibit a coherent macro-movement in roles which are millions of times larger than the molecules. As can be seen in Fig. 4.1, the motion of the roles forms a hexagonal pattern on the surface of the liquid. This pattern is in fact an outcome of the movement of the hot liquid, which rises through the center of the honeycomb cells, and of the cooler liquid, which falls along their walls. All this happens as if by an external force. Yet no such force exists – the spatial order appears spontaneously, by means of self-organization.

In the early 1900s this experiment was registered as just another interesting example of *convection* – a process in fluid dynamics referring to the flow of heat, e.g., molecules, from the hot to the cold region of the liquid. In the 1960s it became one of the canonical experiments of several new theories about systems that are *open* in the sense that they exchange matter and information with their environment and *complex* in the sense that their parts are numerous and form a complex network with feed-forward and feedback loops. Such system are never in rest – they are far from equilibrium and exhibit phenomena of chaos, bifurcation, phase transition, fractal structure and the like. In the 1960s it was common to refer to these theories as theories of *self-organization*. In the last decade, it has become more common to refer to this body of studies as *complexity theory* or more precisely *complexity theories*.

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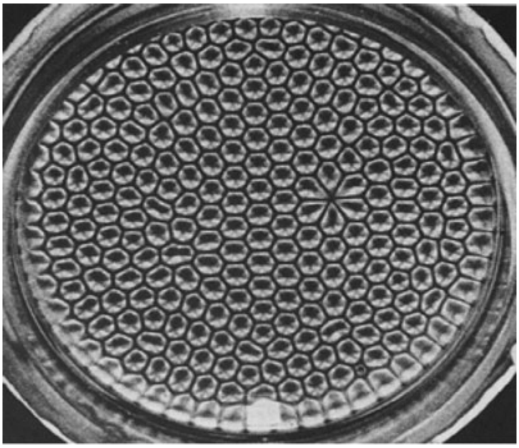

Fig. 4.1 Top view of a liquid in a circular vessel (from Haken 1996). When the liquid is heated from below and the temperature gradient exceeds a critical value, hexagonal cells are formed. In the middle of each cell the liquid rises, sinking back down at the edges of the hexagon

4.1.2 A Concise Introduction to Self-Organization and Complexity

The notion of *self-organization* appeared already in the early years of cybernetics, implicitly in the writings of McCulloch and Pitts (1943), and explicitly in studies such as Ashby's (1947) psychological discussion of the nervous system, and Yovits and Cameron's (1959) and Forester and Zopf's (1962) studies in the domain of system theory. Its modern form, however, is related to several theories developed since the mid-sixties, in particular to Haken's (1977, 1987, 1990, 1996) theory of *synergetics*, to Prigogine's *dissipative structures* (Nicolis and Prigogine 1977; Prigogine 1980; Prigogine and Stengers 1985), to Eigen's (1971) *catalytic networks*, as well as to Lovelock (1979), Maturana and Varela (1980), and Margulis (1995). Of the latter, Haken's synergetics and Prigogine's dissipative structures were probably the first to be applied to cities and urbanism. The authors who first coined the notion of 'self-organization' were fascinated mainly by the property of noncausality of the systems they have confronted. That is to say, by the finding that in certain situations external forces acting on the system do not determine or cause its behavior, but instead trigger an internal and independent process by which the system spontaneously self-organizes itself. The authors of the second wave of studies, led, as noted, by physicists such as Haken and Prigogine, were attracted by an even more complex process; the latter can be nicely illustrated by the above Bénard experiment that has since become a classical way to convey the notion of self-organization.

Most theories of complexity have been applied to cities with the implication that we now have a whole domain of theory and research that I have called *complexity theories of cities* (CTC). The domain of CTC already includes a rich body of research on *fractal cities* (Batty and Longley 1994), *self-organization and the city* (Portugali 2000), *cities and complexity* (Batty 2005), cellular automata and agent base urban simulation models (Benenson, and Torrens 2004), studies on cities from the perspective of Bak's *self-organized criticality* (Batty, ibid), studies on cities as networks (ibid) and much more.

The Bénard experiment, which has been repeated and elaborated by others, exhibits the main features of self-organization. First, that a system that is open and is thus part of its environment can attain a spatio-temporal structure and maintain it in far from equilibrium conditions; not in spite of, but as a consequence of, a sufficient flow of energy and matter. This contradicts the traditionally held view in physics, that systems must be looked at as essentially isolated from their environment. According to the second law of thermodynamics, such systems tend to move toward molecular disorder, that is to say, toward an increase of entropy.

Second, that this flow of energy and matter through its boundaries allows the system not only to spontaneously self-organize, attain a certain structure, and maintain it in far from equilibrium conditions, but also to "create" or "invent" novel structures and new and novel modes of behavior. Self-organized system are thus said to be "creative".

Third, self-organized systems are complex in two respects; one, in the sense that their parts (e.g., the molecules in the liquid) are so numerous that there is no technical way to establish causal relations among them; two, in that their parts and components are interconnected in a nonlinear fashion by a complex network of feedback and feedforward loops. Mathematically this form of behavior can be described by a set of nonlinear equations.

While the various complexity/self-organization theories and approaches that have been suggested since the emergence of this paradigm in the 1960s, and by implication also the various CTC, share the above-noted properties, they differ in two interrelated respects: Firstly, they differ with respect to their time scale and as a consequence in their mathematics, and also in the properties and processes they emphasize. More specifically, some refer to the longer time-scale evolution of complex systems – in our case cities and urbanism, while others to their shorter-term evolution and/or behavior. Based on this time-scale distinction, we can identify two major types of CTC (Fig. 4.2): long-term (or *comprehensive*), CTC versus short-term complexity theories, and complexity theories of cities.

Long-term comprehensive complexity theories of cities are the urban theories derived from the founding theories; first and foremost from Haken's theory of *synergetics* (Haken 1983, 1987) and also from Prigogine's theory of *dissipative structures* (Nicolis and Prigogine 1977; Prigogine and Stengers 1984); to some extent urban interpretations derived from Bak's *self-organized criticality* (Bak and Chen 1991) can also be added to this group. They are long-term and 'comprehensive' in the sense that they refer to all stages of the evolution of such systems: the bottom-up process of *emergence* that brings complex systems into a global ordered state and the process of *steady state* that keeps them is a structurally stable state. Of the latter, Haken's *synergetics* is the most comprehensive one due to its *slaving principle* (see below) and its emphasis on *circular causality*, that is to say, the feedback process by which the system "enslaves" the parts that brought it into being.

Short-term complexity theories limit their focus of interest to one part of the process. Most theories in this domain are short-term *emergence* complexity theories

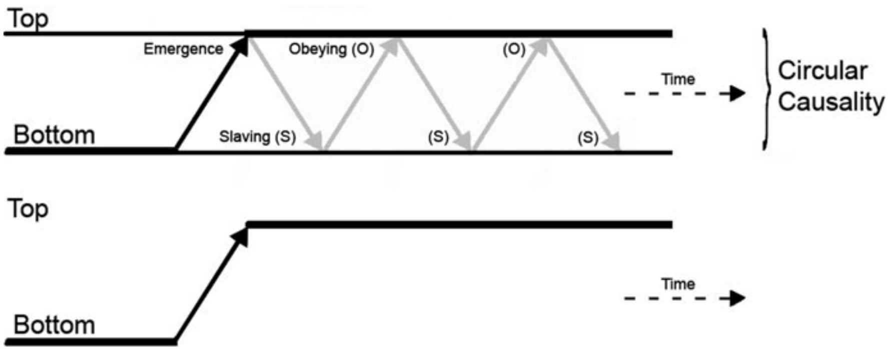

Fig. 4.2 Long-term (*upper drawing*) vs. short-term (*lower drawing*) complexity theories and CTC. A typical comprehensive complexity theory (*upper drawing*) is Haken's synergetics according to which local interactions/synergy between the parts (*bottom*) gives rise to an order parameter (*top*) that then enslaves the behavior of the parts (*bottom*). By "obeying", the parts strengthen and reproduce the order parameter and so on in circular causality. Compare to Fig. 4.4. Short-term CTC (*lower drawing*) focus exclusively on the bottom-up process of emergence by which the local interaction between the parts gives rise to a global systemic property, behavior, or phenomenon

that concentrate on the process of emergence, that is, the bottom-up process by which local interaction between the parts gives rise to a global structure. These theories do not theorize on the conditions and dynamics of the steady-state stage that keeps the system in a structurally stable state for long periods. Mandelbrot's theory of fractals is of this nature. On the other hand, chaos theory (or theories) is (are) a short-term complexity theory that looks at the reverse process of the "emergence" of chaos out of order.

The second distinction concerns *complexity theories* vs. *complexity models*. That is, theories that theorize about the dynamics and properties of complex systems versus models by which one can study the various phenomena and properties that typify complex systems. To be sure, all complexity theories and CTC come with their specific formalism and models. However, only CA (cellular automata), AB (agent base), and graph theoretic approaches can be described as "pure" models; firstly, in the sense that they do not make strong statements about the very dynamics of cities as complex systems. Secondly, and as a consequence of the above, they can be employed as tools to simulate various phenomena theorized by the "genuine" theories. One might object to this distinction by saying that these complexity models emphasize bottom-up emergence processes of complex systems. This is indeed so. However, the use of these models is not exclusive to the study of complex systems – they can and have been used, as means to simulate mechanistic simple systems, and, can and have been employed as means to simulate top-down processes for instance. A case in point is the FACS models introduced in Sect. 4.4.2 below, and employed in Part IV, Chaps. 17, 18.

Looking at the short history of CTC studies, one can observe a movement of interest from CTC to complexity models of cities. As we shall see below, CA, AB and graph-theoretic network models have become the most dominant approaches in the study of cities as complex, self-organizing systems. Chap. 5 below discusses the advantages but also the disadvantages of this situation.

The aim of this chapter is twofold: To introduce and discuss the various CTC, and, by so doing also to further elaborate on the various complexity theories from which they were derived. The discussion proceeds under the title of eight categories of "cities" which are related to general theories or specific methodologies. These eight cities are grouped into long-term CTC, short-term CTC and complexity models of cities. Under the long-term CTC come 'dissipative cities', 'synergetic cities' and self-organized criticality 'sandpile cities' (Sect. 4.3), under short-term CTC come 'chaotic cities' and 'fractal cities', while under complexity models of cities come 'cellular automata' and 'agent-based cities', 'FACS cities' and network 'small world cities' (Sect. 4.4). The discussion of each category of cities starts with a short introduction to the general principles of the approach and then elaborates its complementary self-organizing city.

4.2 Long-Term Complexity Theories of Cities

4.2.1 Dissipative Cities

Dissipative cities are the product of Prigogine's theory of *dissipative structures* and its application, by Allen and coworkers, to the study of cities and systems of cities (Allen 1981; Allen and Sanglier 1981; Allen et al. 1985). As the name indicates, Prigogine's theory of self-organization puts specific emphasis on the process of dissipation. A good starting point for his argument might be the conjunction between Boltzmann's order principle and the Bénard experiment as described above. The latter, as noted, exhibits a coherent motion, which "means that many molecules travel with nearly the same speed". According to Boltzmann's principle (which relates entropy to probability), there is almost no chance for this coherent self-organized motion to occur; "yet it occurs" explain Prigogine and Stengers. The reason is that in

> *far-from-equilibrium condition, the concept of probability that underlies Boltzmann's order principle is no longer valid .... Classical thermodynamics, leads to the concept of 'equilibrium structures' such as crystals. Bénard cells are structures too, but of a quite different nature. That is why we have introduced the notion of "dissipative structures", to emphasize the close association, at first paradoxial, in such situations between structure and order on the one side, and dissipation or waste, on the other. We have seen ... that heat transfer was considered a source of waste in classical thermodynamics. In the Bénard cell it becomes a source of order. .... The interaction of the system with the outside world, its embedding in nonequilibrium conditions, may become in this way the starting point for the formation of new dynamic states of matter – dissipative structures. .... Bénard cells, like all dissipative structures, are essentially a reflection of the global situation of nonequilibrium producing them* (Prigogine and Stengers 1985, p 142–144).

For anyone familiar with location theory the close resemblance between the hexagonal structure of the Bénard cells and the Christaller's (1966/1933) and

Lösch's (1954) hexagonal landscapes of central places (above, Chap. 2 Figs. 2.6–2.9) not just invites, but almost demands, a comparison. And indeed, this challenging similarity was taken up by Allen and coworkers who in a series of studies have reformulated the static central place theory of Christaller and Lösch in the dynamic terms of Prigogine's dissipative structures.

Allen and coworkers have developed a sequence of several models, which elaborated their theoretical treatment of hierarchical landscapes of central places, first with respect to systems of cities in a given region and later at the intra-urban scale in connection with a single city. At a later stage they have also applied their models to real case studies of Brussels and the Belgian provinces (Sanglier and Allen 1989; see also: Pumain, Saint-Julien, and Sanders 1987).

A typical model of Allan's starts with an infrastructure of localities in a region, each with its residents and jobs. The actors are individuals who migrate in order to get employment, and employers who offer or take away jobs depending on the market's situation. The migration (or interaction) between localities and the introduction and extraction of economic activities (i.e. employment opportunities), create for each locality a kind of local "carrying capacity" and for the system as a whole nonlinearities and feedback loops which link population growth and manufacturing activities. For example, in Allen and Sanglier's study from 1981, the positive feedback is due to common infrastructure, economies of scale, etc. and the negative feedback is due to crowding, pollution and other factors. An example for a simulated scenario produced by the model is Fig. 4.3. This specific scenario starts with a hypothetical region (not represented in Fig. 4.3) characterized by a rectangular lattice of homogeneous localities (similar to the region shown in Fig. 2.7 *bottom, right*). Then, the mere play of chance factors, such as the place and time where different enterprises and migrations start, produce symmetry breakings, which entail an uneven distribution of population and employment (Figs. 4.3a–d). The result is an evolutionary process by which new urban centers emerge, grow, and form the whole of the regional system of central places; as the system evolves, some old localities grow, others decline or even disappear, thus constructing the specific history of this region.

The application, by Allen and coworkers, of the theoretical principles of dissipative structures to the question of the emergence of a hierarchical landscape of central places, immediately exposes the similarity and difference between the "old" static approaches of Christaller and Lösch, and the new treatment by means of self-organization. In both the old and new approach, economic activities and interactions give rise to central places, which are usually urban centers. However, while in the old formulations the landscape reflects an equilibrium state which is the optimized sum of the properties of the various economic forces, the new landscape is "more than the sum of its parts" – it reflects a far-from-equilibrium situation in which the spatial hierarchical order among the central places is obtained, maintained, and then transformed, by means of an interplay between interaction and fluctuations, on the one hand, and dissipation (as in the Bénard cells), on the other.

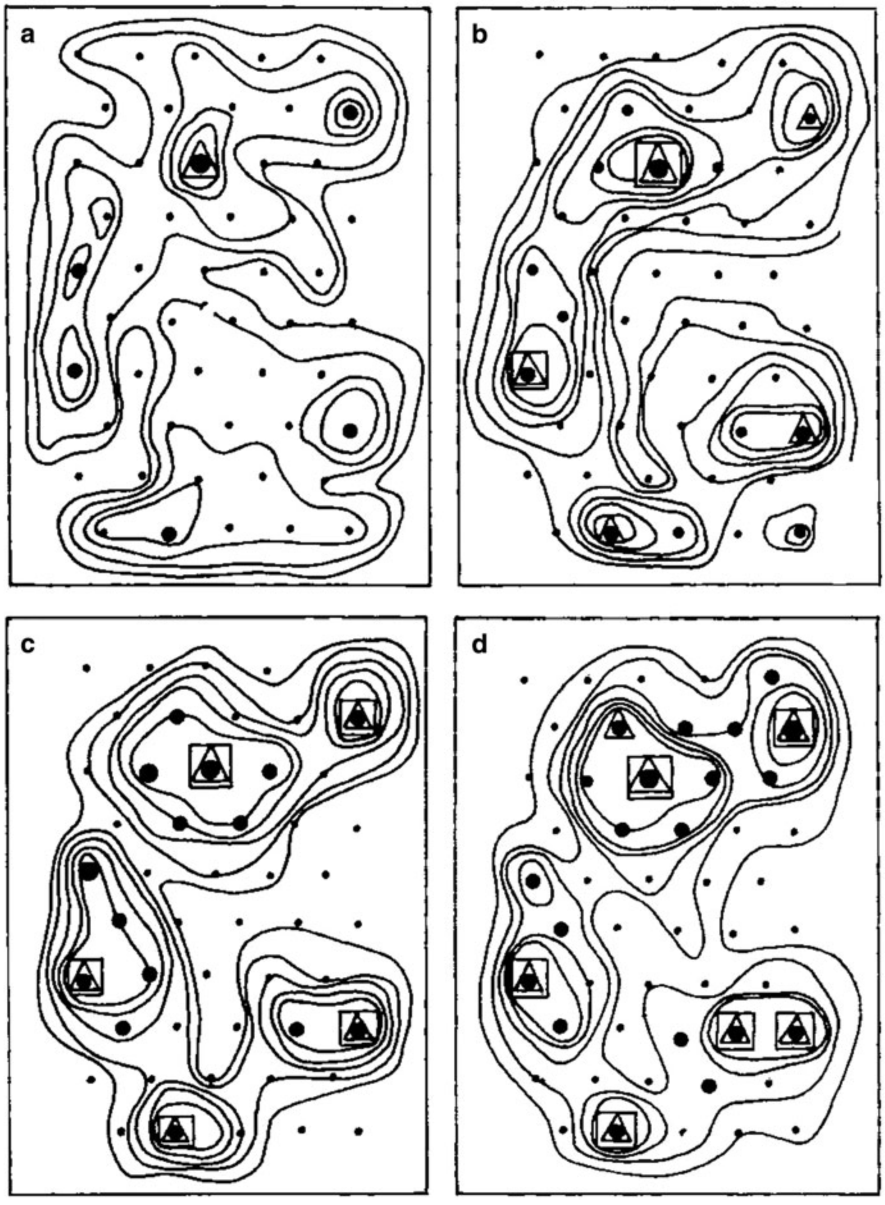

Fig. 4.3 Allen and Sanglier's (1981) simulated evolution of a dissipative system of cities. (a) at time (t) $t = 4$; (b) at $t = 12$; (c) at $t = 20$; (d) at $t = 34$. A small dot represents a settlement with one economic function; large dot a settlement with two economic functions; large dot inside a triangle – three functions; the latter inside a square – four functions

4.2.2 Synergetic Cities

Synergetics – the working together of many parts, individuals, subsystems, groups.. is the name assigned by Hermann Haken to his theory of self-organization (Haken 1979, 1983, 1985, 1987, 1990, 1993, 1996). As the name indicates, the emphasis here is on the interrelations, interactions and synergy among the many parts of the system and its overall structure and behavior.

Though synergetics originated in physics, it is by no means a physical theory that tries to reduce complex phenomena to the laws of matter. From the start Haken emphasized that the physical systems he was studying are similar in their behavior to phenomena of collective behavior in a variety of disciplines, and indeed, many of the notions which now form the theory were revealed and developed by a detailed investigation of case studies in a variety of domains, including sociology, psychology, cognition, AI (artificial intelligence) and also cities and urbanism. In all these studies Haken's (1996, p 39) central methodological guide was to "look for qualitative changes at macroscopic scales". Some of these case studies, in particular those of the laser, pattern formation in liquids, pattern recognition and the finger movement experiment, have become paradigm cases and a convenient way to convey the principles of synergetics. For the purpose of the present comparative discussion it will be useful to present three such cases – the laser paradigm, the pattern formation paradigm, and the pattern recognition paradigm.

4.2.2.1 The Laser Paradigm

The process that produces the laser can be regarded as the generic paradigm of synergetics. The gas laser consists of a glass tube filled with a gas of atoms or molecules. The gas tube has two mirrors at its ends, which serve to reflect the light running in axial direction rather often so that this kind of light wave can interact sufficiently strongly with the individual atoms. Because at least one of the mirrors is only semi-transparent, the laser light can eventually emerge through this mirror.

In a usual lamp, when an electric current is sent through the gas, the individual atoms may get excited and emit individual independent light waves. In the laser, the individual electrons in the atoms correlate their movements and generate a beautifully ordered coherent light wave (Fig. 4.4). This is a typical act of self-organization. There is nobody who tells the laser system how to behave in such a coherent fashion; it finds its well-ordered behavior by itself.

The interpretation of synergetics starts with Einstein's observation that when an excited atom emits a light wave, this light wave may cause other excited atoms to deliver their energy to that light wave so that this light wave is enhanced in its intensity. In the laser, initially quite a number of atoms emit their light waves independently of each other and with somewhat different wavelengths. Each of these might get support from the other excited atoms. In this way a kind of a Darwinian competition among the light waves for the energy resources of the excited

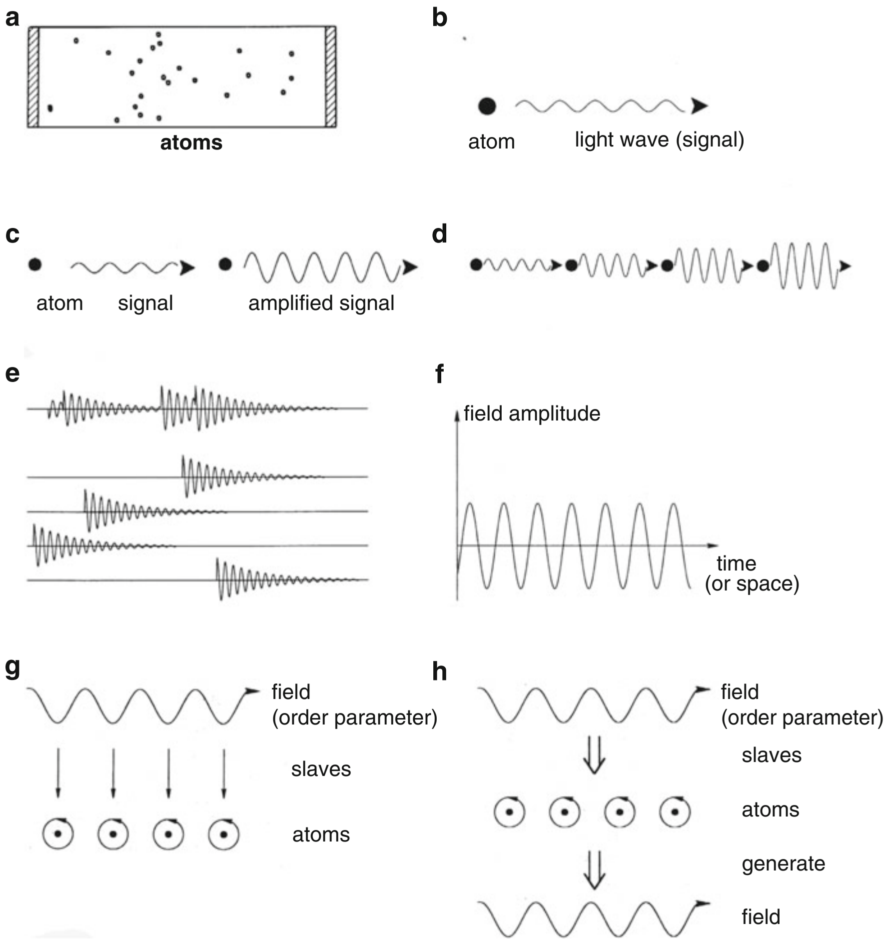

Fig. 4.4 The laser paradigm. (**a**) Typical setup of a gas laser. A glass is filled with gas atoms and two mirrors are mounted at its end faces. The gas atoms are excited by an electric discharge. Through one of the semi-reflecting mirrors, the laser light is emitted. (**b**) An excited atom emits light wave (signal). (**c**) When the light wave hits an excited atom it may cause the atom to amplify the original light wave. (**d**) A cascade of amplifying processes. (**e**) The incoherent superposition of amplified light waves produces still rather irregular light emission (as in a conventional lamp). (**f**) In the laser, the field amplitude is represented by a sinusoidal wave with practically stable amplitude and only small phase fluctuations. The result: a highly ordered, i.e. coherent, light wave is generated. (**g**) Illustration of the slaving principle. The field acts as an order parameter and prescribes the motion of the electrons in the atoms. The motion of the electrons is thus "enslaved" by the field. (**h**) Illustration of circular causality. On the one hand, the field acting as order parameter enslaves the atoms. On the other hand, the atoms by their stimulated emission generate the field (after Haken 1988/2000)

atoms begins. This competition is won by an individual light wave, which grows fastest. The winning light wave describes and prescribes the order in the laser and it is thus called the *order parameter*. It dominates the movement of the individual electrons as if by enslaving them and forcing them to move in its own rhythm. In the language of synergetics this is called the *slaving principle*.

The transition from the state of a lamp with its microscopically chaotic light field and the state of the laser with its well-ordered light field is quite sharp and occurs at a critical strength of the power input by the current into the laser. Thus the change of a single, rather unspecific, parameter, the power input in the case of the laser, may cause a systemic phase transition. This parameter is termed *control parameter*.

When the laser wave is perturbed, it adjusts rather slowly compared to the adjustment time of the individual electrons. This is quite a general feature: the order parameters are slowly varying quantities compared to the enslaved subsystems. Consequently, when excited atoms are shot into the tube, they are enslaved by the order parameter (i.e. the light field in that tube) first by delivering their own energy to the order parameter, and then by acquiring its rhythm. This interplay between the rhythms of the system and its subsystems is analogous to many cases in human life: Language can be regarded as a slowly moving order parameter. When a baby is born, it is subjected to the language of his or her parents and the other people. The baby learns the language and in technical terms is thus enslaved by the language. But by doing so, he and she eventually "emit" their personal energy into the language and in this respect support the language. As we shall see in some detail below, the same happens in city dynamics: the individual who immigrates to a new city has to learn the city and adapt to its rhythm. The individual is thus enslaved by the city's order parameter. But by adapting to the global movement of the city the individual's energy enters into, and supports, the order parameter of the city. This phenomenon is called *circular causality*.

Quite clearly, the concept of order parameters and their relationships to the individual parts of the system, a relationship governed by circular causality, applies to a great variety of phenomena in society. On the one hand, the individuals are the parts of a human society and determine its macroscopic manifestations, such as language, religion, form of government, culture, educational system or city structure. On the other, the behavior of the individuals is determined by these macroscopic manifestations or institutions, which play the role of order parameters. Order parameters may compete with each other, or may coexist, or may cooperate. Such phenomena are well known in laser physics with respect to the electric field strength acting as order parameters. In social life these phenomena also occur, e.g., languages may compete and one language may win the competition as it happened in the United States, where two main streams were competing with each other, namely English and German. In other nations languages may coexist as in Switzerland and in Israel. Finally, in a way languages may cooperate, e.g., when terms originally generated in one language are adopted by another language. This happens quite often with technical terms taken from English, for example.

4.2.2.2 The Paradigm of Pattern Formation

The case study here is the Bénard instabilities. As we've seen, as the temperature difference between the heated layer at the bottom and the cool layer on top exceeds a critical value, quite suddenly a macroscopic motion of the liquid becomes visible (Fig. 4.1 above). The temperature difference thus controls the macroscopic behavior of the system; in the language of synergetics it is thus called *control parameter*.

As the control parameter grows, the liquid starts its motion, rolls are created, their rolling speed increases, and the initial resting state becomes unstable. *Instability* thus shows up. Slightly above the instability point, the system may undergo quite different collective motions of role configurations (Fig. 4.5). At the beginning the amplitudes of these role configurations are small and independent of each other. When they grow further, they start to influence each other – in some cases they compete until one configuration suppresses the others, in others, they co-exist and even stabilize each other. "The amplitudes of the growing configurations are called *order parameters*. They describe . . . the macroscopic structure of the system" (Haken 1996, p 39).

The order parameters not only determine the macroscopic structure of the system, but also govern the space-time behavior of its parts. By winning the competition the order parameters enslave the many parts of the system to their specific space-time motion. This is a basic theorem of synergetics and as noted above, it is called *the slaving principle*.

In some cases, for example when the fluid is enclosed in a circular vessel, all directions for roll systems are then possible, each being governed by a specific order parameter. Which pattern will eventually be realized, depends on initial conditions. It is as if the system internally stores many patterns. This repertoire of patterns is not stored in a static fashion, but is dynamically generated anew each time. This property is termed *multistability*.

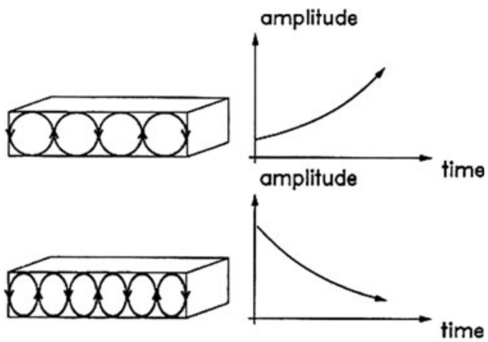

Fig. 4.5 *Left*: two different role configurations in a fluid. *Right*: The behavior of the amplitudes of these configurations in the course of time. While in one case the amplitude increases, in the other it decays

4.2.2.3 The Paradigm of Pattern Recognition

A typical experiment of pattern recognition can start as follows: a test person (or a computer) who has many patterns, of faces, city maps, etc., stored in memory, is offered a portion of one of the patterns. The task is to recognize the pattern – to decide what face, city map, etc. it is. According to synergetics, what happens is a process analogous to pattern formation as described above: at the start, the cognitive system of the person (or computer) is in a state of multistability as it enfolds many patterns, which coexist. When a few features or part of the pattern is offered, several pattern configurations and their order parameters are formed by means of *associative memory*. The order parameters enter into competition and when a certain order parameter wins the competition and enslaves the cognitive system, the task of recognition is implemented. This analogy, which is illustrated in Fig. 4.6, was first demonstrated by Haken in 1979 and has since become the basis for an intensive study of synergetics of cognition and of brain development and activity (Haken ibid 1979, 1990, 1996). Figure 4.7 is a typical implementation with respect to face recognition, by means of the so-called *synergetic computer*.

As suggested by Portugali and Haken, the above conceptualization offers also an appropriate framework for the study of cognitive maps of cities, regions, and large-scale environments (Portugali 1990; Portugali and Haken 1992). The basic idea is that cities, regions etc. can be regarded as large-scale patterns, which can never be seen in their entirety. As a consequence, the cognitive system constructs a whole cognitive map on the basis of only a partial set of features available to it. Thus it can be said that a partial set of environmental features offered to a person triggers a competition between several configurations of features and their emerging order parameters, until one (or a few) wins and enslaves the system so that a cognitive map is established.

Synergetics have developed from the start two approaches to the study of phase transition and qualitative change in self-organizing systems. The first approach study phase transition and qualitative change by means of probability distributions and direct numerical solutions. This line of research has used the conceptual framework of order parameters and the slaving principle in a rather implicit manner; its main instrument was the so-called *master equation*. The second approach

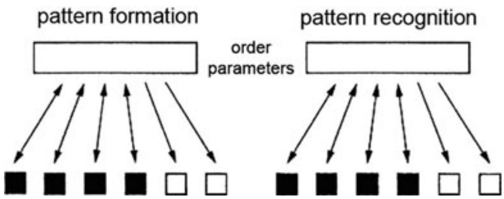

Fig. 4.6 Haken's (1979, 1991) analogy between pattern formation and pattern recognition. *Left:* a configuration of some parts of a system gives rise to an order parameter which enslaves the rest of the parts and brings the whole system to an ordered state. *Right:* a few features of a pattern shown to a person (or a computer) generate an order parameter which enslaves, and thus complements, the rest of the features, so that the whole pattern is recognized

Fig. 4.7 Pattern recognition of faces by means of the synergetic computer. *Top*: examples of prototype patterns stored in the computer, with family names encoded by letters. *Bottom*: when part of a face is used as an initial condition for the pattern recognition equations, their solution yields the complete face with the family name

developed by focusing on the state variables of the system and by an explicit consideration of the order parameters, the slaving principles and the other tenets of synergetics as presented above. These two lines of research are characteristic also of the approaches of synergetic cities. One approach, led by Weidlich and coworkers has developed sociological and economic applications of synergetics by employing the master equation, and the other approach, by Haken and Portugali, was inspired by Haken's elaboration of synergetics in the domains of cognition, pattern recognition and brain activities.

4.2.2.4 Slow Cities and Fast Regions

One way to look at Haken's synergetics and its slaving principle is in terms of interplay between slow and fast processes:

> *If in a system of nonlinear equations of motion for many variables these variables can be separated into slow ones and fast ones, a few of the slow variables … are predestined to become "order parameters" dominating the dynamics of the whole system on the macro-scale* (Weidlich 1998).

This perspective stands at the basis of Weidlich's and coworkers studies on sociodynamics and more recently on cities and urbanism (Weidlich 1987, 1994, 1997, 1998).

According to this perspective, fast and slow processes are easily identifiable in processes of settlement and urbanism. The fast ones typify the local urban micro-level of building sites, streets, subways, etc., whereas the slow processes typify the macrolevel of whole regions, which are often described as systems of cities. The relations between the slow and the fast processes are described by the slaving principle: on the one hand, the regional system

> *serves as the environment and the boundary condition under which each local urban microstructure evolves. On the other hand, the . . . regional macrostructure is . . . the global resultant of many local structures* (Weidlich 1998).

This circular causality between the local and the global, allows one to study global regional systems by assuming that local processes adapt to the slow regional ones, and to study local urban processes by treating the regional context as given, and of course to study the complex interplay between the local and the global. In all three cases Weidlich (1999) has prescribed a four stages approach: stage 1 concerns the configuration space of the variables; stage 2, measures the utility of each configuration; stage 3, defines transition rates between configurations which are in fact utility differences; stage 4 derives stochastic or quasi-deterministic evolution equations for the system under consideration. The central evolution equation is the master equation, which defines the probability that the configuration under examination is realized at a certain time.

The above theoretical procedure has been used to study the role of population pressure in "fast and slow processes in the evolution of urban and regional settlement structures", and in urban evolution. Figure 4.8 illustrates some results from these studies, in which the city capacity for building and development is related to population pressure. Figure 4.8a shows the evolving city capacity when the urban plain is uniform, and Fig. 4.8b, when it is disturbed in one of its sites.

4.2.2.5 Pattern Formation and Pattern Recognition in the City

Thus far, most applications of synergetics to the domain of cities and regions were in line with Weidlich's approach as described above. That is, they have employed mainly the very early and basic notions of synergetics – the order parameters and slaving principle – and usually in a rather implicit way. On the other hand, much of the advance made in the last four decades in synergetics was done in connection with issues of cognition and brain functioning. In fact, the above analogy between pattern formation and pattern recognition provided the foundation for these advances.

Haken and Portugali (1995) suggested that the above analogy is specifically attractive to the study of cities. The latter can be perceived as complex, self-organizing systems, which are both physical and cognitive: individuals' cognitive maps determine their location and actions in the city, and thus the physical structure of the city, and the latter simultaneously affects individuals' cognitive maps of the city. In their preliminary mathematical model Haken and Portugali construct the city as a hilly landscape which is evolving, changing and moving as a consequence of the

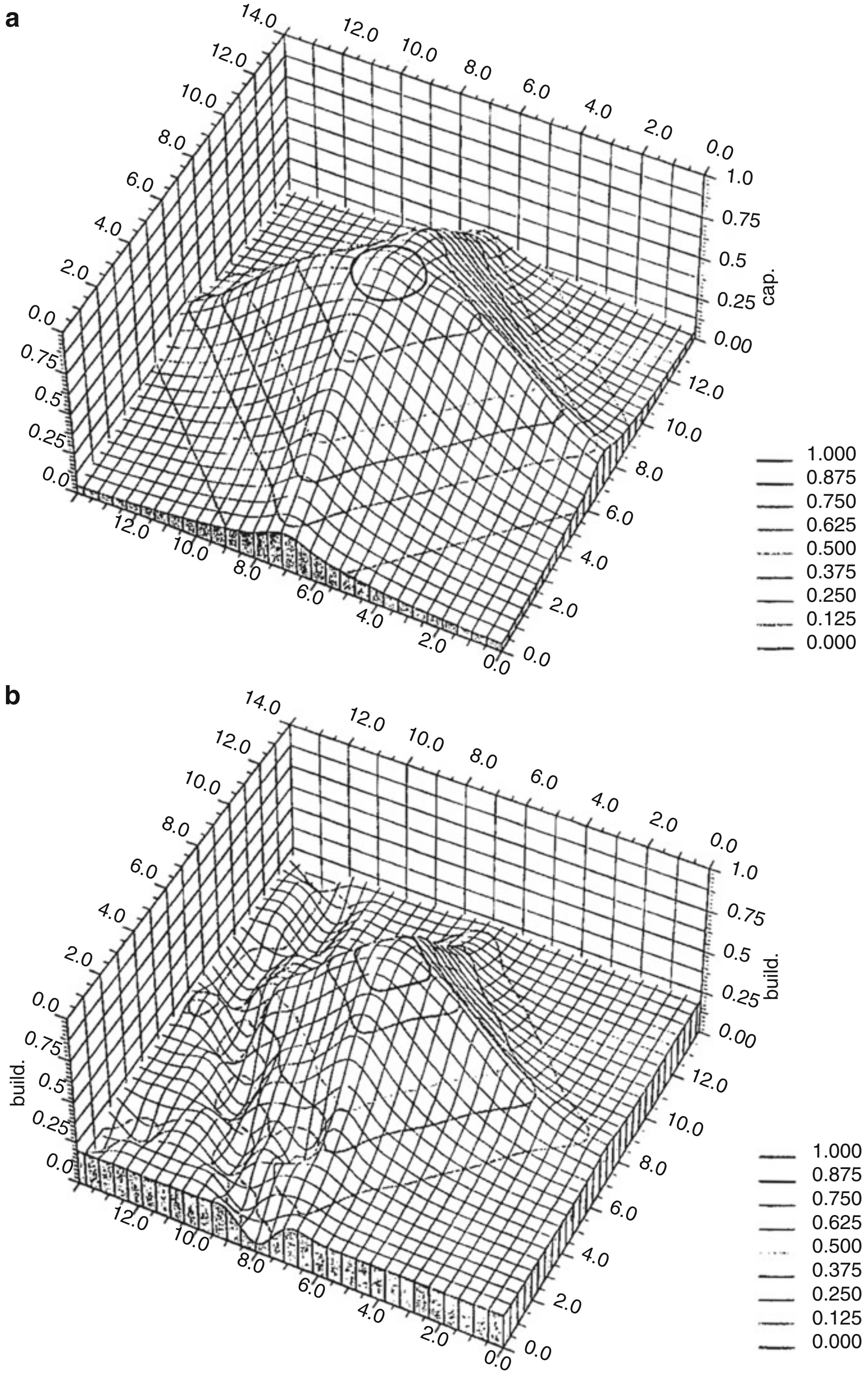

Fig. 4.8 Building and development under population pressure (Weidlich 1999). *Top*: on a uniform urban plain. *Bottom:* on an urban plain with disturbances

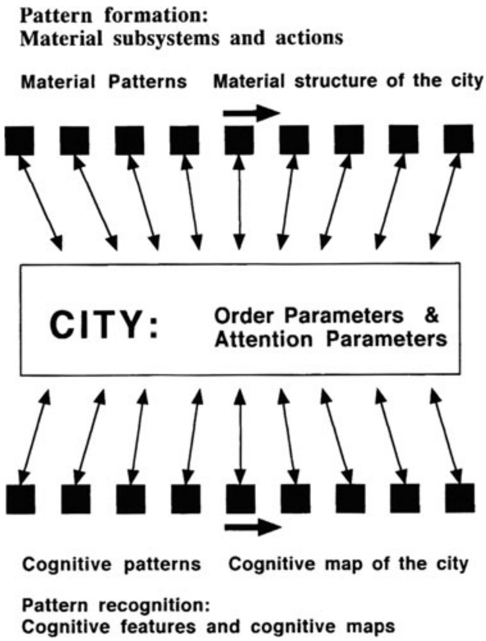

Fig. 4.9 The city as a self-organizing system that is at the same time both physical and cognitive. Its emerging order- and attention-parameters enslave the city's cognitive and material patterns

movement and actions of individuals (firms etc.). The latter give rise to the order parameters, which compete and enslave the individual parts of the system and thus determine the structure of the city. The significant and new feature of this exposition is that the order parameters enslave and thus determine, two patterns: one is the material pattern of the city, and the other is the cognitive pattern of the city, that is to say, its cognitive map(s). This is exemplified diagrammatically in Fig. 4.9.

One of the more interesting outcomes of the model is the set of *attention parameters*, which emerge by means of self-organization. The latter can be seen as the order parameters of specific subsystems composing the pattern. In a state of multistability, or in case of an ambivalent pattern (e.g., 'vase or faces?' in Fig. 19.4) they determine which aspect of the pattern is seen (i.e., attracts attention) first. This is of outmost importance in city dynamics. The city is full of patterns, yet individuals are attentive to only a few of them. The latter form the cognitive maps of the city and it is according to them that individuals and firms behave, take decisions and act in the city. In the model we investigate cases were one attention parameter dominates the dynamics and cases where no cross-attention is paid; that is, when two or more urban communities are cognitively not aware of each other. This situation entails the emergence and persistence of an urban cultural or socio-economic mosaic where a few coexisting attention parameters govern the dynamics. In Part IV (Chaps. 19, 20), we present the above approach in full and elaborate it in connection with city dynamics and decision making in the context of urban and regional planning.

4.2.3 Sandpile Cities

Imagine building up a sand pile by slowly adding particles, as in Fig. 4.10, for instance:

> *As the pile grows, there will be bigger and bigger avalanches. Eventually a statistical stationary state is reached in which avalanches of all sizes occur, that is the correlation length is infinite. Thus, in analogy with equilibrium thermodynamical systems, the state is 'critical'. It is self-organized because no fine-tuning of external fields was needed to take the system to the critical state: the criticality is unavoidable.*
> *The sandpile has two incongruous features: the system is unstable in many different locations; nevertheless the critical state is absolutely robust. On the one hand, the specific features, such as the local configurations of sand, change all the time because of the avalanches. On the other, the statistical properties, such as the size distribution of the avalanches, remain essentially the same* (Bak, Chen, and Creutz 1989).

Applied metaphorically to the domain of cities the scenario can go like this:

> *Imagine a growing city – demographically by a steady inflow of population and spatially by the new locations (parcels of land) they occupy. As more and more people come to the city, locations of various sizes (avalanches) will be occupied. Eventually a statistical stationary state is reached in which occupation of locations of all sizes (avalanches) occur. . . . . Thus, in analogy with equilibrium thermodynamical systems, the state is 'critical'. It is self-organized because no fine-tuning of external fields was needed to take the system to the critical state: the criticality is unavoidable.*
>
> *The emerging city has two incongruous features: it is unstable in many different locations; nevertheless the critical state is absolutely robust. On the one hand, the specific features, such as the local configurations of locations, change all the time because of the avalanches. On the other, the statistical properties, such as the size distribution of locations (the avalanches), remain essentially the same.*

The sandpile is the canonical example of Bak's (Bak 1996; Bak, Chen, and Creutz 1989; Bak and Chen 1991) *self-organized criticality* (SOC). As just illustrated, it can naturally be, and indeed has been, applied to cities (Batty 1995, 1996; Batty and Xie 1999; Batty 2005). It adds to the "grand" complexity and self-organization theories, such as synergetics and dissipative structures, a kind of a zooming-into the internal dynamics of self-organized systems in their steady-state

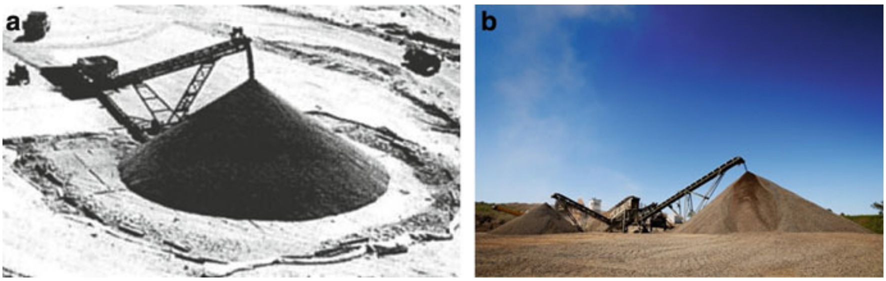

Fig. 4.10 The sandpile is the canonical example of self-organized criticality

periods – when the system is governed by what in synergetics is called order parameters. Similarly to synergetics, for instance, SOC refers to systems in their growing process: In synergetics one speaks of a growing control parameter (e.g., slowly adding particles to the sandpile). As in synergetics so with SOC, as the control parameter crosses a certain threshold – a critical point in the language of SOC, the system (sandpile) enters a steady state. The interesting part of SOC starts here: it shows how complex and rich the internal dynamics of a steady-state situation can be. – It demonstrates that during steady state the system that is subject to continuous growth maintains its overall structure by means of temporally unpredictable avalanches whose size distribution takes the form of the power law.

With respect to cities, SOC suggests, first, that when the population of a city, or a system of cities, is growing, the morphology of this growth shows up in locations of various sizes. Second, that when this growth crosses a certain critical threshold, the city, or system of cities, enters a steady state. Thirdly, when looking into the dynamics of this steady state it can be seen that this growth advances by means of avalanches of locations of various size. Fourthly, while the temporal distribution of these morphological locational avalanches is chaotic and unpredictable, their size distribution remains robust and takes the form of the power law.

For students of urbanism the statistical observation that "the size distribution of avalanches remain essentially the same" and takes the form of the power law, implies an immediate link to the century-old 'rank-size rule', according to which the size-distribution of cities remains essentially the same under circumstances of ongoing population growth (Chap. 2, Sec. 2.4 above). COC in this respect provides a theoretical foundation for the rank-size rule, which was often criticized for not having any theoretical basis. As we'll see below the same can be said about fractal and network theories that are closely linked with SOC.

However, the essence of self-organized criticality is not the final statistical size-distribution, but the process behind it. The problem here is that in the human domain of cities there is no sufficiently detailed data to describe this dynamics. As a consequence, most applications of COC to the domain of cities took the form of "computer simulations of what are essentially idealized systems" (Batty 2005, p 433). In *Cities and Complexity* Batty (ibid) indeed presents such a computer simulation of an idealized urban growth process. By means of the latter he demonstrates how the dynamics of the sandpile model "is consistent with the maintenance of a stable urban form". Commencing with a hypothetical city with its central business district (CBD) and subcenters, and with the assumption that population is distributed in that city according to the power law, he simulates a sandpile urban growth process (Fig. 4.11): Successive units of development – the urban agents – enter the various areas of the city. When the capacities at the various urban areas exceed their critical threshold, relocations ("avalanches") of urban agents/population occur – similarly to avalanches in the sandpile. As can be seen in Fig. 4.11, the avalanches occur with increasing frequency as the city builds up.

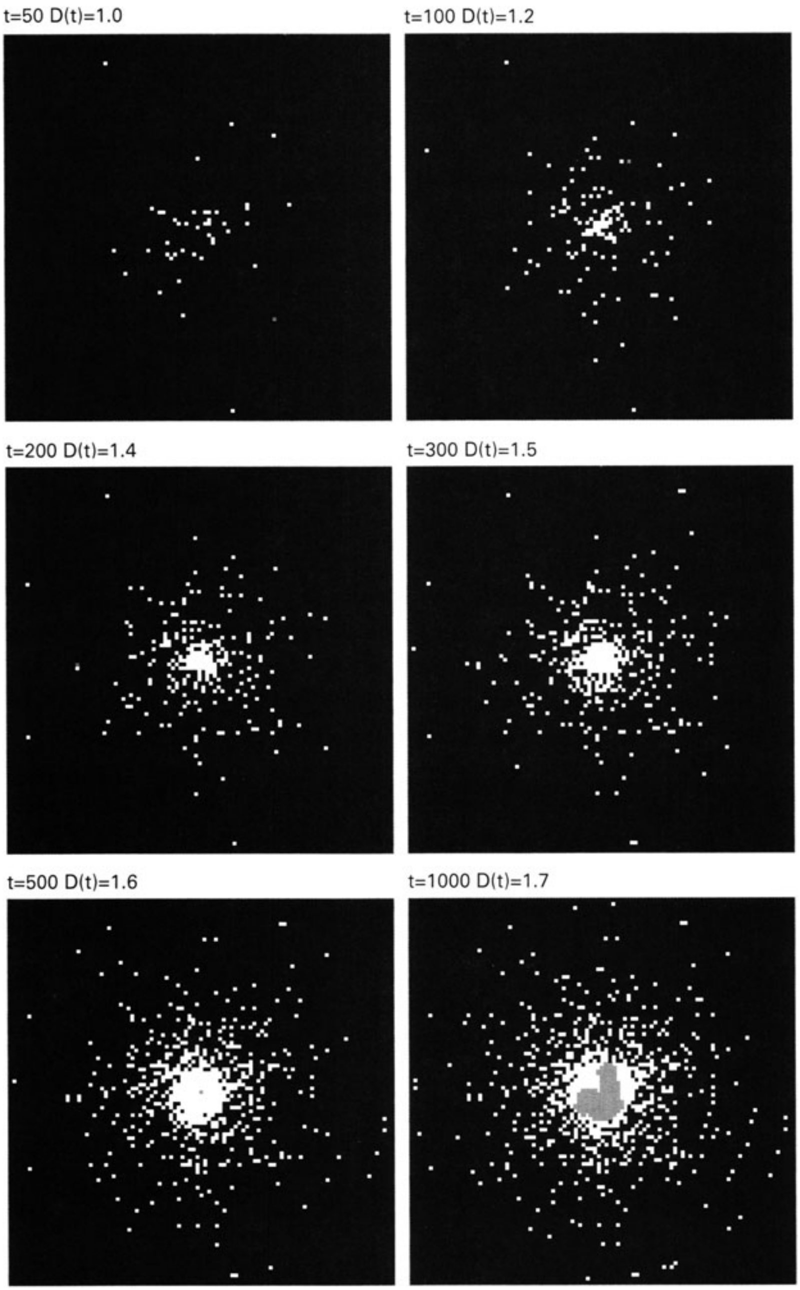

Fig. 4.11 Batty's (2005, Fig. 10.1) simulation of a hypothetical urban growth model in terms of COC. "The model is constructed as a simple agent-based structure with units developments acting as agents responding to two features of the landscape: density constraints . . . and .. the sand pile rules" (ibid 434). The white dots/areas represent populated urban areas; the lighter gray tone in Fig. 4.11 (*bottom, right*) "indicates the extent of an avalanche that leads to relocation of . . . agents at the time when the simulation reaches 1000 units" (ibid). D(t) is the fractal dimension at time (t)

4.3 Short-Term Complexity Theories of Cities

4.3.1 Chaotic Cities

While the origins of chaos theory can be traced back to Henri Poincaré in the 1880s and Jacques Hadamard in 1890s, its modern use is due to Edward N. Lorenz (1963) and Mitchell Feigenbaum (1978), among others, as well as to the emergence in the 1960s of complexity and self-organization theories as theories about "order out of chaos". Chaos theory, which has since become one of the leading complexity theories, refers to one form of chaos (Haken 1996, Chap. 13), namely, *global, macroscopic*, *deterministic chaos* (by contrast to *local microscopic chaos*).

Local chaos stems from the irregular motion or behavior of the very many individual parts of a complex system. Examples might be the motion of the molecules of a gas, the movement of cars on an uncrowded freeway, or of people in an uncrowded piazza, and so on. In all such cases the individuals are moving in an irregular and uncoordinated trajectories.

Deterministic chaos refers to systems that are *sensitive to initial conditions*. The famous example here is Lorenz *strange attractor* that describes a system (point x, y, z) that jumps irregularly from one region of space to the other as a result of small changes in initial conditions (Fig. 4.12). As is well recorded, Lorenz has found this property accidently when as a matter of shortcut he was running his weather equations with the decimal .506 instead of .506127; the result was a completely different weather forecast. This effect was at a latter stage described by Lorenz as *the butterfly effect*.

In terms of synergetics, deterministic chaos arises when as a consequence of self-organization, for example, the many individual parts are enslaved by a few order parameters, and as a consequence exhibit a coordinated motion. On the face of it this new state is the exact opposite of chaos; yet, it is not. Quite often in these cases, the system is dominated by order parameter(s) which are macroscopically chaotic: for some time one order parameter dominates the system, then suddenly another. Such jumps occur irregularly in a chaotic manner due to the fact that these systems are *sensitive to initial conditions*.

Similarly to fractal theory (below), the development of deterministic chaos theory is computer-dependent: Starting from a deterministic situation the theory shows how by means of an iterative process the system moves from order to chaos. A commonly used example to convey chaos is by reference to population dynamics: As illustrated in Fig. 4.13, a slight change in initial conditions (increasing b from 3.56 to 3.56999) entails an infinite number of solution, that is to say, chaos. Fractal theory looks at the reverse process by which iterative chaotic processes give rise to highly structured fractal patterns. This is nicely illustrated by the so-called *chaos game* (Fig. 4.14). The two theories are in this respect two facets of a single phenomenon and thus complement each other: chaos theory looks at "the way to chaos", while fractal theory at "the way to order".

Fig. 4.12 Two famous notions associated with Lorenz's work: *Left*: Photograph of a butterfly as a reference to his "butterfly effect". *Right*: Trajectories of Lorenz's *strange attractor*. While the two notions refer to quite different phenomena, the "butterfly effect" is internally related to the strange attractor

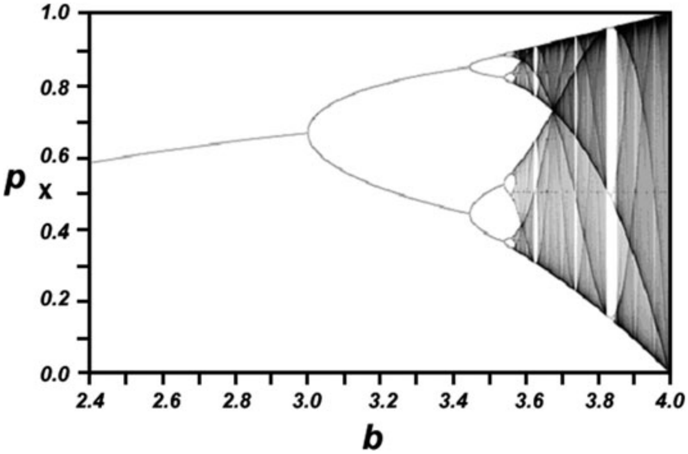

Fig. 4.13 The way to chaos. A simple population dynamics can be described by: $P(n+1) = b.P(n)$, that is, population P at year $n+1$ is P at year n, multiplied by b – the rate of population growth. According to Pierre François Verhulst's (1845) this equation can be normalized to $P(n+1) = b.P(n)(1–P(n))$. Now, when b is small, say 1.00, this equation yields one attractor; when $b = 3.0 \rightarrow$ 2 attractors; $b = 3.44 \rightarrow$ 4 attractors; $b = 3.56 \rightarrow$ 8 attractors; $b =\ldots$; but then when $b = 3.56999 \rightarrow$ infinity of attractors, that is to say, chaos

On the face of it, this tension between chaos and order is specifically and intuitively appropriate for the study of cities for their dual image; namely, that cities are sometimes seen as chaotic entities and sometimes symbols of order: They are chaotic, when one considers the fact that they emerged (and still re-emerge) in an urban revolution(s), or when one faces winding streets of old towns, traffic jams, congestion, pollution, and the like; and they are symbols of planned order when one is attentive to the regularity of urban systems, to city walls, the iron-grid pattern of ancient and modern cities, grand boulevards and so on. Given this image of the city as at once chaotic and ordered, one would expect a multiplicity of studies on chaos

Fig. 4.14 The chaos game. Coined by British mathematician Michael Fielding Barnsley (1993), the chaos game refers to an iterative random process that when repeated a large number of times, might often (not always) give rise to a fractal such as the Sierpinski triangle or a leaf

and the city; yet this is not the case: there are only few applications of chaos theory to cities and urbanism and even those are highly theoretical and with no explicit links to the real dynamics of cities. Some, such as Dendrinos and Sonis (1990) study – *Chaos and Socio-Spatial Dynamics* – refers to socio-spatial dynamics in general with no specific relation to cities, while others that will be discussed next consider cities in a rather conceptual or theoretical manner.

4.3.1.1 Global Chaos in Ancient Urbanism

Global or deterministic chaos shows itself in the long-term evolution of cities and urbanism. A case in point is my interpretation of the archaeological record of the first 3000 years of urbanism in the region of Israel/Palestine in terms of a sequence of three urban revolutions (Portugali 2000, Chap. 15 and further bibliography there): the first, around 3000 B.C. gave rise to some 700 years of the first (Early Bronze) urban era; the second around 2000 B.C. gave rise to the second urban era (Middle Bronze), and a third around 1000 B.C. gave rise to the Iron Age urban culture (Fig. 4.15). The three urban eras are characterized by hierarchical settlement systems (Gofna and Portugali 1988) and as can be seen in Fig. 4.15, each of the three relatively stable urban steady states was preceded by short and unstable-chaotic periods of nonurban nomadic society. From the archaeological record we further know that the first and second urban cultures ended abruptly when the urban system collapsed and large segments of the urban population underwent a process of *nomadization* (which can be regarded the reverse of urbanization).

4.3.1.2 Deterministic Chaos and Urbanism

A very recent example of deterministic chaos in relation to urbanism is Yanguang Chen's (2009) suggestion that "Spatial interaction creates period-doubling and chaos of urbanization". Chen starts from the process of spatial interaction that as we've seen above (Chap. 2, Sec. 27) is central to urban dynamics at the local and

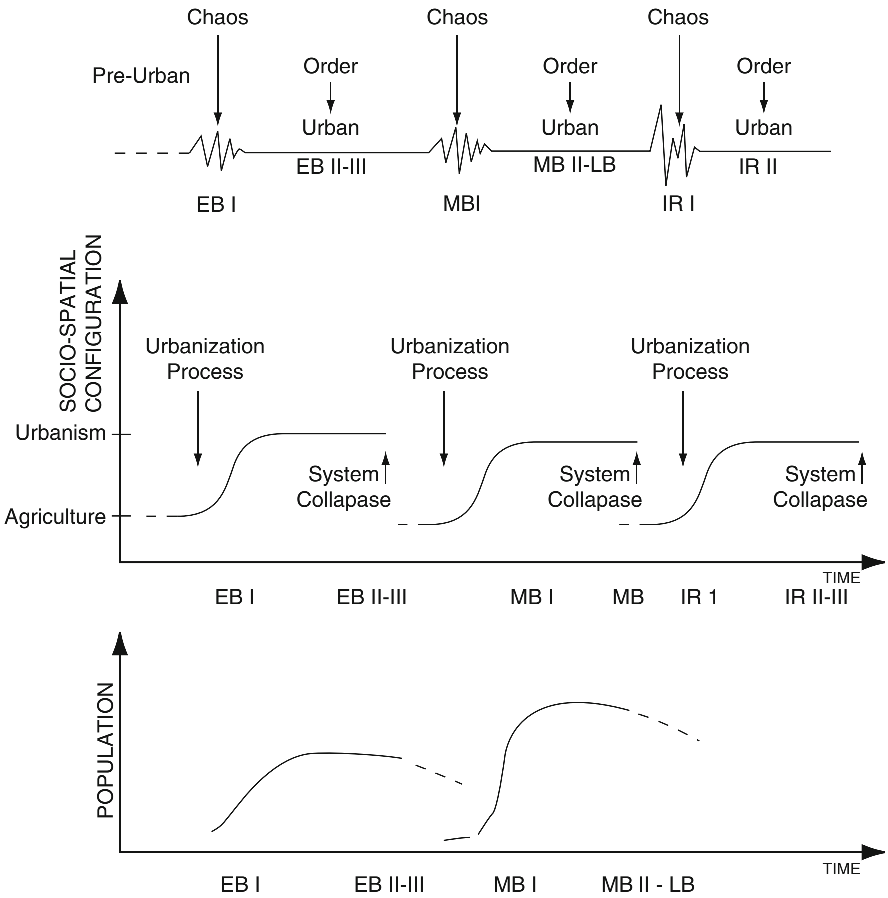

Fig. 4.15 Ancient urbanization and chaos. *Top*: The evolution of the settlement system in Palestine, from the Early Bronze Period to the Iron Age, exhibits long periods of urban steady state that are interrupted by short, nonurban periods characterized by system collapse, nomadization, strong fluctuations and chaos. *Center*: A description of the process as a rhythm between agriculture and urbanism, interrupted by global collapses of the urban system. *Bottom*: The above rhythm between urban steady state and nonurban chaos shows itself also in the calculated population changes (by Gophna and Portugali 1988) in the Early Bronze and Middle Bronze periods. Adapted from Portugali 2000, Fig. 15.8

regional scales. He refers specifically to spatial interaction as it takes place in rural-urban population migration – a process that dominates much of the urban dynamicsvh of China in recent decades. Defining the level of urbanization as "the percentages of urban population" in a given closed system/region, he demonstrates mathematically the title of his paper, namely, that the urban process of spatial interaction can give rise to steady-state behavior, to two-cycle oscillation, to four-cycle oscillation, and finally to chaotic behavior (Fig. 4.16). To this urbanization growth process corresponds the "classical" mark of chaos, namely, sensitivity to initial conditions (Fig. 4.17). However, as Chen is careful to emphasize, this urban chaos is created by the manipulation of the parameters and thus reflects "the possible world rather than the real world. . . . Whether or not urbanization in the real world can exhibit bifurcation and chaos is still a pending question." In a subsequent paper (Chen 2009b) he presents a chaotic attractor produced by the rural-urban interaction model (Fig. 4.18). Commenting on this attractor he notes the following:

> *Clearly, the trajectory [in Fig. 4.18] is infinitely enlaced in the limited phase space, but never repeats itself. This kind of strange attractor can be named rural-urban interaction attractor, whose box-counting dimension is about 1.5, and the correlation dimension is around 0.75. However, as will be illuminated later, it can only appear in an imaginary world instead of the real world.*

While Chen's is a purely theoretical study, his previous studies on the process of urbanization in contemporary China hint that the latter urban process provides the context for this more theoretical account (Chen 2009c and further bibliography there).

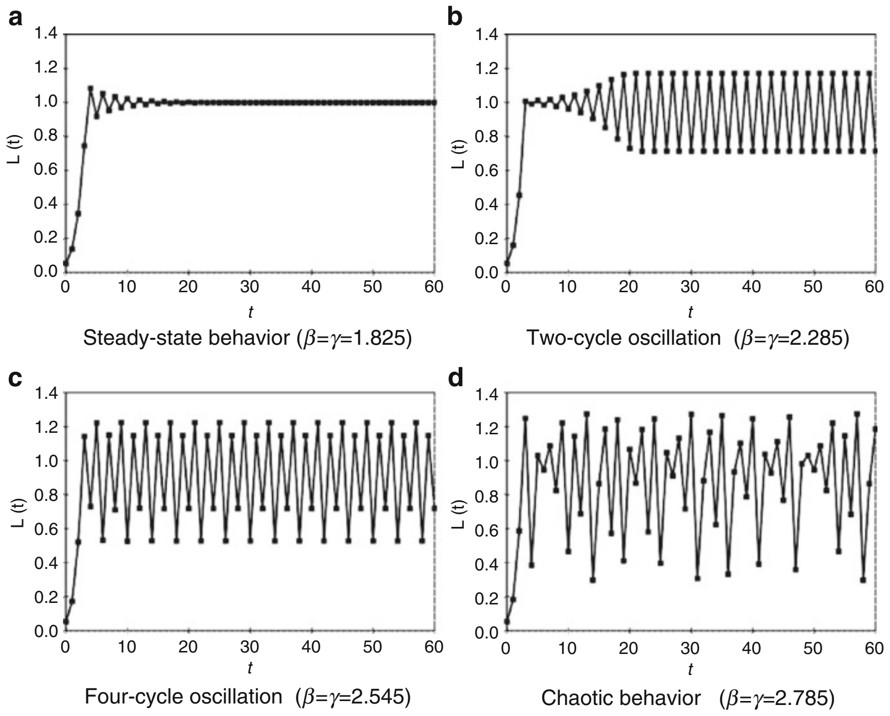

Fig. 4.16 According to Chen (2009, Fig. 1), an urban process driven by spatial interaction can give rise to steady-state behavior, to two-cycle oscillation, to four-cycle oscillation, and finally to chaotic behavior

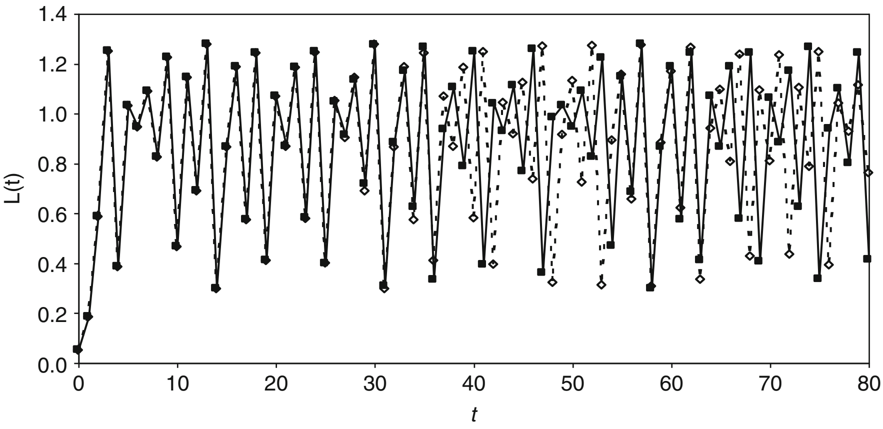

Fig. 4.17 Sensitive dependence on initial conditions of the level of urbanization in chaotic state (Chen ibid, Fig. 2)

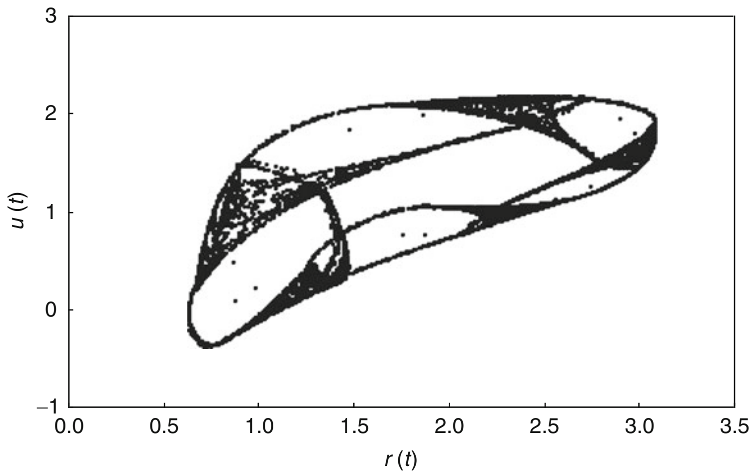

Fig. 4.18 The chaotic attractor produced by the rural-urban interaction model of after 10,000 iterations (Chen 2009a, Fig. 1)

4.3.1.3 Deterministic Chaos in Cities

In the *End of Certainty* Prigogine with Stengers (1997) exemplify deterministic chaos and the sensitivity to initial conditions by assuming two types of motion denoted as – or + within the phase space illustrated in Fig. 4.19. This leads to two situations represented in Fig 4.20. In Fig. 4.20 *Left* there are two regions, one corresponding to motion – and the other to motion +. Given Fig. 4.20 *Left*, they write the following:

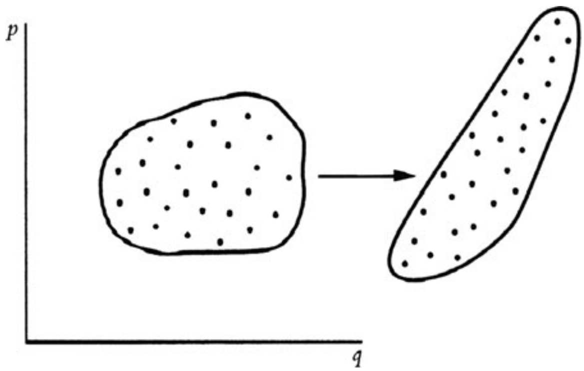

Fig. 4.19 Prigogine with Stengers' (ibid Fig. 1.4, p 34) illustration of ensembles in phase space: "Gibb's ensemble is represented by a cloud of particles differing according to their initial conditions. The shape of the cloud changes over time"

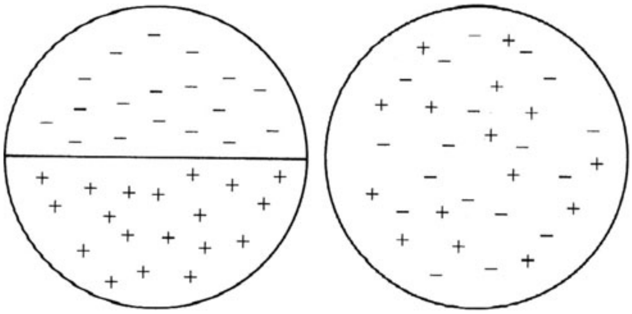

Fig. 4.20 *Left*: A stable dynamical system in which "the motions denoted as + or – lie in distinct regions of phase space". *Right*: An unstable dynamical system in which "each motion + is surrounded by – and vice versa". (Prigogine with Stengers ibid p 36, Figs. 1.5 and 1.6)

> *If we discard the region close to the boundary, each – is surrounded by –, and each + by +. This corresponds to a stable system. Slight changes in initial conditions do not alter the result.* (Prigogine with Stengers ibid, pp 35–6).

Then they turn to the diagram in Fig. 4.20 *Right* and continue (ibid, p 36):

> [In Fig. 20 *Right*], *instead, each + is surrounded by –, and visa versa. The slightest change in initial conditions is amplified, and the system is therefore unstable.*

A similar situation emerged from our cellular automata urban simulation model called *City* (Portugali 2000, Chap. 5). Here we've simulated a scenario by which agents of two cultural groups (Greens and Blues) come to a city when each agent has a tendency to reside among its own people – Green agents among Greens and Blue agent among Blues. At the beginning the city is highly unstable/chaotic and sensitive to initial conditions (as in Fig. 4.21 *top, left* and Fig. 4.22), but then as a consequence of this sensitivity, one can observe a process of self-organization that ends with a highly stable urban landscape with Greens and Blues segregated in different regions of the urban landscape (as in Fig. 4.21 *bottom, right*, Fig. 4.22 and Fig. 4.23 *top*).

However, there is an important difference between Prigogine with Stengers' example and ours: In the case of Fig. 4.20 Prigogine with Stengers (1977, p 35) ask

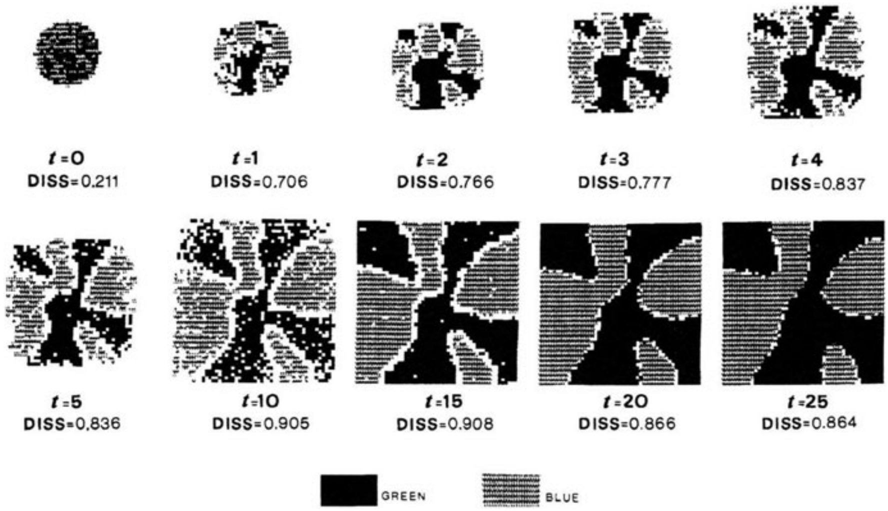

Fig. 4.21 Time evolution of segregation in a city with two cultural groups (Portugali 2000, Fig. 5.2)

us to "discard the region close to the boundary" (between the homogeneous – and + areas). In our case the boundary is an emergent property of the dynamics. Furthermore, when we zoom-in into the boundary we see that it remains chaotic (Figs. 4.22, 4.23), that is, the boundary is a dynamic entity that is constantly changing and moving. Our interpretation is that this chaotic boundary is necessary in order to keep the rest of the city stable. It is as if the city maintains its global structure by socio-spatially imprisoning local chaotic elements that threaten its global stability. We have termed this phenomenon *the captivity principle* and suggested that it might play a supplementary role to Haken's slaving principle (Portugali 2000, Chap. 5.8; Haken and Portugali, in preparation).

The play between chaos and order might show up not only in the long-term evolution of the city, but also in its daily routines. The movements of cars on the roads, of pedestrians on pavements and the like, are characterized by shifts between instable and stable motions and as such have been studied by reference to chaos theory.

4.3.2 Fractal Cities

Fractal Cities is the title of Batty and Longley's (1994) book in which they show how Mandelbrot's (1983) theory of fractal geometry can be applied to the study of cities, their structure and evolution. In that book, as part of their contribution to the issue, they have also summarized the literature on cities and fractals. Since it first appeared, there have been may applications that are discussed in Batty's (2005)

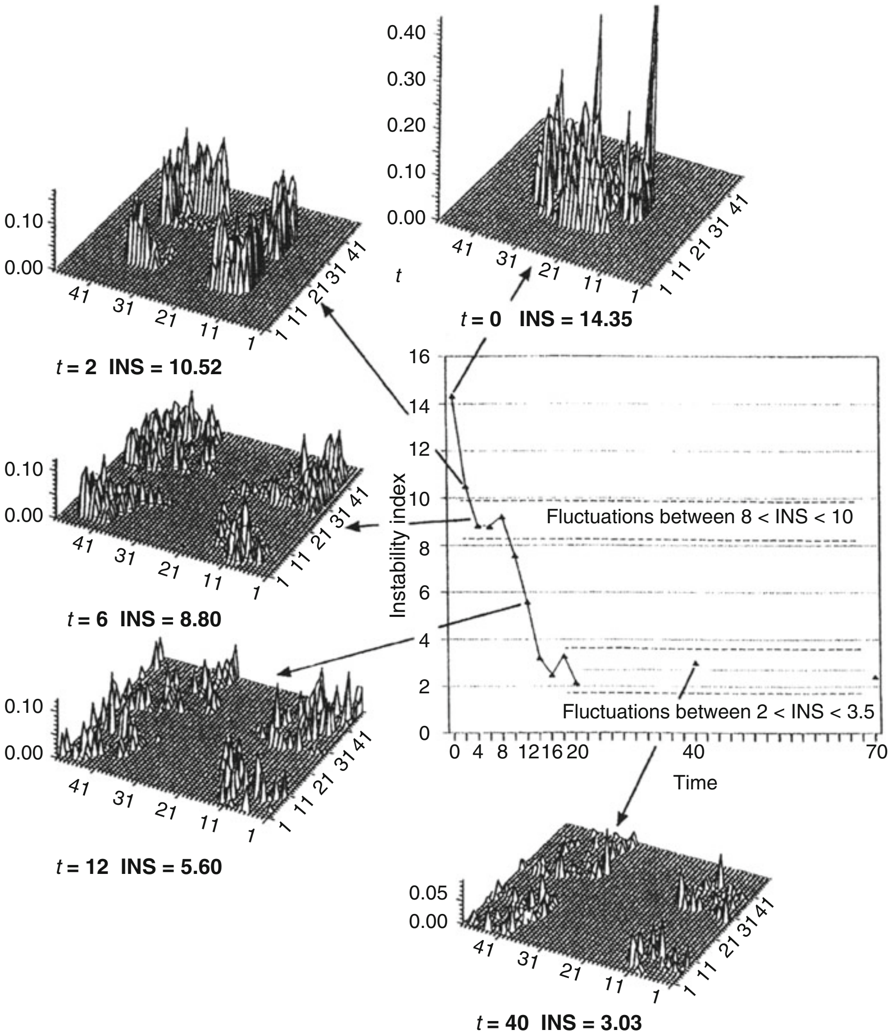

Fig. 4.22 Time evolution of SIS (stability-instability surface) in a city with two cultural groups when 33% of one of the groups (Greens) are neutrals, that is, indifferent as to their neighbors (Portugali ibid Fig. 5.8)

recent book in which fractals are seen as an important medium in the understanding of *Cities and Complexity*.

Mandelbrot's theory – to my mind, visually the most beautiful complexity theory – is based on two interrelated notions known as *self-similarity* and the *fractal dimension*, and, on the idea that a rather simple iterative process might produce highly complex geometrical forms. The notion of self-similarity has a long history that goes back to Leibnitz in the 17th century who discussed

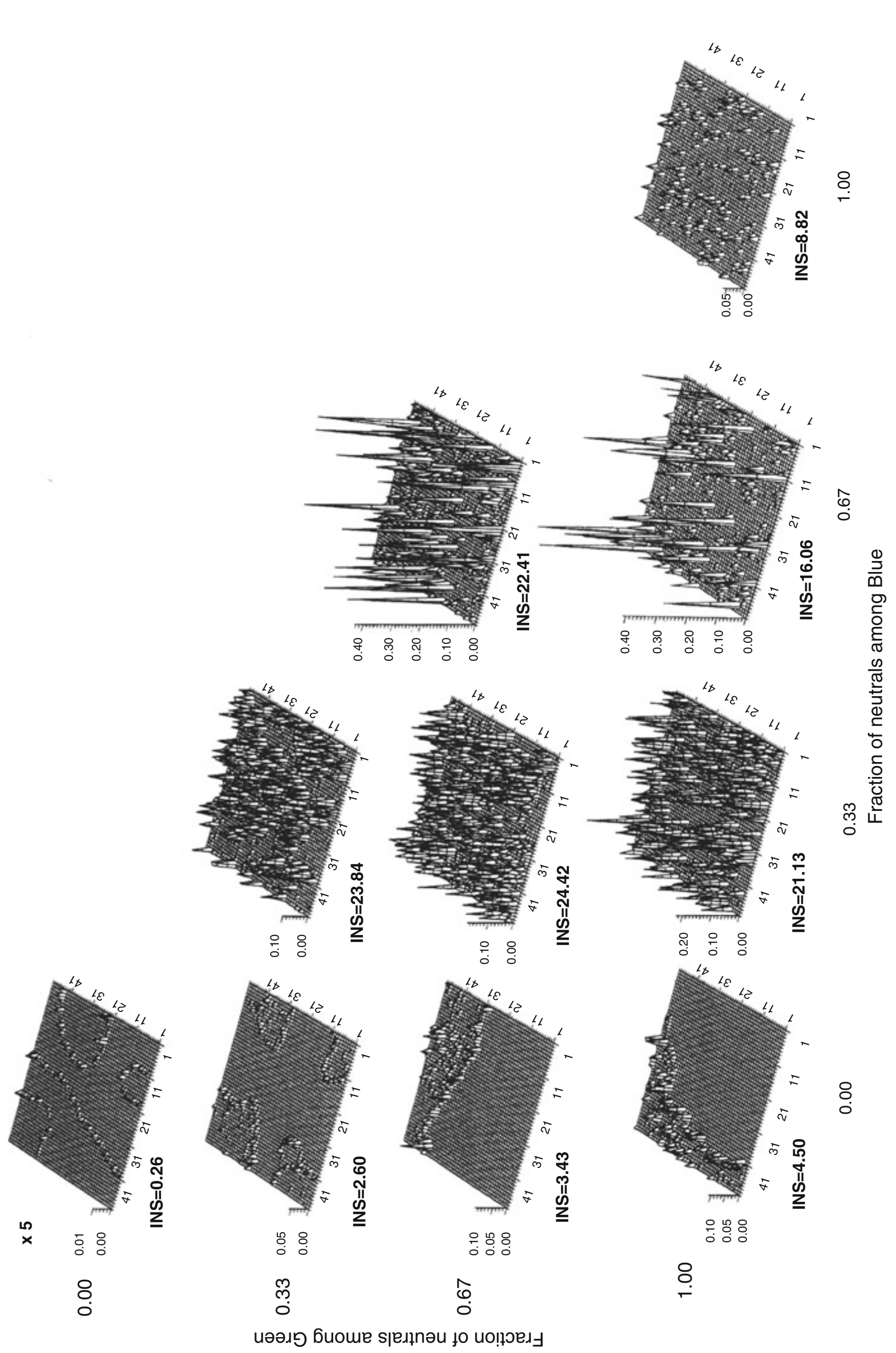

Fig. 4.23 Time evolution of SIS in a city with two cultural groups when the fraction of neutrals in one of the groups (Greens) is growing from zero to 33%, 67%, and 100%. (Portugali ibid Fig. 5.6)

recursive self-similarity. Some famous landmarks along the way are the *Cantor set* from 1883, *Koch curve* or *Koch snowflake* from 1904 (Fig. 4.24), *Sierpinski triangle* and carpet from 1915, and *Levy C curve* from 1938. In 1960 Mandelbrot explored self-similarity in a famous paper "How long is the coast of Britain: Statistical self-similarity and fractional dimension" and in 1975 he coined the notion *Fractal*. While Mandelbrot came to the idea of fractals by studying market behavior (Barcellos 1984), his theory of fractals became famous and popular after he published in 1982, *The Fractal Geometry of Nature*. In the 1980s, he also introduced the so-called *Mandelbrot set* that appeared on the cover page of *Scientific American* from August 1985 and became the icon for the whole theory (Fig. 4.24).

The notion of fractal dimension is somewhat counter-intuitive – it says that fractals do not have the conventional dimension of 0 (point), 1 (line), 2 (plane), 3 (cube) but rather broken dimensions such as 0.35 (an object that is more than a point but less than a line), or 1.6 (more than a line but less than a plane), and so on. This notion follows directly from the property of self-similarity: Thus the fractal dimension of the Koch curve, for instance, is 1.26. A nice illustration to the usefulness of the broken dimension is Mandelbrot's (1967) paper "How long is the coast of Britain?" mentioned above. The answer: its length is infinite because due to self-similarity the finer the scale of the measuring device the longer becomes the line. How then can we compare the coast of Britain to that of, say, Israel? By their fractal dimension: Both are fractals whose fractal dimension is more than a line but less than a plane, however, the coastline of Britain is more indented than that of Israel and therefore its fractal dimension will be closer to 2.

The development of Fractal geometry was associated with the development of computers and the possibility they offered to simulate sequential iterative processes; so much so that some observers have referred to fractals as computer-made artifacts. And indeed, all computer-made fractals mentioned above were created by such an iterative process in which simple relationships and rules gave rise to complex forms. The bold claim of Mandelbrot was that these computer simulations authentically

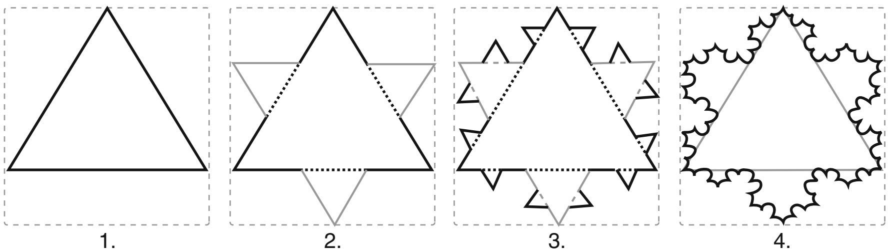

Fig. 4.24 *Koch snowflake*. First described by Swedish mathematician Niels Fabian Helge von Koch in 1904, the building of this fractal starts with an equilateral triangle and continues with the removal of the inner third of each side, building another equilateral triangle at the location where the side was removed, and then repeating this iterative process indefinitely

mimic the way nature produces its own complex, self-similar forms such as trees, leaves, coastlines, mountains or lakes.

As shown by Batty and Longley (ibid) in great details, the above properties of self-similarity, broken dimension and iterative processes together with their corollaries such as the power law size distribution, were for years implicit in the study of cities: In the theoretical central place systems of Christaller and Lösch, in the size distribution of systems of cities of Auerbach, Zipf and others, in studies about the morphology of cities and more. In their book, Batty and Longley have explicated these properties and added to them their own new studies and other studies such as Beguigui (1995) about the fractal structure of Paris' Metro/train system and Frankhouser (1994) about the fractality of urban structures. In their book they introduce and elaborate the various models by which fractal structures can be generated and simulated and show how such models can, on the one hand, simulate the growth of a tree, while on the other, the urban growth of a city and/or a metropolitan area (Fig. 4.25).

As a theory about complex self-organizing systems Fractal geometry is closely related to chaos theory. As we‘ve seen above (Fig. 4.14), the so-called *chaos game* gives rise to the fractal structure of a leaf. As shown by several authors (e.g., Mandelbrot, ibid), an important property of the Boltzmann‘s strange attractor is that the trajectories of its many parts are self-similar and can be described by a fractal whose dimension is between 2 and 3. More generally, some of the attractors or order parameters, which govern a self-organized system in its steady-state, might be

Fig. 4.25 The DLA (Diffusion limited aggregation) model that is often used to simulate a plant like fractal (*left*), enabled Batty and Longley (1994, Fig. 7.16) to simulate the evolving morphology of the town of Tauton in Somerset, South West England

fractals. That is to say, they have a fractal dimension, and they generate complex, self-similar shapes by means of simple iterative rules.

The above property is significant to our intuitive understanding of the meaning of steady-state and order parameters in self-organizing cities: To say that a city is in a steady state and that it is governed by one or more order parameters does not mean equilibrium and stability, as is the case of Christaller's and Lösch's central place theories, for example, but rather a rich and complex evolution and change according to a given ordering principle. A case in point is the paper by Benguigui et al. (2000): Studying the morphological evolution of the Tel Aviv metropolitan region from 1931 to 1991 they show how this metropolitan area grew first to the north with a fractal dimension of about 1.5 to 1.7 and then from 1985 onwards also to the south with a fractal dimension of 1.667 (Fig. 4.26).

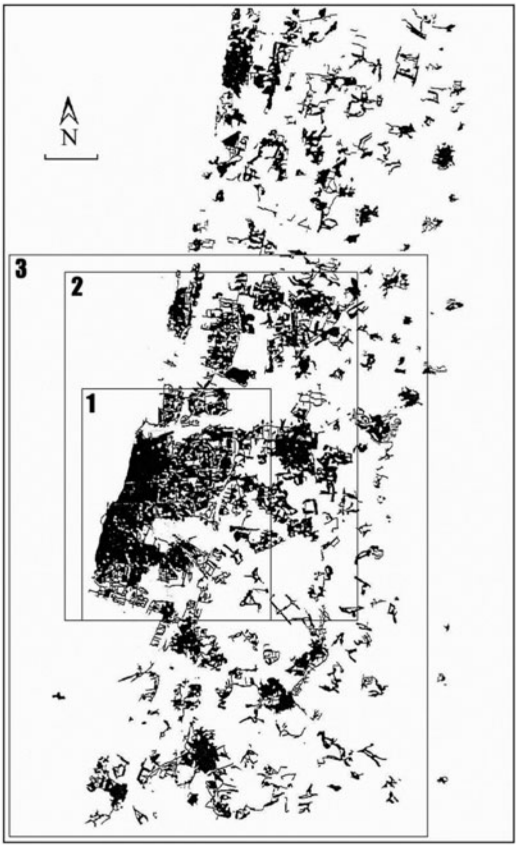

Fig. 4.26 Map of the Tel Aviv metropolitan area divided into three study regions: 1- central part; 2 - northern part; 3 - entire ensemble. From 1931 to 1991 this metropolitan region evolved, morphlogically, as a fractal structure. The central parts 1 and 2 were fractal during the entire period, while their fractal dimension increased with time. The entire metropolitan area became fractal only after 1985. In 1991 the fractal dimension of the Tel Aviv metropolitan area was found to be 1.667 with error of 0.037 (*Source*: Benguigui et al. 2000, Fig. 5)

4.4 Complexity Models of Cities

4.4.1 Cellular Automata and Agent-Based Cities

A standard two-dimensional cellular automata (CA) model is a lattice of cells, where each individual cell can be in one of several possible states (empty, occupied, etc.) and have one out of several possible properties (developed, underdeveloped, poor, rich, and on the like). The dynamics of the model is generated by an iterative process in which for every iteration the state of each cell is determined anew by some transformation rule(s). The rules are local and they refer to the relations between the cell and its nearest neighbors. The name of the game is to see how, what, and in what circumstances, local interrelations and interactions between cells entail global structures, behaviors and properties of the system as a whole. Fig. 4.27 is an illustration.

Agent Base (AB) models can be seen as an extension and elaboration of CA. In place of, or in addition to, the cells of CA, in AB simulation models the focus is on the agents: Each agent is seen as a decision maker that behaves, takes decisions and interacts with other agents and the environment according to a set of pre-determined rules of the game (similar in nature to the transformation rules of CA). However, unlike cells that cannot move and thus have local relations only, agents can move, see and know beyond their local neighboring areas. They thus have nonlocal mezzo and/or global relations that are determined by the above-noted rules of the game. These rules might include also feedback rules that affect the further behavior and action of the agents. This latter property allows agents to "learn", "change their mind" and behavior and thus adapt to changing social, cultural and/or environmental conditions; Fig. 4.28 is an illustration.

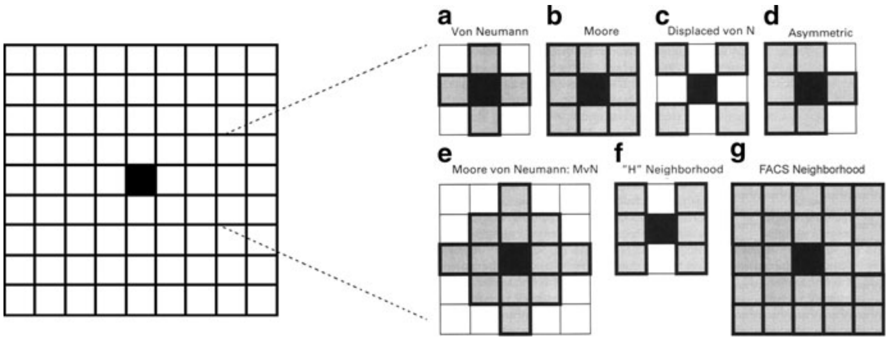

Fig. 4.27 The dynamics of the CA model is generated by an iterative process in which for every iteration the state of each cell is determined anew by transformation rule(s) that refer to the relations between the cell and its nearest neighbors (*left*). Different types of "neighbors" have been, and can be, employed (*right*). Neighbors' configurations **a-c** and **e** were named after their "inventors" (e.g., von Neuman 1951, 1961, 1966; Moore 1970, or combinations thereof – M&N), while configurations **d**, **f**, after their shape. The FACS neighbors (**g**) were used by Portugali and coworkers in their FACS USM (Portugali 2000, Part II and Sect. 4.4.2 below)

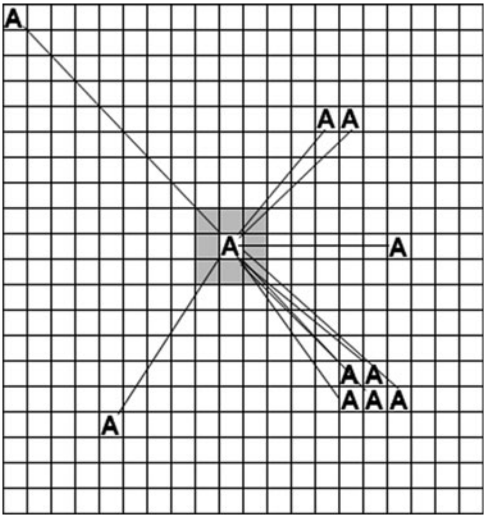

Fig. 4.28 The dynamics of the AB model is generated by an iterative process in which, for every iteration, the state and properties of every agent are determined anew by transformation rule(s) that refer to the relations between the agent and other agents and the properties of the landscape

The origin of CA and AB models goes back to Alan Turing and his ideas concerning self-reproducing machines, to John von Neumann's elegant demonstration that such machines, or *automata*, are in principle possible, and then to John Conway's *game of life* which was an explicit CA game (Gardner 1971). As it turned out, simple CA and AB games are capable of generating very complex global structures and behaviors – a property which made this kind of models a very attractive research tool.

An early, pre-computer, version of agent-based models (that are directly related to cities) was suggested by Thomas Shelling (1971) in his paper "Dynamic Models of Segregation". More recently, CA and AB models have been used quite extensively to simulate and study complex systems and processes of self-organization in a variety of domains. For example, Manneville et. al. (1989) in physics with respect to fluid dynamics and turbulence theory, Demongeot et. al. (1985) in the domain of neurobiology and computer sciences, Langton (1986) in the study of Artificial Life. From a wider perspective it is important to mention Eigen and Winkler's (1983) book *Laws of the Game* and Wolfram's (2002) *A New Kind of Science* (see also Toffoli and Margolus 1987).

The attractivity of CA and AB models to the study of self-organization stems from the fact that the more conventional tendency to use differential equations in models of self-organization, often makes computation

> *very tedious .. In this situation (especially if we are interested mainly in qualitative results) we can abstain from a numerical integration of exact differential equations and turn to the analysis of much simpler systems represented by networks of cellular automata* (Mikhailov 1990, p 40)

The main difference between studies of self-organization by means of differential equations and by means of CA/AB, is that in the first, the basic concepts of self-organization, such as attractors or order parameters, are explicit mathematical elements in the models, whereas in the second case they are implied or derived from the simulation as its interpretation concepts: you set up a CA/AB game, observe its evolving scenario, and then, post factum you derive a phase-space that describes the evolution of an attractor or an order parameter.

The attractiveness of CA models to the study of cities is almost self-evident. Similarly to cities that are built of discrete spatial units such as houses, lots, city-blocks and the like, CA models are built of discrete spatial units – the cells. In real cities the properties of local spatial units (e.g., land value) are determined, to a large extent, in relation to their immediate neighbors; so are the properties of the cells in CA models. These resemblances make CA models, intuitively and mathematically, natural tools to simulate urban processes. However, the dynamics of cities is dominated not only by local relations between its infrastructural physical elements but also by local and nonlocal relations between the many *agents* that are active in the city; that is, human individuals, families, households, firms and public agencies. It is here that *Agent Based* simulation models come in; their aim is to mimic the behavior and action of the many urban agents.

In the last decade CA and AB urban simulation models have become the most dominant media to study cities as complex, self-organizing systems. This shows up in the subtitle of Batty‘s (2005) book *Cities and Complexity: Understanding cities with cellular automata, agent-based models and fractals* (where the edition of “fractals” reflects Batty‘s personal taste). The same applies to Benenson and Torrens‘ (2004) book *Geosimulation: Automata based modelling of urban phenomena*. The main body of the two books is devoted to the various uses of CA and AB models in simulating the many facets of urban dynamics such as land-use, social and cultural segregation, urban morphology, urban spatial economy, movement in cities and more. To some extent *Self-Organization and the City* (Portugali 2000) belongs to this group too as Part II of the book that forms its core presents a family of CA and AB urban simulation models. However, it differs from this group in that the book as a whole and its models make explicit links to social theory and cognitive elements of human behavior in cities. They are described in the next section.

An example of a CA urban simulation model has already been introduced above in the discussion about deterministic chaos in cities (Sect. 4.3.1.3, Figs. 4.21–4.23). Despite its simplicity (or maybe because of that) this model has produced some important insights about the dynamics of cities. As we‘ve seen above, it has exposed the role of (captive) chaos in keeping the city in a steady state. Another interesting outcome of this model concerns the non-correspondence between the global properties of the city as a whole and the local-“personal” properties and tendencies of single urban agents. As illustrated in Fig. 4.29, at the beginning we‘ve run the model with agents belonging to two cultural groups – greens and blues – when all agents are *segregatives*, that is, prefer to live among their own kind; blue agents in blue neighborhood and green in their neighborhoods. But then we introduced neutrals – agents that are indifferent as to their neighbors and we run the model several times with increasing proportion of neutrals. The interesting outcome and insight was that the city remains highly segregative in face of increasing proportions of neutrals with the implication that a small number of segregatives is sufficient to turn the whole city

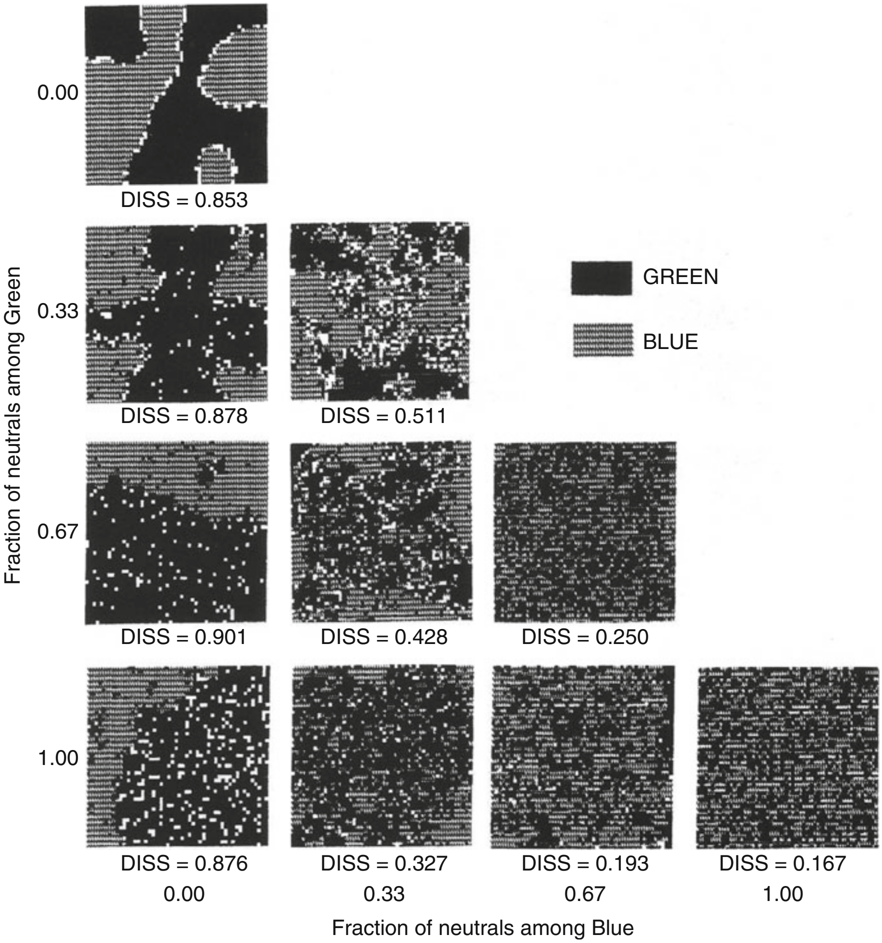

Fig. 4.29 Spatial distribution of two cultural groups with increasing proportions of neutrals and segregatives in both groups (Portugali 2000, Fig. 5.3)

into a segregative city – a finding that is in line with Shelling's (1971) segregation model. The next section introduces a special kind of CA/AB urban simulation modes, whereas in Part IV below two of these models are described in details. For further discussion and information on CA and AB models see the above books by Batty (2004) and Benenson and Torrens (2004).

4.4.2 FACS (Free Agents on a Cellular Space) Cities

FACS – free agents on a cellular space – is a family of simulation models specifically designed to deal with urban dynamics in general and with social and cultural urban segregation in particular. Their central idea is that looking at three sets of relationships can capture the essence of urban dynamics: the interrelationships between infrastructural urban elements such as buildings, parks, roads, etc.; the interrelationships between the various urban agents, and, the interrelationships between urban agents and urban elements.

Computationally – or model-wise, FACS models are built as a superposition between two layers corresponding to two kinds of models: AB and CA. That is an infrastructure layer, which is a usual CA urban simulation model with its 2-dimensional cellular space, and on top, a superstructure layer of individual free agents (Fig. 4.30). They are 'free agents' in that they can move from one cell to the other all over the "city", they have past, they have plans for the future, and they act intentionally; they are capable of learning and can thus change their "mind", action and behavior; they can see beyond local situations, their seeing is subjective and is captured by the notion of cognitive maps. The latter determine their actions and behavior in the city. In short, each free agent is a self-organizing system, each is a virtual human individual, family, firm, planning team and the like.

The link between the two layers is created, on the one hand, by the fact that the properties of each of the cells in the CA is determined by the properties of the agent that occupies it, while on the other, by the fact that the agents are capable of learning. That is, agents constantly observe the state of their neighboring cells and agents, as well as the state of the city as a whole, and evaluate the validity of their internally represented urban perceptions and behavioral tendencies in light of

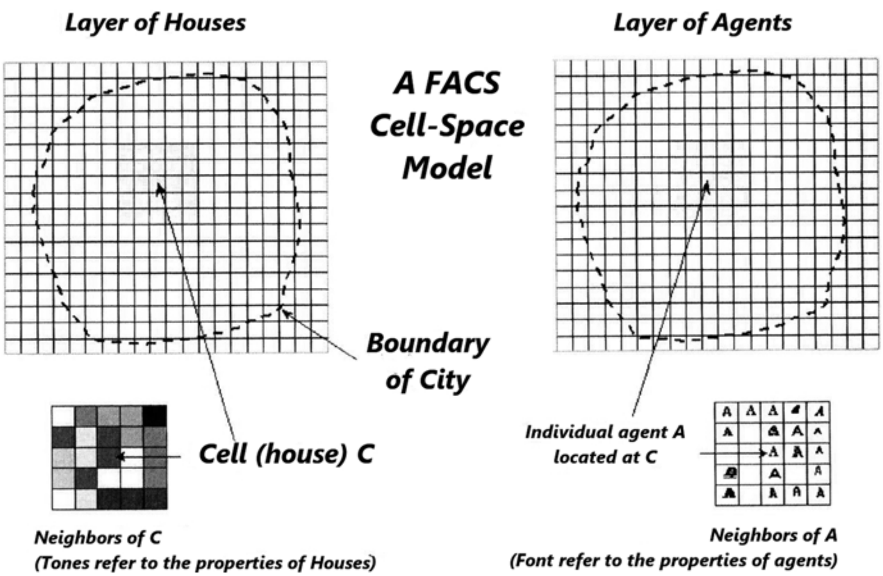

Fig. 4.30 A typical FACS model is constructed of two-layers: an AB population layer of human agents describing the migratory and interaction activities of individuals (*right*), superimposed on a CA infrastructure describing the urban landscape (*left*). (Portugali 2000, Fig. 4.6)

this externally observed situation; and if the dissonance between the externally represented information as it comes from the city and the internally represented information crosses a certain threshold, they change their minds and their corresponding behavioral patterns. The theory behind this kind of modeling is termed SIRN (synergetic inter-representation networks) and it is introduced in some detail in Part II, specifically in Chap. 7. The essence of the SIRN process and FACS models is a circular causation between two-scales self-organizing systems, forming a single network of internal and external representations: the individual free agents determine the city which can thus be seen as the external representation of their actions and behavior; and the city in its turn determines the internal representations (e.g., cognitive maps) of individuals and through these their action and behavior in the city, in a circular causality.

In Part IV, we use FACS models to study how, by means of self-organization, the city dynamics entails the emergence of a new urban cultural group – a phenomenon that is typical of current postmodern and hypermodern cities. We start the game with two groups of individuals, Greens and Blues, belonging to two cultural groups. They enter the city as immigrants, intending to find a proper location in it, where the Greens‘ intention is to live among greens, and the Blues, among blues. If such a free agent finds a satisfying location, it will live there and will become an inhabitant, if not, it will try to move to another location in the city, thus participating in creating the city‘s intra-urban migration. Some agents who cannot find a location according to their intentions, leave the city and thus create its outmigration, and some get stuck in a location that they do not like. Because of various systemic situations they cannot migrate and are thus enforced to behave counter their intentions. The outcome is that they enter a situation of *spatial cognitive dissonance*. With time, in order to resolve this cognitive conflict, some might change their intention, and in certain situations this change of intention gives birth to a new cultural identity in the city.

What we try to achieve by this new kind of modeling is to be able to examine, simultaneously, self-organization at the local level of the individual, and self-organization at the global level of the city: to see how the city dynamics might create a self-organization process at the individual level, and how the latter might entail self-organization at the city level. This approach departs from the usual procedure in self-organization studies which tend to study macro-scale city self-organization by ignoring micro-scale self-organization at the level of the individual, and to study micro-scale cases, as in cognitive studies concerning the behavior of individuals in the city, by ignoring the global self-organization process of the city, or by assuming it as fixed.

4.4.3 Small World Cities

In 1967, social psychologist Stanley Milgram published a paper entitled “the small world problem” in the popular magazine *Psychology Today* (Milgram 1967). Two years later he published (with Travers) a rigorous paper on this issue in the journal

Sociometry (Travers and Milgram 1969). In these papers Milgram presented results from a set of experiments he conducted on "the small world problem", namely, on the probability that two randomly selected people in the United States would know each other. The basic assumption was that the population of the US forms a social network and the aim of the experiments was to count the number of ties needed to connect any two people. In more formal language the aim was to find the average *path length* between any two nodes in the network. Milgram has found that the average path length is about six.

Milgram was not the first to study this issue. In fact he started his experiments in the US after coming from Paris where he was working with other scholars on this very issue. Also, the notion of *six degrees of separation*, which is often attributed to Milgram was in fact coined by the American playwrite John Gare.

For several decades Milgram's experimental results had the fate of most scientific studies, namely, they attracted a small community of scientists interested in this topic. However, at the end of the 1990s the small world phenomenon became popular again when a link was made between graph theory and the study of complex systems and networks. From this conjunctional perspective Watts and Strogatz (1998) demonstrated that complex networks have small world characteristics (Fig. 4.31) while Barabasi and Albert (1999) demonstrated that, depending on their underlying construction or growth principles, complex networks can be *scale free* thus following the *power law* (Fig. 4.32). These pioneering studies of Watts and Barabasi entailed an interdisciplinary wave of a large number of papers and several books in physics, mathematics, computer science, biology, economics, and sociology (Barabasi 2002). The result of this wave became known as the *New Science of Networks* (Watts 2004; Newman et al. 2006; Barrat et al. 2008).

The notion *network* is implicit in all theories of complexity. What Watts, Barabasi and the others did in their new science of networks was to explicate this link. The new science of networks thus became a new approach to, or a theory of, complexity. In particular, Barabasi has demonstrated that the scale-free property of complex systems and the entailed power law distribution are markers of the process of self-organization that typifies complex systems.

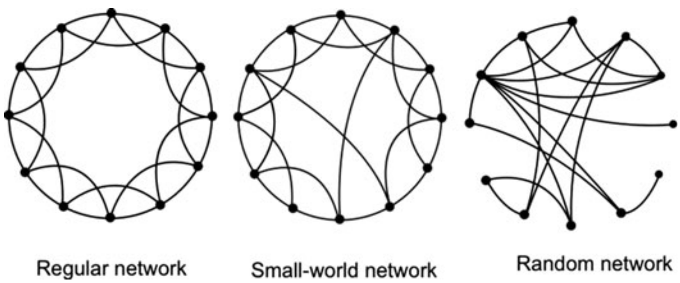

Fig. 4.31 A small world network (*center*) as a superposition of a regular (*left*) and random (*right*) networks

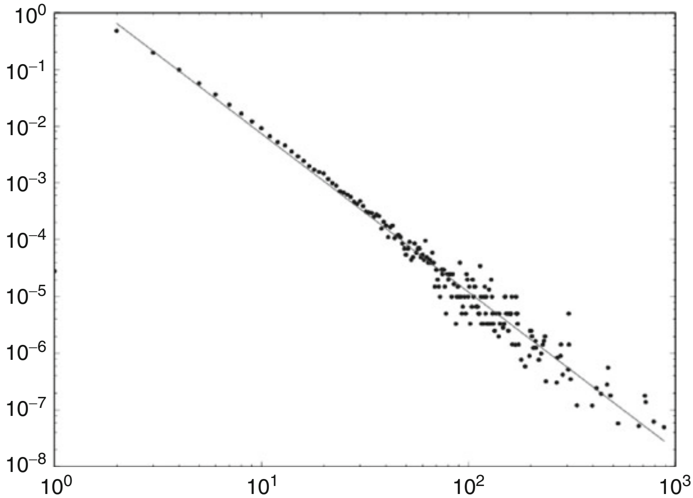

Fig. 4.32 Complex networks are *scale free* in the sense that the size distribution of their vertices and hubs follows the *power law*

The rank-size, scale-free and power law reminds one of the long history of looking at cities in these terms and of the fractal cities described above. It was therefore just a matter of time until the link to the study of cities would be made. This link was first made by Batty (2001) in an editorial entitled “Cities as small world”. Batty‘s editorial note was followed by a large number of studies that applied the new science of networks to a variety of urban domains. Thus, in the domain of transportation one can mention Bin Jiang‘s (2006, 2007) studies that characterize roads‘ traffic dynamics in Gävle, Sweden in terms of scale-free networks; the same was found for the transit system in Beijing (Wu et al. 2007), pedestrian movement (Jiang 2006) and for the canal networks of Venice (Blanchard and Volchenkov 2007). Andersson et al. (2003) showed that the market dynamics generates land values that can be represented as a growing scale-free network. Finally, Batty (2005) in his *Cities and Complexity* has suggested viewing cities and their dynamics from the integrative perspectives of networks, fractals, self-organized criticality and AB modeling.

Viewing cities as networks reminds one also of Alexander‘s (1965) classic “a city is not a tree”, that demonstrated that cities are typified not by a simple *tree network*, but rather by a complex *semi-lattice network* (Fig. 4.33). Alexander‘s view was recently reformulated by Salingaros (2005, 2006) in terms of the new science of networks. Another example is Hillier‘s (1999; Hillier and Hanson 1984) *space syntax* that analyzes the morphology of urban spaces in terms of networks. Space syntax exposes the way society determines the urban morphology and the way the latter feeds back and re-shapes society. The link between space syntax and network analysis has already produced several useful results (e.g., Hillier and Lida 2005).

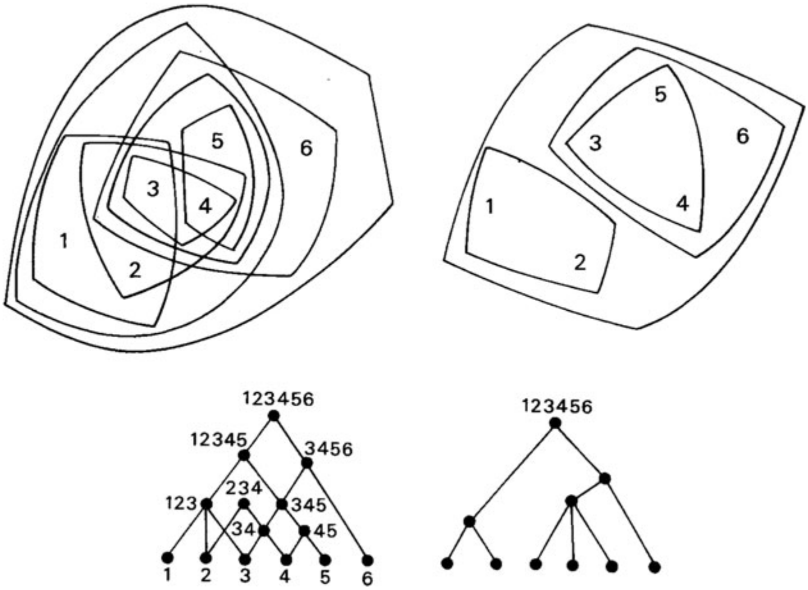

Fig. 4.33 The distinction between a *tree* structure (*right*) and a *semi-lattice* structure (*left*) according to Alexander (1965)

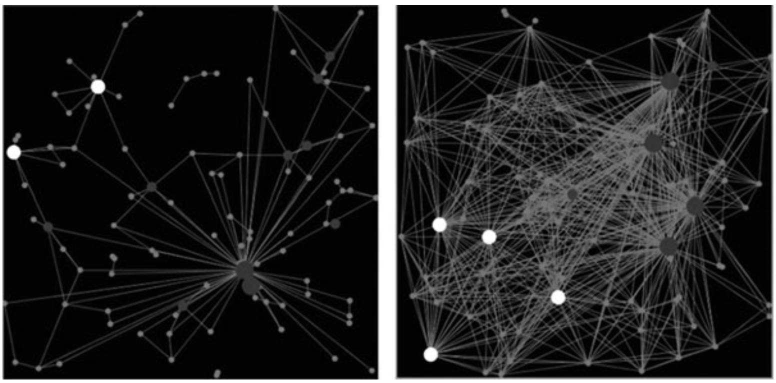

Fig. 4.34 Two examples for urban commuting networks simulated by the model. The sizes and colors of the nodes represent different sizes of urban economic centers

In a recent study Blumenfeld and Portugali (2010) have devised a network simulation model that is built as a superposition between the AB urban simulation model and a network model. A typical scenario of the model starts with a set of spatially independent nodes that represent cities in a region, for instance. The novel property of the model is that the probability for interaction between the nodes follows the logic of the gravity-interaction model, namely, it is directly related to the size of the nodes and inversely to the distance that separate them. Interaction might refer to commuters, and/or migration flows between the cities. When the level of interaction crosses a certain threshold, a link between the nodes is created.

Employing the model Blumenfeld and Portugali simulate and study the evolution and dynamics of urban networks and their different scales. They begin with networks in their intra-city level (i.e. within the city itself) and follow their evolution until they exist in the intercity (i.e. between cities). They show several scenarios that correspond nicely to size distribution of urban networks as observed in reality. Figure 4.34 illustrates two snapshots from the evolving urban landscape.

4.5 Concluding Notes: CTC – First, Second, or Third Culture of Cities?

CTC as we‘ve just seen, having originated in the sciences and by scientists, were introduced to cities by physicists such as Allen and Weidlich and at a later stage were welcomed by quantitative regional and urban scientists. Some thus see CTC as the new science of cities – as a new and more sophisticated version of the first culture of cities. On the other hand, as indicated above, complexity theories themselves form a new science or a new scientific approach, among other things because they have found in matter properties hitherto assigned to life, humans and humanity such as history, evolution, unpredictability, irreversibility, nonlinearity, uncertainty and the like (Portugali 1985). This is so also with respect to CTC and the second science of cities, namely, SMH and PPD cities. As I‘ll elaborate below, both domains are critical of the first science of cities and both share similar views as to the dynamics of cities; and there are differences of course. Based on the explicit links between CTC and the first science of cities and the implicit and subtle connections between CTC and the second culture of cities, my suggestion is that CTC has the potential to become a third culture of cities that bridges the gap between the two cultures of cities and reconciles their seemingly irreconcilable standpoints. This option will be discussed in some length below.

Chapter 5
Complexity Theories of Cities Have Come of Age: Achievements, Criticism, and Potentials

Complexity theories of cities (CTC) have come of age. What some two and a half decades ago was a narrow stream of studies – written mainly by physicists applying theories from physics – has now become not a flood but an established interdisciplinary research domain engaging urban geographers, planners, urban designers, regional scientists, mathematicians, physicists and others. In addition to the constant flow of articles, we start to see attempts at integration in the form of spatial theme issues (*Environment and Planning A*, 2006) and of books (Pumain 2006; Benenson and Torrens 2004; Allen (1997), Portugali 2000, 2006; Batty 2005). In such attempts at integration it is just natural to find appraisals of what has been achieved by CTC in the last two decades and a half.

As the title of this chapter indicates, the aim below is to look back at what has been achieved in the domain of CTC in the last three decades; however, the aim is to do so with appreciation, but also with sober criticism, and then, to look forward at potentials that have yet to be realized. The discussion below thus develops in three steps: achievements (Sect. 5.1), criticism (Sect. 5.2), and potentials (Sect. 5.3).

5.1 Achievements

In the introduction to his *Cities and Complexity*, Batty (2005) notes that CTC have provided sound theoretical basis with mathematical formalism to the intuitive ideas suggested by Jean Jacobs (1961) (and Christopher Alexander too) more than 40 years ago. In a recent *Science* article he writes the following:

> *In the past 25 years, our understanding of cities has slowly begun to reflect Jacobs's message. Cities are no longer regarded as being disordered systems. Beneath the apparent chaos and diversity of physical form, there is strong order and a pattern that emerges from the myriad of decisions and processes required for a city to develop and expand physically. Cities are . . . par excellence complex systems: emergent, far from equilibrium, requiring enormous energies to maintain themselves, displaying patterns of inequality spawned through agglomeration and intense competition for space, and saturated flow systems that use capacity in what appear to be barely sustainable but paradoxically resilient networks.* (Batty 2008, pp 769–771).

J. Portugali, *Complexity, Cognition and the City*, Understanding Complex Systems,
DOI 10.1007/978-3-642-19451-1_5,

Similar things can be said of the relations between CTC and other "classics of urban studies". Allen's dissipative cities, as we have seen above (Chap. 4, Sect. 4.2.1), is in a way a reinterpretation and reformulation of Christaller's central place theory in terms of Progogine's dissipative structures; Sasaki and Box (2003) suggested "Agent-Based Verification of von Thünen's Location Theory"; Weidlich's synergetic cities (Chap. 4, Sect. 4.2.2), applies Haken's theory of synergetics to population distribution in cities; our own synergetic and FACS cities (Chap. 4, Sect. 4.4.2) suggest a reinterpretation to the "old" ecological and economic approaches to cultural segregation in cities in terms of synergetics and FACS theories; and just recently the close to 100-years-old rank size rule of Auerbach (1913) is being reinterpreted in terms of Barabasi's and Watts' "new science of networks" and its power law distribution (e.g., Batty 2005). Finally, it is interesting to note that what Batty said above about Jacobs, applies also to Christopher Alexander's messages of the 1960s and 1970s, namely, that the new science of networks reconfirms Alexander's (1965) view from the 1960s that 'a city is not a tree' but rather a complex semi-lattice network, and, that beneath the apparent chaos and diversity of physical form that typify cities, there is a highly ordered *pattern language* that exist in humans' heads and in the world (Alexander et al. 1977).

The first achievement of CTC is thus not so much in identifying new urban phenomena as in giving a single and sound theoretical basis to a variety of urban phenomena and properties that so far were perceived as independent of each other and thus interpreted by reference to different theoretical bases: The pattern of land use in cities that in the past has been interpreted in terms of Thünen's economic theory, the spatial segregation of ethnic, cultural and socio-economic social groups in the city that in the past has been interpreted in ecological terms, the size distribution of cities in a region, the economic and geographical spatio-hierarchical pattern of central places in cities, metropolitan regions and countries, the structure of road networks of cities as well as the structure of communication between cities, the perception of cities and more urban phenomena (see Chap. 2, above), all have today a single theoretical basis; all have already been interpreted as complex networks emerging out of local interactions between urban agents that give rise to the global structure of cities (Fig. 5.1).

The second achievement of CTC is that it has added new insights to our understanding of cities – new insights that reflect the very basic properties of complexity. A few (and by no means inclusive) examples will illustrate this point:

First, complex systems, cities included, are typified by the property of nonlinearity. In the case of cities this implies that the local action and/or behavior of a single and "small" urban agent (say, a single person) might affect the city much stronger than the action of a big and strong agent such as the city planning team. This (somewhat counter-intuitive) insight sheds new light on the role and importance of the human individual in shaping the urban landscape and its dynamics. A case in point is the story of Tel Aviv balconies as presented below in Chap. 15, Sect. 15.1.3.

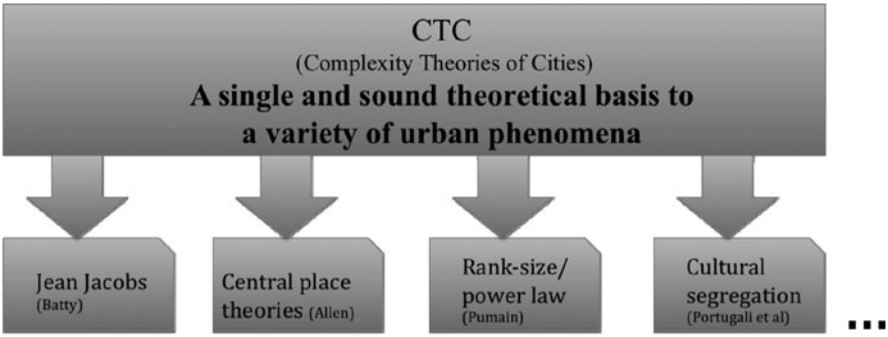

Fig. 5.1 CTC provide a single and sound theoretical basis to a variety of urban phenomena and properties that so far were perceived as independent of each other and were thus interpreted by reference to different theories

Second, complex systems, cities included, are typified by the phenomenon of *emergence*. In the case of cities it means that the local interactions between urban agents often give rise to properties that exist only at the global scale of a city. For example, that a high level of cultural/ethnic segregation in a city, does not imply highly segregative behavior on the part of individual urban agents. As illustrated in the past (Portugali 2000) and below (Chap. 17), a very small proportion of segregative urban agents might give rise to a highly segregative city. The lesson is that we have to be aware of the differences between the individual and the collectivity. (Note that this phenomenon can be interpreted also by reference to the property of nonlinearity).

Third, the property of emergence further implies that the city, by means of its very dynamics, can give rise to new urban entities and identities – for example, to a new cultural group. As illustrated in the past (Portugali 2000) and below (Chap. 17), several of the cultural groups that characterize the multicultural cities of our time, were created in this way. This, in its turn, implies that we have to see the city not only as a representation of larger socio-economic or cultural forces, but as a socio-cultural force in itself.

Fourth, some cities are often described as symbols of order while others as symbols of chaos. As noted above, CTC teach us that “beneath the apparent chaos and diversity . . . there is strong order and a pattern . . .”. Furthermore, from the notion of *edge of chaos* (Kauffman 1993; Langton 1990) follows that chaos and order do not necessarily contradict one another. With respect to cities this implies that, firstly, the tension between chaos and order often keeps cities on “the edge of chaos” – a situation that enables cities to be adaptive complex system and withstand environmental changes (Batty 2005, pp 479–482). Secondly, in some cases pockets of “captive” urban chaos might be necessary in order to maintain the stability of the rest of the city (Chap. 4, Sect. 4.3.1.3). Thirdly, chaos might be the precondition for new order to emerge. For example, pockets of captive urban chaos are areas of high potential for change (ibid).

5.2 Criticism

In early 2008 I was invited by sLIM (http://www.slim.nu/en/lg11introen.php) to give a talk on "The theory of self-organization and its potential for addressing the 21st century city both in the developing and developed world". The motivation for this meeting was the observation that the 21st century is marked by a strong sensation of change the signs of which are abundant: Globalization, civil society, privatization, the decline of the national welfare-state and of course cities; cities capture the core of this change: For the first time in human history more than 50% of world population live in cities, several cities around the world turned into mega-cities with population of over 20 million, the economy and sphere of influence of many world or global cities extend beyond the boundaries of their nation state and yet parallel to and within this trend we see a countertrend toward localization or "glocalization". The above sensation and situation shows itself also in the increasing popularity and dominance of theories and perceptions of reality that emphasize change and instability; in the shifts from modernism to postmodernism, from structuralism to poststructuralism, from constructivism to deconstuctivism, from systems in equilibrium to systems in far from equilibrium, from closed to open systems, from entropy to self-organization and complexity with notions such as chaos, edge of chaos, fractal structure, nonlinearity and the rest (Portugali 2005a).

It is therefore not surprising that some of the basic aspects of 21st century society and cities are often described in terms taken from the language of complexity theories and CTC: The most prominent example is Castells' (1996) *The Rise of the Network Society* and his notions of *space of flow* and *information city*. A more recent example is Healey's (2007) book *Urban Complexity and Spatial Strategy*. It is important to note that both Castells and Healey are using the notion 'complexity' literally without the theoretical formalism and meaning added to it by complexity theory. On the other hand, Thrift (1999), in a paper on "The place of complexity", refers to complexity theory itself.

The idea of the students who organized the sLIM seminar was that CTC must have a lot to say about the 21st century city. Preparing the talk I realized that while this is indeed the case, so far CTC have said very little about the 21st century city and its specific properties. Most researchers in the domain of CTC preferred and still prefer to focus on rather traditional, conservative and somewhat anachronistic urban issues: central place theory, land use, rank-size distributions of cities, national systems of cities and the like – issues that were dominant in the 1950s and 1960s.

As we've seen above in some detail (Chap. 3) in the early 1970s the study of cities underwent a kind of paradigm shift when several students of the quantitative-positivist approach to cities – David Harvey being the most predominant of them – started to criticize their own camp on the ground that the arsenal of scientific theories and methods developed by quantitative urbanists and location theorists is "incapable of saying anything of depth and profundity.." (Harvey 1973, p 129) about the real problem of cities in the 1960s and 1970s. We've have further seen above that the result was a split between the two cultures of urban research and that the hermeneutic-critical approach dominated the field for more than two decades.

Can we or should we draw a parallel between the tension between the two cultures of cities – the scientific and the humanistic – some 40 years ago and today? Is there a ground to say that CTC are "incapable of saying anything of depth and profundity.." about the burning urban issues of the 21st century city – about processes of globalization and glocalization, about the emergence of megacities of over 20 million people, of urban planning and governance in a society with emerging civil society? I don't think so; not only because CTC have a potential (that has yet to be realized) to add new insight to our understanding of 21st century urbanism, but also because it has a potential to go beyond the two cultures of cities and in fact to unite them (Portugali 2006a and below Chap. 11). On the other hand, I do think that there is a danger that if CTC go in their current direction they will soon become a new version of the old quantitative approach and as such subject to the same criticism leveled at it in the early 1970s.

5.2.1 What Went Wrong?

What is the current trend of CTC and why it might lead to irrelevant urban studies? The answer in short is that the current trend is to see CTC as a new generation of quantitative urban simulation models (USM) capable of describing, simulating and predicting urban scenarios in an efficient and accurate way – much better than the old generation of quantitative methods of the 1950s, 1960s, and 1970s. Implicit in this current trend is the view that what gives the new generation of USM an edge over the old generation is, firstly, the mathematical formalism and simulation methodologies developed by the various complexity theories, in particular cellular automata (CA), agent base (AB), and more recently network models (Chap. 4, above); secondly, the new computation technologies that enable to run the new and more sophisticated USM and to crunch huge amounts of data.

There is nothing wrong of course in sophisticated simulation models crunching huge quantities of data by means of fast computers. What's wrong is, firstly, that simulation models originally designed as media by which to study phenomena of complexity and self-organization become the message itself. Secondly, that CTC tend to overlook the fact that complexity theories form a new science that is critical of the first culture of cities. Thirdly, and as a consequence of the above, that most studies in the domain of CTC are silent about the qualitative message of complexity theories to cities. Fourthly, that students of CTC have indiscriminately applied to cities theories and models originally developed to deal with natural phenomena, ignoring the implications of the fact that cities are not natural phenomena but rather artifacts. Let me elaborate.

5.2.2 The Medium is the Message

"The Medium is the Message" is a notion coined by McLuhan (1964), suggesting that the medium by which a message is being conveyed participates in forming its content; and, that in some cases the medium becomes the message itself. A book versus a television are often cited as two media that affect differently the content of a given message. To the latter I would add mathematical models and USM, too. The situation by which USM have become the message shows up in several phenomena and trends. Firstly, CA and AB USM, as noted above, have become the most popular approach to simulate the dynamics of cities. Their popularity stems from the fact that they are intuitively related to the dynamics of cities, simple to use, and easy to run with empirical data. And indeed the insight they added and still add to our understanding of cities is rather important. On the other hand, however, their intensive use is not without a price: The medium has too often become the message; too often complexity theories of cities and cities themselves are seen through the "eyes" of CA/AB models – as theories of cognitively simple interacting agents that in a bottom-up process give rise to cities and systems of cities that are stable and robust. The problem is that as we'll see in some detail below (Part II), urban agents are cognitively complex and cities are not robust – not if we study their *longue durée*, that is, their long-term evolution and dynamics.

Secondly, in their search for statistical data to feed their models, practitioners of urban simulation models tend to overlook the nonquantifiable urban phenomena. This is so with respect to "classical" qualitative urban phenomena such as those of the 21st century cities mentioned above and this is so also with respect to classical phenomena of complexity theory. A case in point is the phenomenon of chaos that as we've seen above (Chap. 4 Sect. 4.3.1) is not on the agenda of CTC. The reason to my mind is that chaos is hard to identify in cities by means of published statistical data and as a consequence, with few exceptions (ibid), there are no applications of chaos theory to cities.

Thirdly, the medium of CA/AB has too often become the message in yet another respect: many students in the domain of CTC and USM tend to employ CA/AB USM as sophisticated predicting devices, overlooking the fact that complexity theories imply that complex systems are essentially unpredictable – the elementary properties of the theory, such as nonlinearity, chaos, emergent properties and the like imply unpredictability. By so doing these practitioners of complexity theory run into a paradox: they claim that cities are complex systems but they treat cities as if they were simple systems.

5.2.3 Implicit Criticism

Proponents of CTC are by and large sympathetic with the first science of cities and implicitly or explicitly regard themselves as belonging to the first culture of cities as the new, more sophisticated, science of cities. What they often fail to see, however, is that CTC have two significant interfaces with the second culture of cities, namely, with SMH and postmodern cities. Firstly, similarly to social theory oriented urbanism, CTC is critical of classical urbanism and planning. Secondly, and related to the above, CTC perceive the urban process in a way similar to social theory oriented urban studies. The aim of this section is to elaborate on the first interface.

CTC never explicitly criticized classical urbanism and yet the criticism is there, implicit in the very logic of CTC: Classical theories of cities assume that cities are essentially closed systems and as such tend toward a state of equilibrium (e.g., the classical location theories of Thünen, Weber, Christaller and Lösch and their followers) and maximum entropy (e.g., Allen Wilson's family of entropy maximization models – Wilson 1970). CTC per contra assume that cities are essentially open systems and as such are in a permanent state of "far from equilibrium condition" and "on the edge of chaos. Furthermore, classical urbanism and planning theory pre-supposes that cities are essentially predictable and as such controllable and planable (e.g., the rational comprehensive planning approach); CTC as we've just seen (and will further see below) imply the exact opposite.

Needless to stress that the above criticism has yet to be fully elaborated and spelled out; its essence, however, is apparent. It is also apparent that by overlooking this criticism proponents of CTC often tend to treat "their" complex, self-organizing cities as if they were classical systems – in the case of PSS (Planning Support Systems), for instance (see Chap. 12).

As we've seen above, social theory oriented urban studies are critical of the first culture and science of cities for applying to cities positivism – the quantitative scientific method that was originally developed for the study of matter and mechanistic phenomena. They claim that the human domain is fundamentally different from the domain of nature and as a consequence the application of the scientific approach to the study of cities and the practice of planning leads to reductionism; in the human domain, they claim, the "soft" hermeneutic approaches are therefore more appropriate. Marxists further claim that positivism is not just an inappropriate approach mistakenly applied to the human domain but an ideological false consciousness that obscures people's view from their real state of existence in an unjust capitalist social structure.

CTC agree with social theory oriented urban studies that the human-urban domain is different and that therefore applying the classical approaches to the human domain of cities leads to reductionism and misconception of the urban process, and, that the specific structure of society and the city must be taken into consideration when studying cities; but they agree on the above for a different reason: the complexity of the system. Classical urban theorists and planners have treated the city as simple and classical and yet it is complex and nonclassical. In fact, as implied by Batty (2008), the message was on the wall already in the 1960s – in what has been termed above (Chap. 3, Sects. 3.4, 3.5; Chap. 4, Sect. 4.5) as *the third culture, namely*, in the writing of Jean Jacobs (1961) and Christopher Alexander (1965) who have perceived cities as complex systems several years before formal complexity theory came to the fore. But classical urbanists failed or rather were not able to respond to these new ideas because they were part of, and enslaved by, the first culture of cities.

5.2.4 The Qualitative Message of Complexity Theory to Cities

Most CTC studies ignore the new insight that complexity theories can add to our understanding of cities in general and to the cities of the 21st century in particular. Batty's discussion about the general message of CTC as described above and few other studies about this issue (Portugali 2000, 2006a) are exceptions that prove the rule. One reason for that has already been suggested above: The qualitative urban phenomena do not lend themselves to quantitative-statistical analysis and thus are of little interest to mainstream CTC: The growth of cities beyond the nation state, the role of civil society in their dynamics, the implications of complexity and self-organization to planning and design, like other burning questions of 21st century cities, are all "qualitative", with no "hard" data and as such not in mainstream discourse of complexity theories of cities. It must be emphasized that some qualitative urban phenomena can and have been modeled and simulated by means of CTC USM. For example, our FACS models have been employed to study the process by which the urban dynamics entails the emergence of new socio-cultural groups in the city (Portugali 2000, Chap. 8, and see Chap. 17 below). However, since there is no simple way to back such models by "hard" quantitative data they are treated as too theoretical or "pedagogic" (Batty 2005) and as such less attractive.

One might justly argue that every research domain has boundaries and that the above qualitative issues of complex agents and of 21st century cities fall beyond the boundaries and scope of CTC. My view is that this is not the case. One reason for this view is that so far complexity theories were applied to cities only partially, that is, only selected parts of the processes that make a system complex were applied to the domain of cities. A second reason is that CTC have not as yet crossed the boundary of simple, mechanistic applications.

5.2.5 Partial Application

In the previous chapter it has been suggested to distinguish between comprehensive or long-term complexity theories vs. short-term complexity theories, while on the other, between complexity *theories* of cities and complexity *models* of cities. From the perspective of these distinctions one can observe, firstly, that while the founding theories, namely Prigogine's dissipative structures and even more so Haken's synergetics, were comprehensive theories, putting full emphasis on all three aspects and long-term evolution of complex systems, subsequent theories became more specific. Secondly, that CA, AB and network urban simulation models that currently dominate the field focus mainly on the process of emergence, that is, on the dynamics by which local interactions give rise to a global structure.

There is nothing wrong, of course, with the above trend as long as the various approaches complement each other – as long as more theoretical viewpoints shed light on the multiple aspects of complex systems. It starts to be problematic, however, when in order to make their point, the new theories, models and points of views put shade on, or dismiss as not "quantitative" or "scientific" or up to date, previous ones. This is exactly what happened in the domain of CTC. It started with comprehensive complexity theories of cities and urbanization that theorized about both the short and the *longue durée* of cities and urban processes. However, as more and more researchers joined the club, the comprehensive view of cities and urbanism was put aside and the theoretical focus moved to the short-term urban phenomena. One result was that CTC became less and less relevant to the general study of the long-term qualitative aspects of cities and urbanism – exactly the kind of issues that today typify 21st century cities and urbanism and today stand at the center of interest of the general discourse about cities. Furthermore, as we've seen above, while the long-term CTC tended to employ USM as a medium by which to explore the various aspects, in the short-term CTC and specifically in complexity models of cities, the medium of USM has become the message and the search for data to feed the models led many to ignore urban phenomena on which there is no easily accessible quantitative data.

5.2.6 Adaptive vs. Nonadaptive Application

Complexity theories were originally developed in the sciences and by reference to natural phenomena, thus for example, the Bénard experiment was employed by Prigogine in developing his dissipative structure, Haken has developed his theory of synergetics by reference to Bénard and the phenomenon of the LASER beam, and Bak's theory of self-organized criticality was inspired by the sandpile experiment. An exception is Mandelbrot who started to developed his theory of fractals by reference to the economy (Barcellos 1984) and to *The (Mis)Behavior of Markets* (Mandelbrot and Hudson 2004). However, his theory became fully accepted and appreciated when he demonstrated *The Fractal Geometry of Nature* (Mandelbrot 1982) and when the theory was applied to processes that give rise to snow flakes (Koch's algorithm) or to plants (Lindenmayer's algorithm). All these theories were applied to cities as we've seen in some detail above – applied in a *mechanistic* but not *adaptive* way.

Complex systems are often described as *complex adaptive systems*, that is, systems capable of adapting their structure and behavior to the environment into which they enter or are being introduced (Gell-Man 1994; Holland 1992). A human being is a typical adaptive system. Adaptability is an important property of complex systems resulting from the fact that such systems are open and capable of self-organization. Nonadaptive systems, per contra, maintain their structure irrespective of the environment. Nonadaptability is a property of closed, simple and mechanistic systems.

In *The Quark and the Jaguar* Nobel Laurent in physics Gell-Mann (1994, p 17) characterizes a complex adaptive system as follows:

> *... a complex adaptive system acquires information about its environment and its own interaction with that environment, identifying regularities in that information, condensing these regularities into a kind of 'schema' or model, and acting in the real world on the basic of that schema. In each case there are various competing schemata, and the results of the actions in the real world feed back to influence the competition among those schemata.*

It is interesting to mention in this connection, firstly, the similarity to Haken's *synergetics* as described above; in particular the similarity between Gell-Mann's *schema* and Haken's *order parameter* and also the emphasis of both on the competition between schemata/order parameters and on feedback with the real world. Secondly, the similarity to Prigogine with Stenger's (1997, p 62) who compared the closed system 'crystal' to the open system 'town': "A crystal", they write, "can be maintained in a vacuum, but if we isolate the town, it would die ...". The property of *Openness* that typifies complex systems is thus a precondition to their *adaptive* capability.

In light of the above, I suggest a distinction between *adaptive to nonadaptive applications*. By *adaptive applications* I refer to situations by which a theory or notion is being transferred from one domain to the other by adapting its structure to the specific properties of the new domain. By *nonadaptive applications* I refer to situations by which a theory or notion is being transferred from one domain to the other by maintaining its structure irrespective of the specific properties of the new domain.

With few exceptions, most complexity theories were applied to cities in a nonadaptive manner. One part of these applications was made by physicists whose main interest was not cities but the models they applied. This is evident from the fact that many such papers are published in journals such as *Physica A*. For these physicists as well as for the editors of the above journals, cities are nothing but another source of data by which one can feed and test the models. The important finding of such studies is that the size distribution of several systems of cities obeys the *power law*, that several cities, metropolitan regions, rail and road networks are *fractals*, that many cities and their road networks are *small world* and so on. Another part of the applications was made by students of cities and urbanism attracted by the opportunity to develop a science of cities that is based on the strong theoretical and methodological foundations of complexity theories. The fruits of the various applications are that today we have the domain of CTC and USM with significant achievements as described above.

And yet, cities are not natural entities such as liquids, light beams, snow flakes, sand-piles or trees and their parts are not atoms or molecules, or sand grains. Cities are *artifacts*, that is, artificial systems – *facts of art* and human culture – and their parts are human beings that unlike sand grains can think, learn, plan, forget, change their mind, ... and their actions and behavior are products of intentions, plans, social and cultural norms, political pressure and the like. These properties enable humans to adapt to their environment and these properties make each human being a complex, self-organizing adaptive system. The fact that CTC and complexity models of cities tend to overlook this uniqueness of cities entails a twofold problem: First, there is a limit to what CTC in their present nonadaptive form can say about cities – they can say very little on the really interesting and qualitative problems of cities in the 21st century. Second, CTC have no new feedback to complexity theories, no new insight or new contribution to the general domain of complexity theory.

5.2.7 *The Limits of Nonadaptive CTC*

CTC show that cities and transportation routes are fractals, that their size distribution obeys the power law, that bottom-up local interactions between simple agents can give rise to complex global patterns of land-use and ethnic segregation and so on. But what does it mean that a city is fractal? That a system of cities is fractal? Why are they fractals and are typified by a power law distribution? What do we learn about cities from the fact that they can be modeled and simulated in a way analogical to sand-grains or trees? Some forty years ago Wilson (1970) has demonstrated that entropy maximization spatial interaction models can mathematically describe a whole set of urban phenomena ranging from transportation, to retail, housing and more. Entropy, as is well known, is a property of closed and simple systems and as such the exact opposite of complex self-organizing systems. Nowadays, CTC demonstrate that its urban simulation models can explain the same set of urban phenomena as properties of open and complex systems. In what family of models should we believe – in the models that treat cities as closed systems, or in models that treat cities as open systems? I make this point not in order to discredit complexity models of cities, but to emphasize that a best fit between model and data is not enough. The fact that a given model can successfully generate a tree and a city doesn't mean that a city is a tree – it is not.

As discussed above (Chap. 4), in 1965, Alexander published a paper that has since become famous: "A city is not a tree". In this study, Alexander makes a distinction between two ways of thinking about cities: one is in terms of a hierarchy or a tree, and the other in terms of a semi-lattice (above, Fig. 4.33). The two cities differ from each other in their structure – a tree vs. a semi-lattice, and in the processes that created them and that take place in them.

In this article Alexander demonstrates that despite the similarity between the hierarchical structure of a tree and that of a city (or system of cities), a city is a much more complex network than a tree – it has a semi-lattice structure. In the "tree city" each subsystem in the city is independent from all other subsystems of its level, and it can thus interact with them only via a higher order subsystem. In the semi-lattice city there are overlaps between subsystems of the same order, so that interaction can occur vertically, horizontally and in oblique. As noted by Alexander, it is not only the overlap which makes the difference, but

> *more important is the fact that the semi-lattice is potentially a much more complex and subtle structure than the tree..: a tree based on 20 elements can contain at most 19 further subsets of the 20, while a semi-lattice based on the same 20 elements can contain more than 1,000,000 different subsets* (Alexander 1965, p 382).

Students of CTC like to quote this paper because it implies that cities are very complex networks. Alexander wrote about these differences as an urban designer with the aim to negate "natural" to mechanistic cities:

> *I want to call those cities which have arisen more or less spontaneously over many, many years natural cities. And I shall call those cities and parts of cities which have been deliberately created by designers and planners artificial cities. Siena, Liverpool, Kyoto, Manhattan are examples of natural cities. Levittown, Chandigarh and the British New Towns are examples of artificial cities.*

This terminology is to my mind misleading for the simple reason that unlike the *tree*, which is by definition a genuine natural entity, Siena, Liverpool, Kyoto, Manhattan as well as Levittown, Chandigarh and the British New Towns are all *artifacts*. The more significant question is therefore 'what makes artifacts such as Siena or Kyoto more complex (with a semi-lattice network) than the natural entity tree and cities like the British New Towns? The answer is implicit in Alexander's paper:

> *For example, in Berkeley at the corner of Hearst and Euclid, there is a drugstore, and outside the drugstore a traffic light. In the entrance to the drugstore there is a newsrack where the day's papers are displayed. When the light is red, people who are waiting to cross the street stand idly by the light; and since they have nothing to do, they look at the papers displayed on the newsrack which they can see from where they stand. Some of them just read the headlines, others actually buy a paper while they wait.*
>
> *This effect makes the newsrack and the traffic light interactive; the newsrack, the newspapers on it, the money going from people's pockets to the dime slot, the people who stop at the light and read papers, the traffic light, the electric impulses which make the lights change, and the sidewalk which the people stand on form a system – they all work together.*

They all work together because of the *human agents* that are involved in the dynamics that unlike the traffic lights, the newsrack and the headlines, can see and read from a distance, change their trajectory and buy a newspaper, and by means of these cognitive capacities the people, the newspapers, the traffic lights and the other spatially fixed objects form a system – "a unit in the city" as Alexander calls it.

A tree is a typical example of a complex system and a typical example of a fractal structure that can and has been generated by a variety of algorithms including CA. So far CTC has demonstrated that a city is a tree. To go beyond that, CTC have to look not only at the similarities between natural and artificial entities but also at their differences. The same applies to the relations between CTC and complexity theories at large: as long as CTC will treat cities as trees, as long as they will apply the various complexity theories mechanistically in a nonadaptive way, they will not be able to add and contribute to the general theories of complexity; in order to contribute to this general body, CTC will have to look not only at the similarities between natural and artificial entities but also at their differences (see Wilson 2006 for the contribution to complexity theory). Two such differences that concern the specific nature of urban agents and cities as artifacts are discussed below in Chap. 6, Sect. 6.5.3.2.

5.2.8 Simple vs Complex Agents

Studies on cities show that many of the properties of urban objects (e.g., land value, cultural image, etc.) are determined by their relations to their nearest neighbors. CA is a model in which the properties of every cell are determined in a similar way: by the cell's relations to its nearest neighbors. This similarity makes CA a rather attractive model to simulate cities. Their disadvantage is that in cities we have, in addition to relations between objects/cells, relations between the many urban agents. CA cannot simulate these relations, at least not explicitly and it is here where AB models come in – they add to the dynamics of urban objects the action of, and interaction between, the many urban agents. As the name AB indicates, the agent is the most important entity of this kind of models. But what is an agent in general and in the context of cities in particular?

In *Cities and Complexity* Batty (2005) addresses this issue. Surveying the literature on the history and meaning of the notion *agent* he defines agents as:

> *... objects that do not have fixed location but act and interact with one another as well as the environment in which they exist, according to some purpose. In this sense agents are usually considered as acting autonomously. ... Autonomous agents thus cover a wide variety of behaving objects from humans and other animals or plants to mobile robots ...* (Batty ibid, pp 209–210).

He then follows Franklin and Graesser (1997) and classifies agents' action and sensing capabilities as ranging between "passive" agents that can only react to what they encounter in the environment, to "cognitive" agents that in addition to reaction also act according to some protocols and goals. Batty then introduces a set of urban simulation models. Some of these urban models are reactive, while others are "cognitive". From Batty's survey it is not clear whether or not urban agents are reactive or cognitive nor whether urban agents are similar to or different from agents in other domains. Apparently this is so since his models are generative. In fact there is no discussion in the literature of CTC about the nature and meaning of urban agents.

The absence of such a discussion is more severe in face of the fact discussed above that since the mid-1950s there is a science of cognition that studies the nature of agents and since the early 1960s there is a branch of cognitive science that specialized in spatial cognition and behavior of agents including urban agents, that is, how human agents perceive and cognize space, how they navigate and behave in space, or take location decisions (Kitchin and Blades 2002; Portugali 1996a, 2004, 2005). Apart from a few exceptions, CTC ignore this body of knowledge.

5.3 Potentials

The potential contribution of complexity theories of cities that has yet to be realized is implied by the criticism discussed above. Let me emphasize the main points. First, as noted above, so far CTC have exhausted mainly the short-term theories.

The potential that has yet to be realized here is thus to further elaborate on the long-term CTC and to create a better balance between the short-term and long-term aspects of cities as complex self-organizing systems. This issue is discussed in Sect. 11.3.1 entitled “CTC: The deeper messages”.

The second potential follows from the fact that complexity theories came and still come with quantitative and qualitative messages and from the observation that so far CTC have applied mainly the quantitative message. The potential that has yet to be realized is to develop a better balance between the qualitative and quantitative messages of complexity theories and their application to the study of cities. As emphasized in the past (Portugali 2000) and as will be further emphasized below, CTC have the potential to bridge between the two cultures of cities, that is, the “quantitative” science of cities and the “qualitative” social theory oriented study of cities.

The third potential concerns building links between social theory oriented urban studies and CTC. This potential is a corollary from the second one. As noted above and as will be further elaborated below, some of the qualitative insights already added by the CTC to our understanding of cities are similar to ideas that have developed independently in the context of the general study of cities, for example, the role of bottom-up urban processes. In social theory oriented urbanism the bottom-up approaches reflect a political and/or ideological stand; in CTC it is a property of cities as complex self-organizing systems. As will be shown below, there are many interesting links between social theory derived, and complexity theories derived, interpretations of cities and urbanism.

The fourth potential is to develop CTC oriented theories of urban planning and design. In the 1950s and 1960s mainstream-planning theory has developed as the applied branch of the first culture of cities. As we shall see below in Part III, the emergence of the second culture of cities had a strong impact on urban planning (and design) in the sense that since the early 1970s to date, planning theory is developing as an aspect of the second culture of cities, namely, of social theory oriented urban studies. This is one of the reasons to my mind for the almost absence of links between CTC and mainstream planning theory. A better link between CTC and social theory oriented urban studies will provide a good context to realize the potential of a CTC approach to urban planning and design. Chap. 15 below discusses the interrelations between CTC, social theory oriented urban theory and planning.

Finally, the fifth potential is to develop CTC as an adaptive application of the main body of complexity theories. As noted above so far most CTC are essentially nonadaptive applications indicating and emphasizing the similarity of cities as complex systems to complex material and organic natural systems. While important, this is not sufficient. The potential yet to be realized is to study also the differences between material and organic systems as complex systems, and cities as complex systems. Two such differences were mentioned above: Firstly, urban agents as the parts of the complex system ‘city’ are cognitively different from other animals as parts of organic systems and obviously from entities that form the parts of material complex systems. Secondly, cities are artifacts. The challenge is thus to develop a cognitive approach to CTC and to study cities as artifacts. Realizing this potential is the key for the realization of the four potentials discussed above and is also the task of the remainder of this book.

5.4 Concluding Notes

CTC is today at a crossroad or to use the language of complexity theories, at a bifurcation point. Two main attractors can be observed from this position: one, that CTC belong to the first culture of cities and should thus be seen as the second science of cities – more elaborated and sophisticated than the previous one that dominated the field in the 1950s and 1960s for the reasons noted above: it has better technology, stronger theoretical basis and more sofisticated urban simulation models. This first attractor is currently the dominant one, as we've seen, but it has several severe drawbacks that have been specified above.

The second attractor is that CTC will realize its full potential by building two bridges: one between CTC and social theory oriented urban studies. This bridge will link CTC to the main body of urban theory and, as a consequence, to the central issues of 21st century urbanism. The second bridge is between CTC and cognitive science or more specifically with environmental/geographical cognition – that branch of cognitive science that deals with human (and animals') cognition and behavior in large-scale extended environments which in the case of humans includes also cities and systems of cities. Based on these two bridges CTC will be able to develop its own identity within the overall field of complexity theories as a science of complex artificial environments and thus become the link between the two cultures of cities – a point of view I've started to elaborate in a paper entitled "Complexity theory as a link between space and place" (Portugali 2006) and will further be elaborated in the chapters below.

Part II
Complexity, Cognition and the City

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

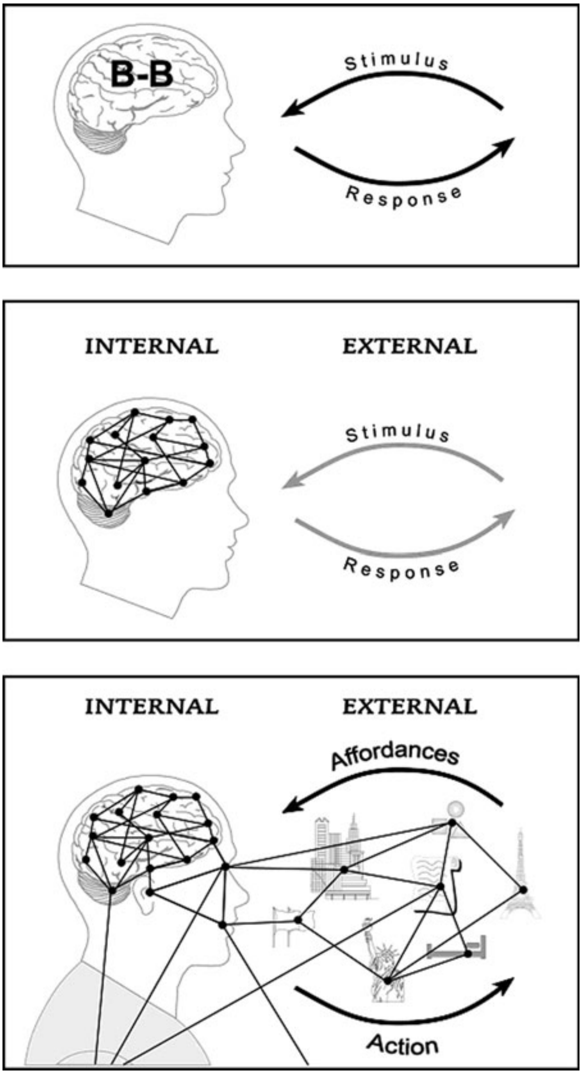


Fig. 6.1 *Top:* The BB model of behaviorism. *Center*: The model of classical cognitivism. *Bottom*: Embodied cognition

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

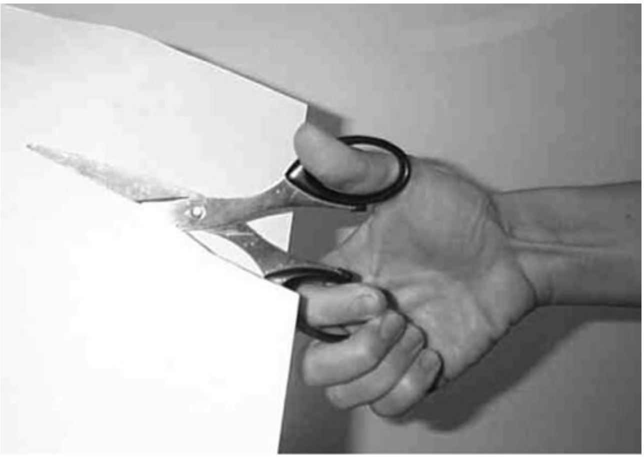


Fig. 6.4 An artifact often functions as an extension of the body. This figure follows Gibson's (1979b) Fig. 3.1, on which he writes: "A tool is a sort of extension of the hand. This object in use affords a special kind of cutting, and one can actually feel the cutting action of the blades"

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

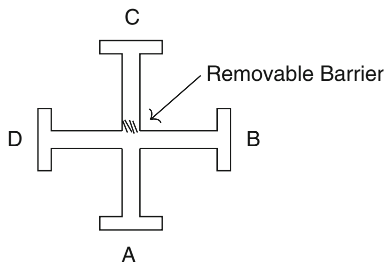
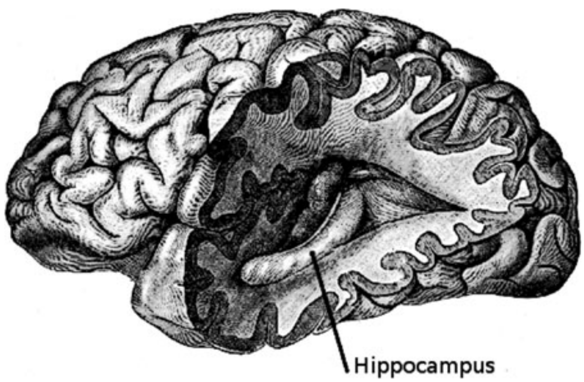


Fig. 6.5 Tolman's maze experiment. First, the rats were placed at A when B was the goal (food). Second, the rats learned several times to run to B to get the food. In doing so, they would have to turn right to get to point B. Third, the rats were placed at point C. Now, if the rats turned right and went 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

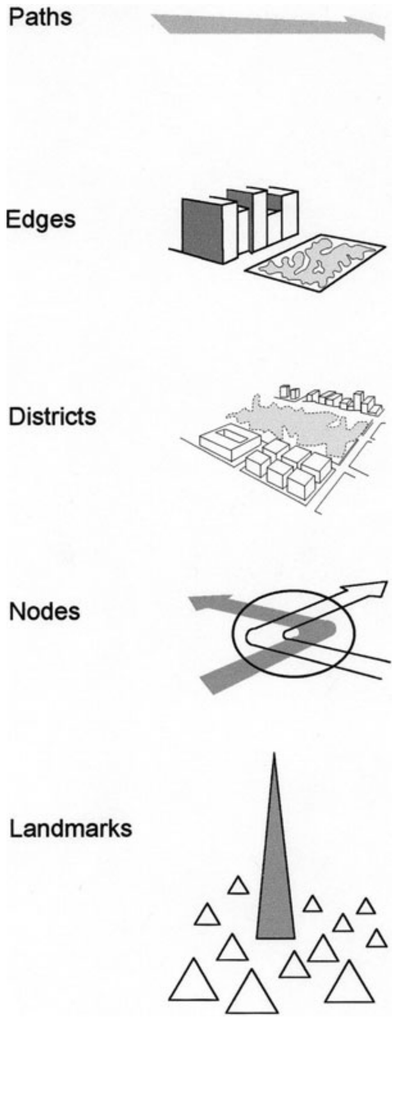


Fig. 6.7 Lynch's (1960, p. 47-8) five elements are specifically significant in shaping people's images of the city and in making the city *legible*

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*

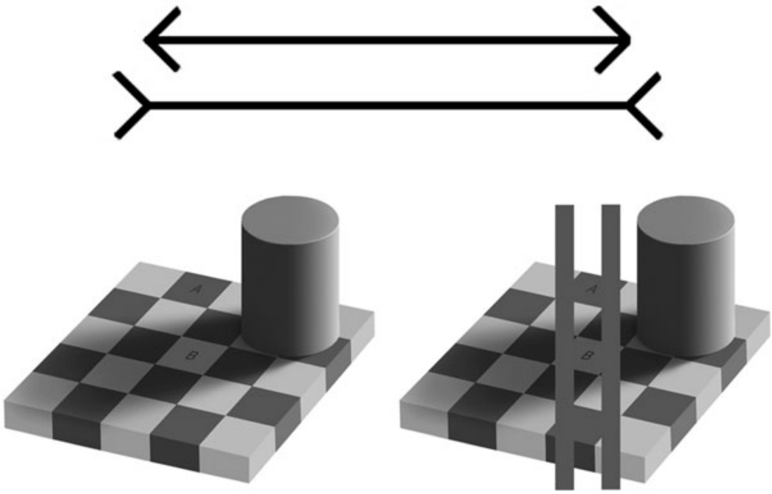


Fig. 6.8 *Top*: The Müller-Lyer illusion devised by him in 1889. Viewers invariably "see" that the lower line is longer than the upper one; yet the two are identical in their length. *Bottom*: The Checker-shadow illusion. The squares marked A and B are the same shade of gray, yet they appear different (*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.

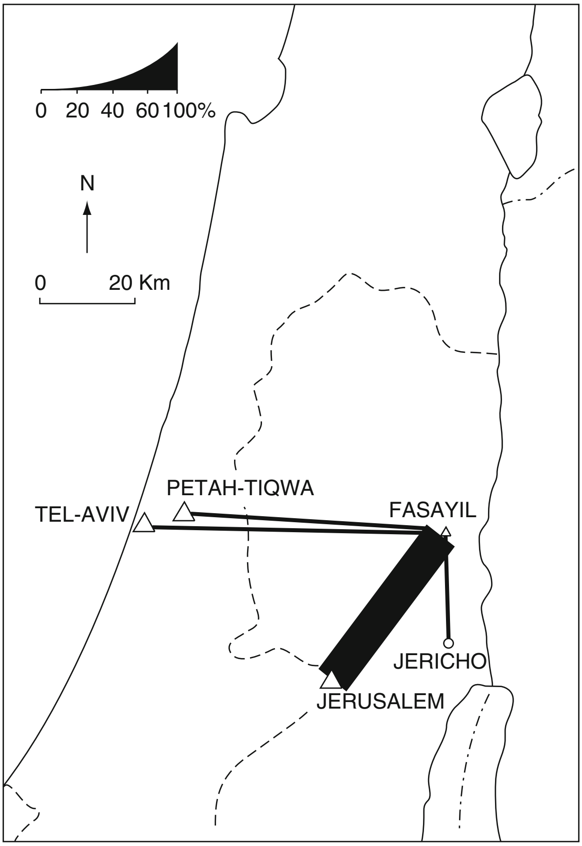


Fig. 6.10 Situated distortion. In an experiment conducted by Portugali (1993) inhabitants in the settlement Fazael were asked to indicate the nearest city to their own settlement. Most respondents indicated Jerusalem, while from the map it can be seen that it is, in fact, Jericho. Unlike the above distortion 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

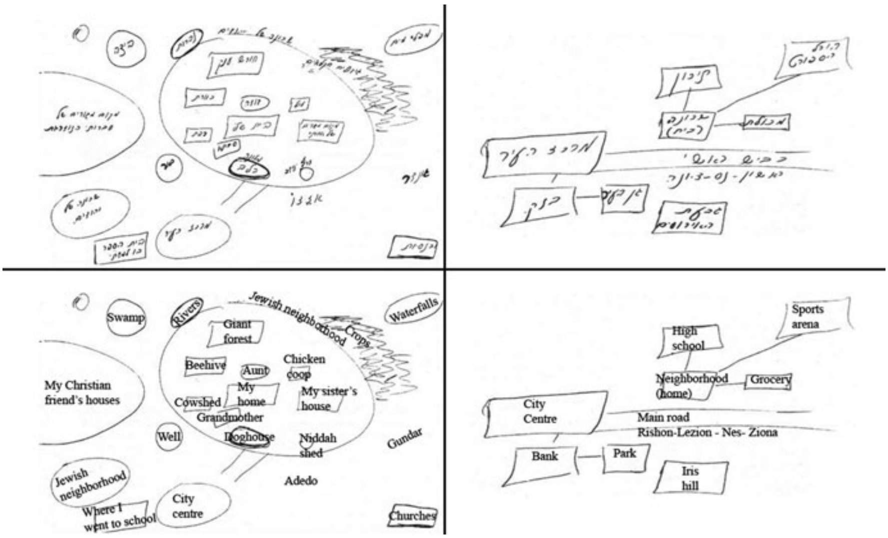


Fig. 6.12 ABCities drawn by an Ethiopian Jew living in Israel. *Top* (*left* and *right*): The original drawings with their Hebrew text; *bottom* (*left* and *right*): the same drawings with their text translated to English. The differences are dramatic: the drawing of the home left in Ethiopia is full 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

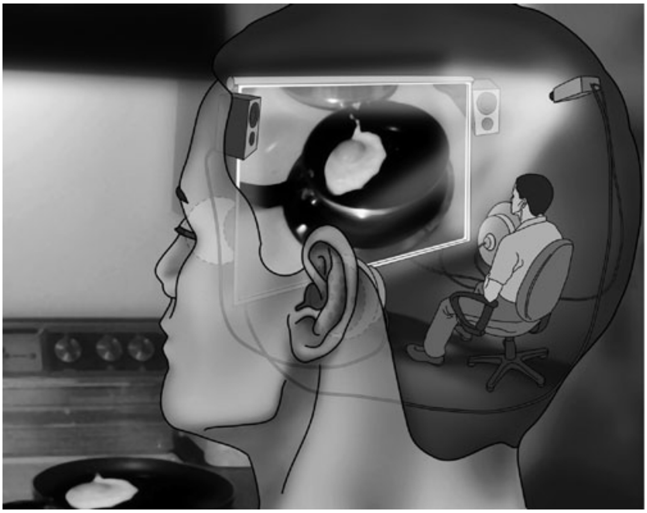


Fig. 6.13 The paradox of the homunculus (Latin for 'little man'). Poper and Eccles (ibid) portrey the entity *Self* as a kind of programmer (i.e. homunculus) on the hardware (computer) of the brain. But who/where is the homunuclus of the programmer's mind/brain and the homunuculus of the homunuculus's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

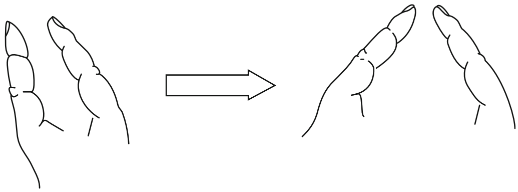


Fig. 6.14 Kelso's finger movement experiment. While initially people can move their index fingers in parallel, beyond a critical speed of the finger movements the relative position of the fingers switches involuntarily to the antiparallel, i.e., symmetric, position

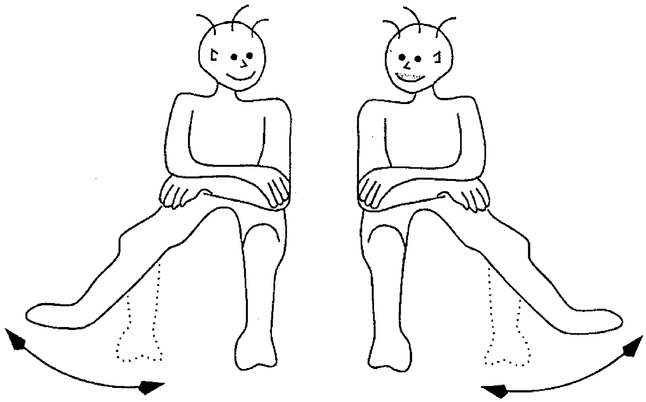


Fig. 6.15 The Schmidt, Carello, and Turvey (1990) leg movement experiment with results identical to the above Kelso's experiment

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

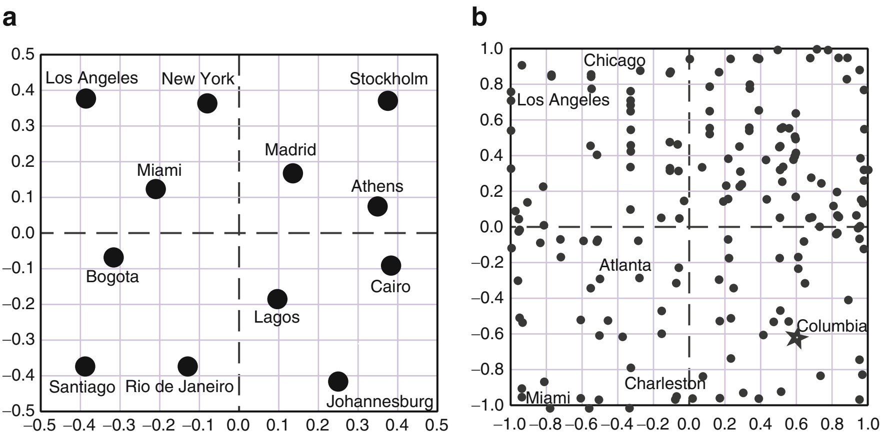


Fig. 6.16 Lloyd's (2000, Figs. 3 and 7) SOCM. Plots of the location of 12 world cities (*left*) and 232 US cities (*right*) simulated by the Kohonen neural network. In both cases the SOCM are systematically distorted

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.

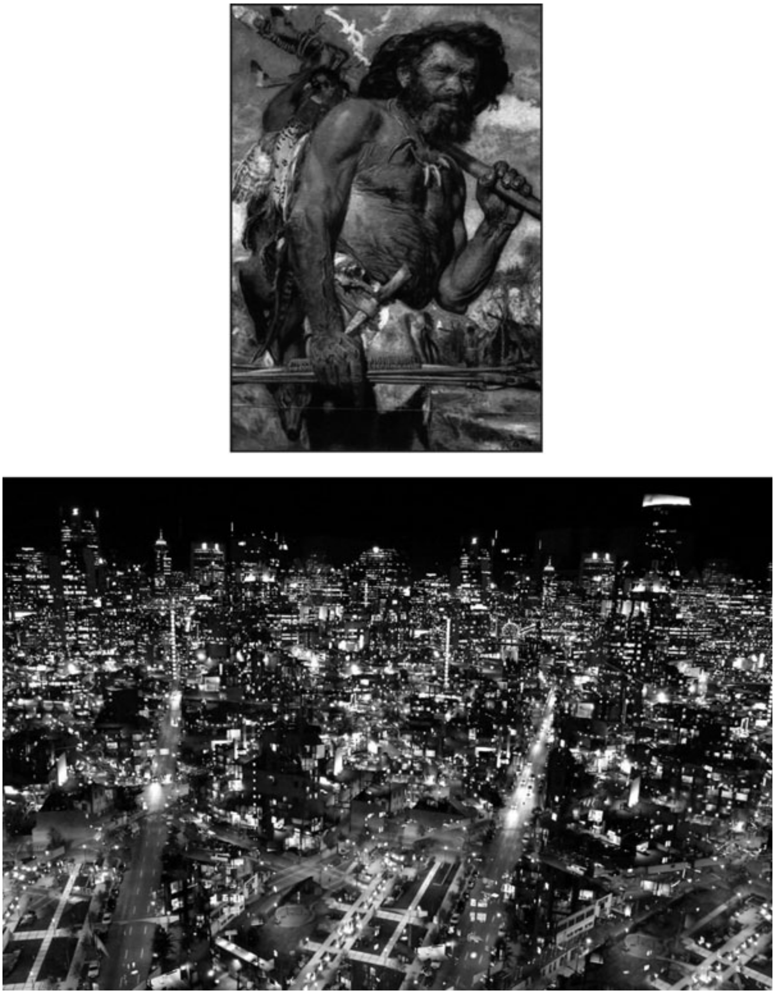


Fig. 6.18 The artifact city has an immediate effect on the human urban agent

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.

Chapter 7
SIRN – Synergetic Inter-Representation Networks

7.1 Introduction

SIRN (synergetic inter-representation networks) was originally developed by Haken and myself as an approach to cognition and cognitive mapping that integrates two notions: *IRN (inter-representation network)* and *synergetics*. We have elaborated SIRN is two steps. In the first step we have elaborated a general SIRN theory and model; in the second step we have derived from the general model three submodels that refer to the way the interacting network of internal and external representations is related to the cognition and (spatial) behavior of, firstly, a single person (the intra-personal submodel), secondly, several persons acting sequentially (the inter-personal submodel) and finally, many persons acting simultaneously (the interpersonal with a common reservoir submodel). As we shall see below in some detail, the canonical case study for the latter submodel is the *city game* with the implication that SIRN is, in fact, a cognitive theory of urban dynamics.

The discussion below starts with a short and preliminary introduction to IRN and SIRN (Sect. 7.2). It then deals with the seven basic propositions of SIRN (Sect. 7.3). Next, the SIRN general model and its three submodels (Sect. 7.3) are presented and finally, the chapter concludes with notes that indicate the way SIRN will be further elaborated in subsequent chapters.

7.2 IRN and SIRN: A Preliminary Introduction

According to IRN (Portugali 1996), the cognitive system in general, and the one associated with cognitive maps in particular, extend beyond the individual's mind/brain into the external environment. This is so in the sense that the cognitive system is a network composed of internal and external representations. Internal representations refer to entities constructed by the brain that represent information of the external environment, while external representations to entities constructed by means of humans' mimetic, linguistic and artifact-making capabilities that represent

J. Portugali, *Complexity, Cognition and the City*, Understanding Complex Systems, DOI 10.1007/978-3-642-19451-1_7,

information generated by the mind/brain. External representations are, therefore, the product of the ability of humans to externally represent ideas, emotions, and thoughts.

The IRN view of cognition was inspired, on the one hand, by Bohm's (1980) theory of order, in particular by his notions of *implicate*- and *explicate-order*, on the other, by Haken's (1983a, b, 1987) synergetics approach to self-organization. It was originally developed, however, in the context of Portugali's (1993) *Implicate Relations: Society and Space in the Israeli-Palestinian Conflict*. The notion of 'implicate relation' that provides the theoretical framework of this study, illustrates how Bohm's and Haken's theories supplement each other, both with respect to society – the focus of the above study, and to cognition – the focus of the present chapter.

Synergetics adds to the notion of IRN the view that the brain/mind, cognition, cognitive mapping, and the interaction between internal and external representations, are all complex self-organizing systems that evolve in line with the principles of synergetics. SIRN is thus a model and a theory that casts IRN into the formalism of synergetics (Haken and Portugali 1996).

7.2.1 From IRN to SIRN

IRN commences with a distinction between what I suggest here to call cognitively *simple*, *complicated* and *complex* tasks. *Cognitively simple tasks* are tasks that can be performed by working memory (e.g., $2 \times 3 = 6$) while *cognitively complicated tasks* (e.g., $257 \times 389 = 99{,}973$) are tasks that cannot be performed by working memory due to the "magic number seven plus minus two" that constraints our ability to process information in working memory (Miller 1956). This constraint of humans' working memory was demonstrated by Miller (ibid) in a seminal paper that explored "some limits on our capacity for processing information" in short-term memory. As I further show below (Chap. 8), one way to overcome this limitation is by means of IRN: We first externalize the task (write it down on paper); then we solve part of it internally ($8 \times 7 = 63$); externalize it again and repeat this in a sequence until the task is completed.

Cognitively complex tasks refer to *creative* cognitive tasks, when a person writes, paints, designs etc. Such a task often starts with a vague idea in mind that the person then externalizes by writing it down or by painting ... Here too the process proceeds by interplay between internal and external representations, but with one important addition – *it involves emerging properties*. It is here where synergetics (and complexity in general) comes in and the process becomes SIRN. More specifically, the process might start with a preliminary internal idea (or external cue that entails an internal idea) that the person then externalizes. After a few internal-external iterations, an order parameter (in the sense of synergetics) emerges and enslaves subsequent iterations.

7.2.2 SIRN's List of Basic Propositions

SIRN suggests perceiving the cognitive system as a network composed of individual *and* collective cognitive elements. These elements are termed *representations*. They may be ad hoc products of neural activities in the brain, but also products of bodily activities in the environment. In the first case they are termed *internal representations*, in the second, *external representations*. A key feature of SIRN is that the various representations form a system and a network – an *Inter-Representation Network (IRN)*. Another element is that the parts of that system – its internal and external representations – do not pre-exist as atomistic entities. Rather, they are ad-hoc entities that emerge out of the dynamics. Cognition, therefore, is not a manipulation of stored internal representations, as implied by the computer metaphor of classical cognitivism, but a dynamic process that gives rise to various representations that, by means of their interaction, give rise to a task-specific/context-dependent cognitive system. In some tasks and situations the emergent system is composed of internal representations, in others of internal *and* external representations. In some tasks and situations the latter might be mimetic or lexical behaviors, in others stand-alone artifacts. These task-specific/context-dependent systems attain order, become relatively autonomous, and as such interact with other systems and with the environment. All this happens spontaneously by means of self-organization.

SIRN can be said to integrate the psychological and geographical traditions of cognitive mapping studies, with their urban-architectural tradition. As we've seen in the previous chapter, the psychological and geographical traditions, in line with mainstream cognitive sciences, were interested mainly in the way the mind/brain processes information. The urban-architectural tradition, on the other hand, was interested mainly in the properties of the external environment that make it "legible" (Lynch 1960 and Chap. 6 above). The basic assumption in the latter tradition is that there is something in the form of buildings, streets, squares, cities, parks, and landscapes, that make them better/worse perceived, cognized, remembered, navigated, identified.

Since its first introduction in 1996 the notion of SIRN was further developed and applied to new research domains. On the basis of this new theoretical and empirical material it is now possible to describe SIRN by means of seven basic propositions. They are the following:

> *Humans have an innate capability for representation that comes in two forms: internal and external (1). This shows up in many cognitive tasks that evolve as a sequential interaction between internal and external representations (2). Representations enfold, and convey quantitative (Shannonian) and qualitative (semantic) information (3), and they coexist in implicate and explicate relations (4), in a way reminiscent of the relations between genotype and phenotype (5). From propositions 1–5 follows that the boundaries of the cognitive system should be perceived as distinct from the boundaries of the brain/skull and the body/skin (6). The above network of internal and external representations emerges as a self-organizing system. Its dynamics is best captured by Haken's synergetic approach to self-organization (7).* In what follows I will elaborate each proposition in turn.

7.3 SIRN's Basic Propositions

7.3.1 Innate Capability for Representation

Proposition ***ONE***. *Humans have an innate capability for representation that comes in two forms: external and internal.*

This proposition is illustrated in Fig. 7.1. Internal representations are the outcome of brain processes the end-product of which is various forms of information – visual, olfactory, haptic, lingual, etc., combinations thereof, as well as emotions, intentions and the like – that are enfolded (i.e. represented) in the matter of the brain. External representations refer to behavior or actions that represent internal representations. External representations can be further divided into *bodily* and *artifactual* representations. Bodily representations are representations made by the body and never extend beyond it, such as mimetic or lexical representations. Artifactual representations are made by the body, but extend beyond it to become stand-alone artifacts.

The notion of internal representation as utilized here is close to what Varela et al. (1994) have termed "weak representation" – in contrast to "strong representation" that typifies classical cognitivism. According to this view, the brain generates patterns or internal representations in the form of images, cognitive maps and the like. However, such patterns "are not stored in any static way, neither with respect to geographical areas, nor with respect to mode of representation. They are dynamically created anew, each time, as ad hoc entities: The brain is capable of creating a multiplicity of cognitive maps with specific perspectives, scales and modes, by means of learned synaptic connection strengths that govern the cooperation between the neurons" (Portugali 1996b, p 16). Internal cognitive processes thus involve an interaction between symbolic internal representations, but not as static, fixed, stored, internal representations, as implied by the computer metaphor to cognition. The same holds true for bodily external representations. They are also ad hoc entities, created each time anew, when we mimetically or lexically externalize some of our emotions, ideas and other internal representations. The case is different, however, with artifactual external representations. They *do* enfold information or store symbols in static ways. Tools, texts and cities are typical examples in this context.

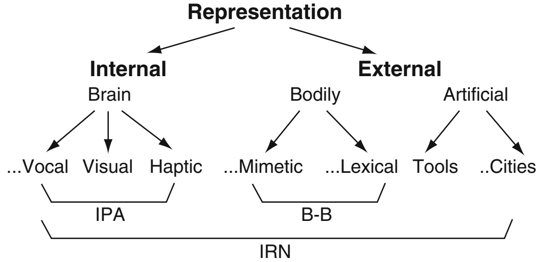


Fig. 7.1 Humans' representation capabilities

7.3.2 *The Interaction Between Internal and External Representations*

Proposition *TWO*. *Many cognitive processes, cognitive mapping included, evolve as an interaction between internal and external representations.*

I will illustrate this proposition by reference to several experiments that can be regarded as paradigm case studies for the operation of SIRN. Before we get to the first case study imagine for a moment a spider building its web (Fig. 7.2). At the start it constructs a small net and is consequently moving in a small area. As the net gets larger the spider is able to move in a larger phenotypical environment (see definition below in proposition 5). Note that the spider is constructing the space on which it is subsequently moving, that the process is sequential and that the structure of the net determines the routes on which the spider can move.

7.3.2.1 Exploratory Behavior

The first paradigm case study starts with a rat placed in a circular arena of 6.5 meters in diameter. This is an experimental setup within which ethologists study the *exploratory behavior* of rats (Golani et al. 1993, 1997, 1999). Exploratory behavior is an interesting phenomenon by which animals introduced to a novel environment have an innate tendency to explore this environment before they turn to habituated activities (On exploration and habituation see Kuba et al. 2006). Put into an arena with a home base, a rat in normal conditions (not induced by hunger, food or drug) typically performs a highly structured behavior consisting of two qualitatively distinct forms of movement: *forward*, and *backward*. Starting from the home base, the rat moves forward relatively slowly, making frequent (5–14) stops along the way. Then, beyond a certain threshold stop it begins the backward movement that is fast and with no

Fig. 7.2 The spider is constructing the web on which it is subsequently moving

stops. In the next excursion the rat moves fast through the previously explored 'familiar' area, all the way to its final stop, from which it starts the exploratory forward movement, as before, and then the backward movement. This time, however, on its fast movement to the home base, it "takes a rest" in some of the previously determined stops. This exploratory behavior continues until the whole area is explored and full with stops, or 'bases', that can be differentiated according to their "size", measured by the duration the rat stayed in them (Fig. 7.3).

Like the spider, the rat too is constructing a material external environment – a network of bases that once constructed determines the pattern of its subsequent exploratory behavior. Here, however, we have ground to say that the rat constructs material bases in the external environment (e.g., by means of smell) and internal representations of them, i.e., a cognitive map, in its brain. As can be seen, the process is sequential, evolving as a play between internal and external representations: the rat constructs a few stops/bases in part of the environment, by so doing it also memorizes them; in the next excursion it makes use of these bases and so on. This SIRN interplay between internal and external representations implies *a new meaning to the notion of cognitive map*: the rat is actively constructing it. It not only passively perceives landmarks that exist out there in the environment, but it practically makes the landmarks – the rat is *landmarking* the external environment as well as its own mind/brain.

Now imagine a person coming to a new city. S/he too will perform a sequential exploratory behavior by means of a play between internal and external representations, but in a different "experimental set up". Unlike Golani's empty arena, the city is full of information. The challenge to the person's cognitive system would be to *select* proper elements in the environment (nodes, landmarks, edges and such) and to memorize them. According to SIRN the act of selecting a landmark, for example, is analogous to the rat's act of constructing a stop/base. In both cases the process is active and implies that the person is actively constructing a cognitive map by actively *landmarking*, *edging*, *pathing* … the city and his/her mind/brain.

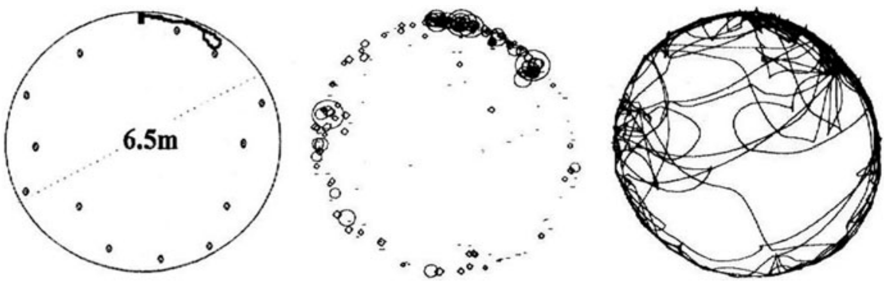


Fig. 7.3 Golani's et al. (1997, 1999) experiments with rat's exploratory behavior. *Left*: Line tracing the rat's forward and backward movements in the first exploratory excursion. *Right*: Line tracing the rat's movement in all progressing episodes. *Center:* The rat's constructed space (arena): stopping locations (bases) with dwell time represented by circles' size

7.3.2.2 Bartlett's Scenarios of Serial Reproduction

For the second paradigm case follow Fig. 7.4, which is one of Bartlett's (1932/ 1961) *scenarios of serial reproduction* devised by him in his study on *Remembering*. A typical Bartlett scenario evolves like this: a test person is given a text or shown a figure and is asked to memorize it. He or she is then asked to externally reproduce it out of memory, by rewriting the text or re-drawing the figure. This externally represented text or figure is given to another test person and so on (see Chap. 13 below for a textual example of Bartlett's serial reproduction). The usual result of such scenarios is that after several strong fluctuations in the reproduction, the text or the figure stabilize and do not change much from iteration to iteration. Bartlett reports that the same happens when the experiments are carried out with a single person. Similar experimental results were obtained by Stadler and Kruse (1990) as part of their attempt to develop a neo-Gestaltian view of cognition in the context of Haken's synergetics.

Bartlett developed the method of serial reproduction as a means to externalize and expose the otherwise internal processes and representations. From the point of view of SIRN, the interpretation is that the process exemplifies an emergent, task-specific, cognitive network of internal and external representations, and a sequential interplay between them (Portugali 1996b; Haken and Portugali 1996). The latter networks and system that has emerged as a synergetic, self-organized cognitive process, is typical of creative work, art and artifacts making. Two nice illustrations here are Picasso's Guernica (Fig. 7.5) and Barancusi's Kiss (Fig. 7.6). Both artworks evolved as typical processes of serial reproduction. However, they differ in the time scale – the Kiss evolved slowly from 1907 to 1937, while the Guernica in a short time during the year 1937, after the town Guernica was bombed (Arnheim 1973). What is specifically interesting in Brancusi's Kiss is that its final reproduction (The Gate of Kiss) was imbedded in the cityscape of Bucharest, thus illustrating how a very personal SIRN process 'goes public'. This brings us to the next case.

7.3.2.3 City Games

The third paradigm case study suggests that the above SIRN processes participate also in the emergence of large-scale collective artifacts such as cities. To illustrate and study such processes Portugali (1996b) devised a set of experiments – *city games* – that can be viewed as a new type of Bartlett scenarios. Their essence is a process of sequential reproduction that is interpersonal, collective, and in addition *public* – the participants observe the game as it develops. Each player in the game is given a 1:100 mockup of a building, and in his/her turn is asked to locate it in the virtual city on the floor. In a typical game (Fig. 7.7), the players observe the city as it develops, and in the process also learn the spontaneously emerging order on the ground. After several initial iterations a certain urban order emerges. The participants internalize this emerging order and tend to locate their buildings in line with it. Such an

Fig. 7.4 A Bartlett's (ibid, p 80–81) scenario of serial reproduction: an Egyptian 'Mulak' (owl) transformed into a cat

Fig. 7.5 An intrapersonal SIRN process in painting. Guernica by Picasso

experiment includes all the ingredients of the SIRN process: a sequential interplay between internal and external representations, the emergence of a collective complex city as an artifact, and a typical synergetic process of self-organization as demonstrated below. [For an application of the city game to urban planning and design see Portugali and Alfasi (2008), Tan and Portugali (2011) and Chap. 13 below]

Having discussed the above interplay between internal and external representations the next question is 'what are representations?' Propositions three to five refer to this question.

7.3.3 Shannonian and Semantic Information

Proposition ***THREE.*** *Representations are entities that enfold, convey and can thus be cognized in terms of two forms of information: Shannonian and semantic.* I'll refer to these two forms of information in some detail in Chaps. 8 and below. Here it is sufficient to say the following: Shannonian information is information as defined by Shannon's theory of information (Shannon and Weaver 1959/1963). That is, a quantity (usually measured in *bits*) that indicates the information capacity of a communication channel, irrespective of the quality or meaning of that information. It is "information with meaning exorcised" (Haken 1988/2000). Subsequent studies have shown that the notion 'communication channel' might refer not only to literal channels

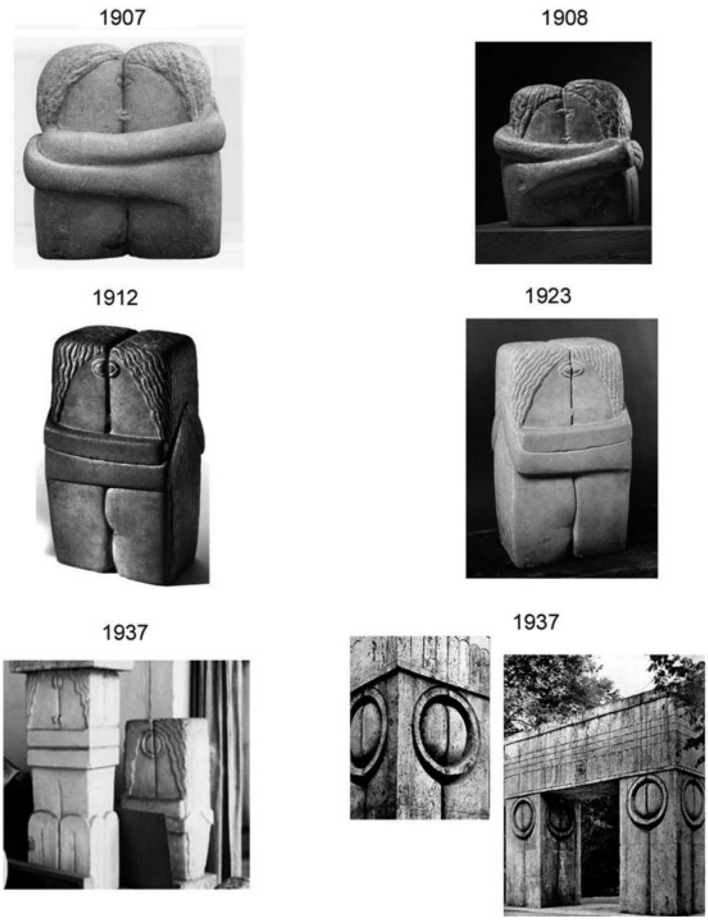


Fig. 7.6 An intrapersonal SIRN process in sculpturing. 'The Kiss' by Brancusi: from a figurative kiss in 1907, to the geometrical/abstract 'Gate of the Kiss' in 1937

(i.e. telephone), but also to humans' short-term memory (Miller 1956), Gestalt shapes (Attneave 1959) and even urban forms such as buildings, streets or whole cities (Krampen 1979; Haken and Portugali 2003). Semantic information, on the other hand, refers to the *meaning* conveyed by a representation as perceived by a specific receiver. The process of pattern recognition, of a face or a cityscape, is a typical example here: one sees a shape (a face, a prominent landmark) as well as the meaning it conveys (a certain person in a good mood, the tower of a holy Gothic cathedral, etc.).

Semantic information can further be divided into *innate semantic information* and *experiential semantic information*. *Innate semantic information* refers to the properties of representations as perceived by animals and humans by virtue of their innate cognitive capabilities. A tower at the center of a flat monotonous city, for example, will be cognized as a landmark by every human individual because of its

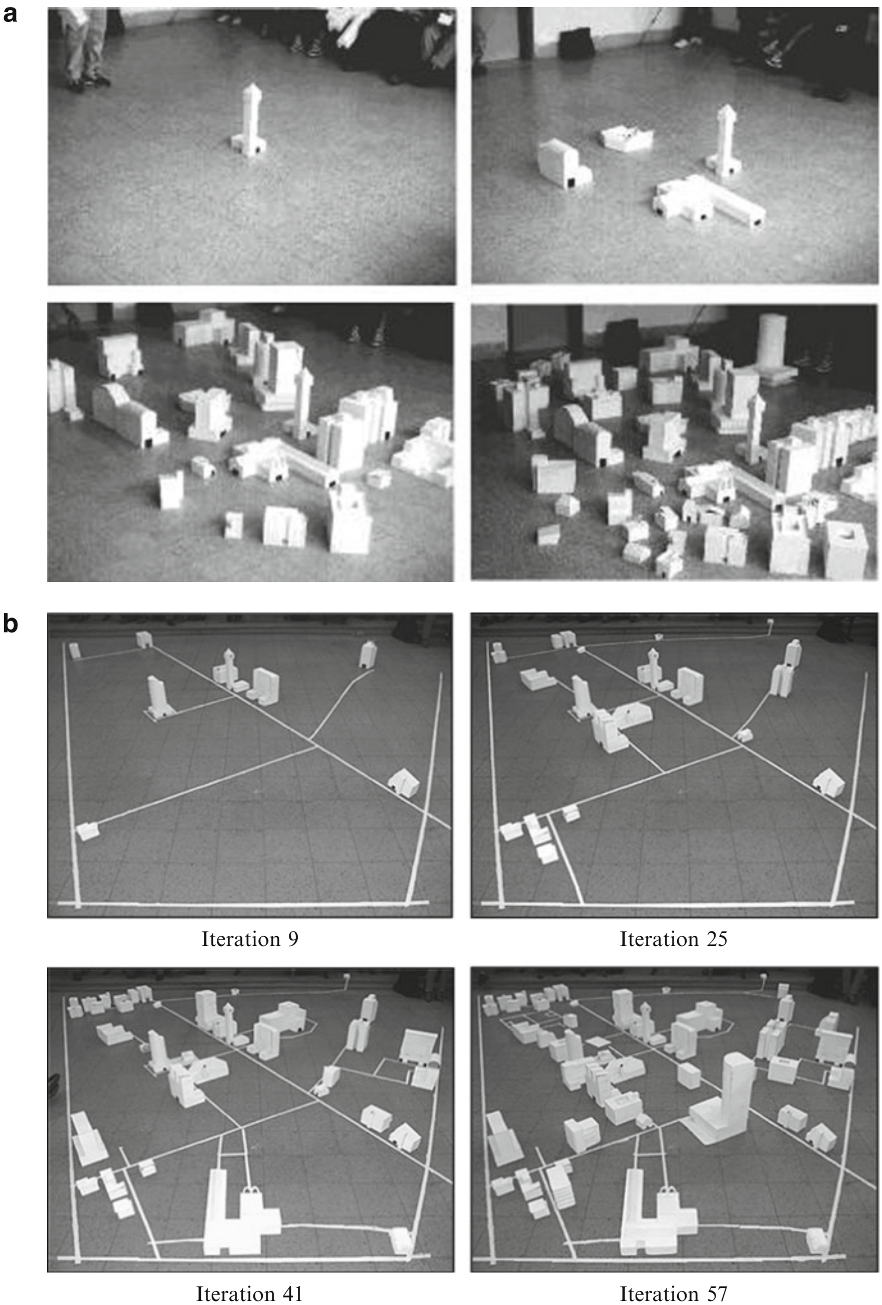


Fig. 7.7 Four snapshots from two city games. **a**: A regular city game (at iterations 1, 15, 35, 57). **b**: A city game with an additional rule that 'each building must be connected to the city's road network'. That is, a player can locate a new building either along an existing road, or else s/he must add an access road to the new building

geometry alone. This kind of information is related to Gibson's (1979a,b) ecological approach and his notion of *affordance*. It suggests that objects afford information by virtue of the specific relations that emerge from the interaction between their physical properties and the psychophysical properties of the perceiver. Such information applies to every individual.

Experiential semantic information, on the other hand, refers to the meaning of representations as perceived by humans by virtue of their subjective personal and cultural (inter-subjective) experience. The above-noted tower at the center of a flat monotonous city can again serve as an example. Here, however, due to its shape and its steal and glass structure, the tower indeed represents a landmark, but also technological sophistication, economic power, and so on. The tower thus enfolds culturally specific *meaning*. I suggest interpreting Lynch's (1960) notion of *legibility* as the experiential-cultural counterpart of Gibson's (1979a, b) affordance: some parts of a city afford landmarks to all, but others, like a text, are legible to those who have learned its language.

On the face of it, Shannonian information is the very opposite of semantic information. This is not exactly so, however. In Chaps. 8–9 that follow it is shown, first, that beyond the differences just mentioned, the relations between Shannon and semantic information are rather complementary. Second, that looking at urban external representations it is possible to use Shannonian bits as a measure of the quantity of information conveyed by the city as a whole and by elements in it (buildings, roads, etc.). Third, that this possibility is preconditioned by the existence of semantic information. That is, given a certain categorization of the city (i.e. its specific semantic structure), the Shannonian information content of each specific urban element can be determined. As shown next, the above view on information comes close to David Bohm's notion of *active information* that is implied from his theory of *implicate order*.

7.3.4 Implicate and Explicate Relations

Proposition *FOUR*. *Internal and external representations coexist in implicate and explicate relations.*

The notion of *implicate order* is the central concept in David Bohm's (1980) philosophy of order and his ontological interpretation of quantum theory (Bohm and Hiley 1993). It suggests a new notion of order in which everything – an entity or a configuration of entities – is enfolded into everything else. This implicate order gives rise to an *explicate order* in which entities are independent of each other and their environment – as we experience objects in the environment. As an analogy to the implicate order Bohm suggested the holographic record. In the latter, one can observe a picture composed of various entities, and yet every point and entity in that picture enfolds all other entities and the whole configuration. This shows up in the fact that if you cut the picture into pieces, you'll still see in each piece the whole picture once again. In the holographic record we thus have two forms of order: the *implicate order*, which describes the above subtle property of *enfoldment*, and the *explicate order* that corresponds to the various entities as we see them in the picture. It looks as if every entity in the picture is fully independent, but we know, and can prove by cutting the picture, that this explicate order is in fact a thought abstracted from the implicate order.

The notion of implicate order corresponds to what Bohm has defined as *active information* (Bohm and Hiley 1993), whereas his explicate order to information as conventionally used (e.g., by Shannon). The implicate-active information is a potential; the explicate-Shannonian information, is its realization in a specific way. Thus a building, a map, or a whole city, are external representations by virtue of the active information they enfold. This potential information is being actualized/realized in specific ways by different individuals depending on their memory content, energy and the task and context within which this specific actualization takes place. The environment and entities in it are thus 'full of information' and can activate "a whole range of potential activities". What aspect of that potential information will practically be actualised depends on the memory and mental energy of the perceiver. – Note the similarity to Haken's (1988/2000) notion of *semantic information* (see definition in Chaps. 8–9 below).

From the perspective of Bohm's implicate order, mind and environment – or in the context of the present book, mind and city – are seen as two entities existing one inside the other or enfolding each other in implicate relations. In terms of cognitive maps this implies, first, that the environment/city is enfolded in the mind in the form of active information that when actualized gives rise to a specific ad-hoc internal representation, that is, to a cognitive map. Second, that the minds of individuals are enfolded in the environment/city in the form of a multiplicity of external representations that create the environment's/city's active information that can be actualized in a specific way. Mind and environment/city are thus only relatively independent – they form a single interactive network with implicate and explicate properties.

7.3.5 Similarity to Genotype–Phenotype Relations

Proposition *FIVE*. *Internal and external representations interact in a way reminiscent of the relations between genotype and phenotype.*

This proposition refers to Dawkins' (1976, 1982) and Dennett's (1991, 1995) "gene-eye-view" on nature and evolution. According to this view genes are the only biological entities that always replicate themselves and as such are genuinely "selfish". Consequently, they and not whole animals, which are occasionally altruistic, stand at the core of Darwinian evolution. Genes, according to this view, do not interact directly with each other, but indirectly through their phenotypes. In his book – *The Extended Phenotype* – Dawkins (1982) suggests that the notion phenotype should include, in addition to the immediate bodily properties of animals, also some of their products such as the bird's nest, the beaver's dam, the spider's web and the like. Note that Golani et al. (1999) define the behavior of "their" rat (our first paradigmatic case study in Proposition two) as performing "Phenotypic stereotypic behavior". To this I would add that the products of this behavior – the stops/bases of various sizes – can be regarded as 'extended phenotypic effects'.

The similarity suggested here is, first, between genes, the DNA molecules, as internal representations of biological information, and brain material entities and activities that internally construct and represent ideas, images, entities and artifacts of the world. Second, between "ordinary" phenotypes as external representations of genetic information, on the one hand, and mimetic, lexical behaviors and so on, as external bodily representations, on the other; third, between extended phenotypes and artifactual external representations. In Chap. 11 of his *Selfish Gene*, Dawkins (1976) speculates with the idea that the various cultural entities that are internally represented in the brain form a new kind of replicators – *memes* – that, analogously to genes in biological evolution, stand at the core of cultural evolution. The memes have only recently appeared on the stage of the world, as a byproduct of biological evolution, but, writes Dawkins, they are already moving fast with their own independent cultural evolutionary process.

The idea of memes as selfish replicators and cultural entities as their "phenotypic" effects, sheds an interesting light on the dynamics of internally represented ideas and entities: Like genes, memes (that is to say, ideas) interact indirectly via their external representations. And, the external environment – the world of external representations – "selects" the internally represented, and often produced, memes, or ideas. This analogy should not be taken too far, however. Memes are not genes. They are not innate nor are they associated with a specific material entity such as DNA molecules. Rather, they are products of a complex interaction between internal brain, and external bodily, activities. As such, unlike genes, they quite often represent objects, categories and other entities and external representations that exist in the world. Furthermore, the relations between genes and their phenotypes are asymmetric: genotypes give rise to externally represented phenotypic effects, but the latter cannot be transformed back into genotypes. Memes and their externally represented phenotypic effects, per contra, co-exist in symmetric relations: an idea about a circle can generate a circle in the world and visa versa.

7.3.6 The Boundaries of the Cognitive

Proposition ***SIX***. *The boundaries of the cognitive system should be perceived as distinct from the boundaries of the brain (the skull) and the body (skin).*

This is the logical conclusion of propositions one to five. More specifically, in cases of external bodily representations the boundaries of the cognitive system extend beyond the brain/skull and include the whole body, whereas in cases of artifactual external representations they extend beyond the whole body and include stand-alone artifacts in the environment (Fig. 7.1, *bottom*). The issue of the boundaries of the cognitive system touches upon the behaviorism-cognitivism historical controversy, Vygotsky's (1978) notion of *mediated activities*, the status of artifacts in cognitive science, Miller's (1956) *magic number seven* and Donald's (1991) notion of *the externalization of memory*.

Behaviorism suggested (Chap. 6 above) understanding cognitive phenomena in terms of the relations between stimuli and responses in the external environment (Fig. 6.1a above). That is, in terms of external representations only, with the mind/brain considered as a black box (B-B). Cognitivism suggests the exact opposite: cognitive phenomena must be understood in terms of internal processes and representations, treating stimulus-response relations as means to reveal processes inside the mind/brain (Fig. 6.1b). Comparing these two figures one can see that beyond the differences the two approaches share a common view (Portugali 1996b, p 11–12): In both the mind/brain with its internal representations, and the environment with its external representations, are perceived as two essentially independent and causally related, entities. SIRN suggests perceiving the boundaries of the cognitive system as in Fig. 6.1c, that is, to treat the behaviorist and cognitivist perceptions as two aspects of a single, integrated, inter-representational network. Note that unlike behaviorism that considered bodily external representations only, the SIRN system proposed here includes also artifactual representations (*bottom* part of Fig. 7.1).

7.3.6.1 Vygotsky

The suggestion to include artifacts within the boundaries of the cognitive goes back to Vygotsky (1978). According to him, *signs*, *tools*, activities, or artifacts, as Cole (1998) prefers to call them, are all integral elements of the cognitive system by virtue of their role as *mediators* in higher psychological processes. A case in point is multiplication aided by a pencil and paper on which, as suggested above, one can externalize (i.e. write down) the numbers to remember. Rumelhart et al. (1986) suggest that the latter example, of the mediating numbers on the paper, is a special case of mediating activities in general, in which "the external environment becomes a key extension to our mind".

This Vygotskian view concerning the role of artifacts was largely suppressed by the prevalent classical cognitivism and its information processing approach. According to the latter, artifacts are externally represented *outcomes* of the process of cognition; as such they provide means for communication and information transfer between individuals. In essence, however, they are outside the cognitive system itself. Chomsky's distinction between external and internal languages (E- vs. I-languages, respectively) as described below in Chap. 11, is a case in point.

As we'll see in Chap. 11, Chomsky's view is that E-languages (and by implication other external "cognitive artifacts") have no place in the picture of cognition. This view dominated and still dominates the field of cognition (see Pinker 1995). As noted above, however, a growing number of studies and views depart from this sort of hard cognitivism. Rumelhart et al. (ibid) and Cole (ibid) neo-Vygotskian approaches, Edelman's (1992) *Theory of Neural Group Selection*, Johnson's (1978) and Lakoff's (1978) *experiential realism*, Donald's (1991) *externalization of memory*, and the more recent pragmatist *embodied cognition* (Varela et al. 1994) as well as the *action-perception* approaches (Thelen 1995; Thelen and Smith 1994: Kelso 1995; Freeman 1999) among others, all tend to see the cognitive system as including interaction with the environment and/or elements in it. These studies provide a supportive environment to the notion of SIRN (see detailed description in Portugali 1996b). They imply that in certain tasks/contexts cognition is confined to the brain; in others to the whole body and in some tasks/contexts the cognitive system includes the brain, the body and stand-alone artifacts in the environment. In the latter case, artifacts often function as an extension of the body – a view suggested by Gibson (1979a,b) and reproduced in Chap. 6 above as Fig. 6.4. To the latter SIRN adds that, as implied by propositions one to five *the very production of artifacts is often an act of cognition* and that *in such cases artifacts function also as an extension of the mind/brain*. The cognitive rationale for this 'extension of mind' follows from what one might call the Tolman-Miller conjuncture.

7.3.6.2 Tolman-Miller Conjuncture

Like Tolman's (1948) "cognitive maps in rats and men", Miller's (1956) "The magic number seven, plus or minus two: some limits on our capacity for processing information" is regarded as one of the seminal works that mark the emergence of cognitive science. Tolman's 'cognitive map' implies that the mind/brain is capable of constructing internal representations in long- and short-term memory. Miller's 'magic number' adds that there are constraints on this capability in short-term memory. That while many phenomena point to the existence of a short-term memory, they demonstrate further that there is a limit for its capacity to process one-dimensional information. Figure 8.6 in Chap. 8 below illustrates this. In his article Miller discusses several "tricks" by which the mind/brain overcomes this innate limitation. One such 'trick', for example, is hierarchical organization of the stored information – a 'trick' that is responsible for systematic distortion in cognitive maps due to hierarchy (Figs. 6.9–6.11 in Chap 6). Another 'trick' that the mind employs, but that was not on the agenda of the information-processing approach, is the 'trick' of externalization and inter-representation. By a sequential play between internalized and externalized representations, bodily as well as artifactual, one can overcome the limits of the magic number seven on "our capacity for processing information". The capability for internal representation enables a person to construct and process, in the brain, images of the environment and/or objects of it; the capability for external representation, to construct artifacts as external representations of the inner images. Many cognitive tasks, especially those that require a long sequence of steps, depend on this innate property; a city is a prominent example. We, therefore, construct the world and cities in it, partly because we cannot go beyond the magic number seven. External representations are in this respect integral elements of our cognitive system.

7.3.6.3 Donald

For Donald (1991), in his *Origins of the Modern Mind*, the invention of writing, some 5000 years ago, marks the climax of *the externalization of memory* – the third and most recent cognitive transition in the evolution of humans' cognitive capabilities. The transition is from the *episodic mind* of the apes, through the *mimetic mind* of the *Homo erectus* (first transition) and the *lexical mind* of *Homo sapiens* (second transition). The essence of this third cognitive revolution is a distinction between the 'old' *biological memory* that resides in the brain, and the 'new' *external memory* that resides in external stores – notably texts, but also nowadays-modern computerized information systems (Fig. 7.8). External memory, writes Donald (ibid, p 309), does not include artifacts and cities because they "are not cognitive". The notion of SIRN suggests differently: "that artifacts such as stone tools, buildings or cities are cognitive entities by virtue of the property that they enfold information and as such are no less externally represented memories than books or GIS programs" (Portugali 1996b, p 32).

7.3.6.4 Summary

We can summarizes the above proposition and relate it to previous chapters by reference to Fig. 7.9. Classical cognitivism that dominated cognitive science until the mid-1970s assumes a complete separation between brain/mind, on the one hand, and bodily action, on the other. As illustrated in Fig. 7.9 *top*, cognitive processes such as perception are treated as conceptually separate from bodily action. More recently, we see a shift toward the pragmatist embodied cognition approaches, according to

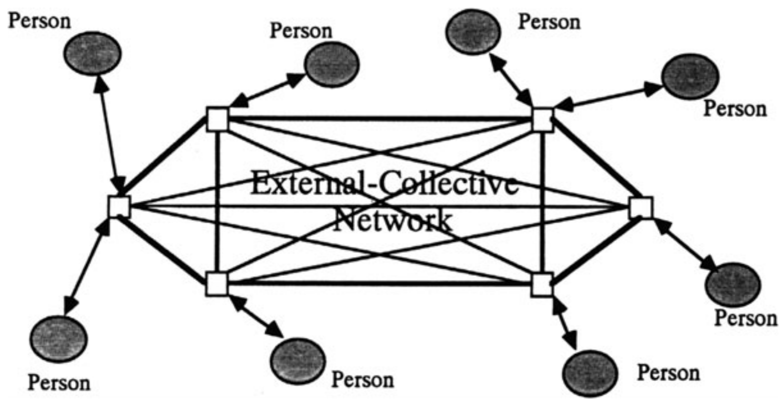


Fig. 7.8 Donald's externalized memory. A network of biological internal memories of individual persons connected to external, nonbiological collective memory (Adapted from Donald 1991, Fig. 8.5)

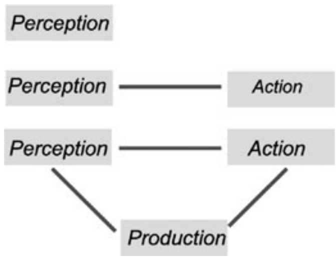


Fig. 7.9 The interrelationships between perception, action and production according to classical cognitivism (*top*), embodied cognition (*center*) and SIRN (*bottom*). In SIRN perception, action, and production form a single cognitive system (Portugali 2004, Fig. 3)

which bodily action is interpreted as being part of the cognitive system. Hence the notion of *Perception–Action* (Fig. 7.9 *center*).

SIRN can be seen as an extension of the action-perception view. It starts from the observation that the new developments that emphasize *embodied* cognition, *action*-perception and task-specificity, imply also the "legitimization" of artifacts. Bodily artifacts such as talking, grabbing, walking etc., are regarded by these approaches as integral elements of the cognitive process itself. Within this context, Gibson (1979b, 40, Fig. 3.1 and above Fig. 6.4) has shown that, in some tasks, stand-alone artifacts such as tools function as an extension to the body. SIRN adds to the latter that in certain tasks and contexts, stand-alone artifacts and the process of their production function not only as an extension to the body, but also as an extension to the mind. In the latter cases, the cognitive process and system includes perception, action and *production* (Fig. 7.9 *bottom*). As will be illustrated below, this interactive perception-action-production process takes place at three scales: *Intrapersonal* that refers to the process as it takes place with a single person, *Interpersonal* that refers to the process as it evolves in a sequential interaction of several individuals, and *Interpersonal* referring to the process as it evolves when several individuals are interacting simultaneously. The latter is also a theory of urban dynamics.

7.3.7 Synergetics

Proposition ***SEVEN***. *The cognitive system is a self-organizing system the dynamics of which is captured by the synergetic approach to self-organization.*

The notion *Self-organization* is a fundamental property of open and complex systems that attain their order spontaneously and are typified by phenomena of nonlinearity, instability, fractal structure and chaos. As we've seen in previous chapters, such systems are *open* in the sense that they exchange matter, energy and information with their environment. They are *complex* in two respects: first, in the sense that their parts are so numerous that there is no technical way to establish causal relations among them; second, their parts and components are interconnected in a nonlinear fashion by a complex network of feedback and feedforward loops. Complexity and self-organization (as we've seen in Chap. 4 above) are, in fact, umbrella terms for several formal theoretical approaches that agree on general principles, but differ in their interpretation of such systems and in the subject matters they study.

As we've further seen above, *Synergetics* – the working together of many parts – is the central property of Haken's theory of complexity. Its second property and methodological guide, is to "look for qualitative changes at macroscopic scales" (Haken 1996, p 39). The theory thus focuses on the working together of many parts in relation to qualitative changes at systems' macroscopic scales. Synergetics was developed by reference to specific case studies that became its basic paradigms: The *laser* paradigm, the *fluid dynamic* paradigm, the *pattern recognition* paradigm, and the *finger-movement* paradigm. The scenario common to all the various cases can be described as follows: A given internal or external *control parameter* that is acting on the system triggers a chaotic movement and interaction between its many parts. This chaotic movement is interpreted as a situation by which several systemic order states compete among themselves. When the control parameter crosses a certain threshold, the hitherto chaotic form of movement and interaction suddenly and spontaneously gives rise to a coherent movement and interaction where all the parts behave in concert. This coherent movement is termed *order parameter*, and the process by which the many parts abruptly "obey" the order parameter and in this way support and reproduce it – the *slaving principle*.

A central effort of Haken and coworkers' research in the last three decades was in the domain of cognition and brain functioning (Haken 1996). The basic proposition in these applications is that the brain and its various cognitive systems are open, complex and, therefore, self-organizing systems and that their dynamics is best described by the principles of synergetics. The paradigmatic case-study here is pattern recognition by means of associative memory: the cognitive system (brain or computer) is given a few features of a certain pattern (i.e. face) referring to one out of a repertoire of patterns which are stored in the brain/computer. This triggers a process of self-organization in which several order-states emerge and enter into a competition. This competition is resolved when a certain order parameter "wins", enslaving the various features by means of associative memory, and a recognition is established.

As we've seen above (Chap. 6), a similar process, though in the reverse direction, takes place with the construction of cognitive maps: The cognitive system constructs an entire pattern/map out of a partial set of features available to it. This is achieved when a certain mapping principle, or 'mapping order parameter', enslaves the various features. Compared to ordinary pattern recognition, cognitive maps' formation concerns very large patterns (e.g., cities). This quantitative difference entails several qualitative implications, among them the central role assigned to external representations and storage in the process of cognitive maps' formation.

With respect to behavior, synergetics suggests seeing brain, cognitive and behavioral processes in terms of open, complex, task-specific/context-dependent systems that achieve their coherence spontaneously, by means of a complex cooperation and interaction between their huge numbers of parts. For example, 'talking', or 'speech production', is a behavior and action that requires the emergence of a task-specific complex system that includes brain neurons, muscles, joints, and a specific synergy between these parts. The interacting elements of that system are, therefore, both internal and external.

To this view SIRN adds, first, that in some tasks the synergy between the many internal and external parts of the system gives rise to internal and external representations; second, that in such cases the process often evolves as an interaction between internal and external representations; third, that in many tasks, such as reading, painting, sculpturing, writing, discourse, carpentry, architectural and urban design, pottery making, navigating and/or shopping in a city, the parts of the task-specific system include, in addition to neurons, muscles and joints, stand-alone artifacts.

7.4 SIRN – The Basic Model and its Three Submodels

7.4.1 The Basic SIRN Model

In a paper from 1996 Haken and Portugali have cast the notion of SIRN into the formalism of synergetics. In this section, I present the graphical part of that study and use it as a means to illustrate 'what SIRN actually does'. That is, how representations become embedded in the external world (i.e. a city) and how they are cognized by human agents.

The derivation of the SIRN model starts with Haken's (1991/2004) 'synergetic computer' as presented in Fig. 7.10. This is a fully parallel computer that represents an alternative to the conventional neural network model in that the elements of its inner layer are order parameters. As can be seen, it is composed of an input layer with model neurons representing the initially given input activity; a middle layer representing the order parameters, and an output layer with neurons representing the final activity of each neuron. The first step is to look at this network from the side, as indicated by the arrow. The result is shown at the *bottom*, *left*. Adding to the latter external inputs and outputs, we arrive at our basic SIRN model (*bottom*, *right*). As can be seen, it has two kinds of inputs, internal and external and two kinds of outputs, again internal and external. The middle node symbolizes the order parameters that emerge out of the dynamic interaction between internal and external representations (Haken and Portugali 1996, Figs. 2–4). The basic SIRN model as derived from Fig. 7.10 is illustrated graphically in Fig. 7.11.

Figure 7.11 can be seen as symbolizing a complex self-organizing active agent that is subject to two flows of information: internal and external. The first is coming from the mind/brain, in the form of ideas, fantasies, dreams, thoughts, and the like, while the second from the 'world' – via the senses, the agent's body and/or artifacts. The interaction between these two flows gives rise to an order parameter that governs the agent's action and behavior, as well as the feedback information flow to the agent's mind. 'Action or behavior' may refer (see Proposition two) to a single individual executing exploratory behavior, reproducing texts or drawings in the

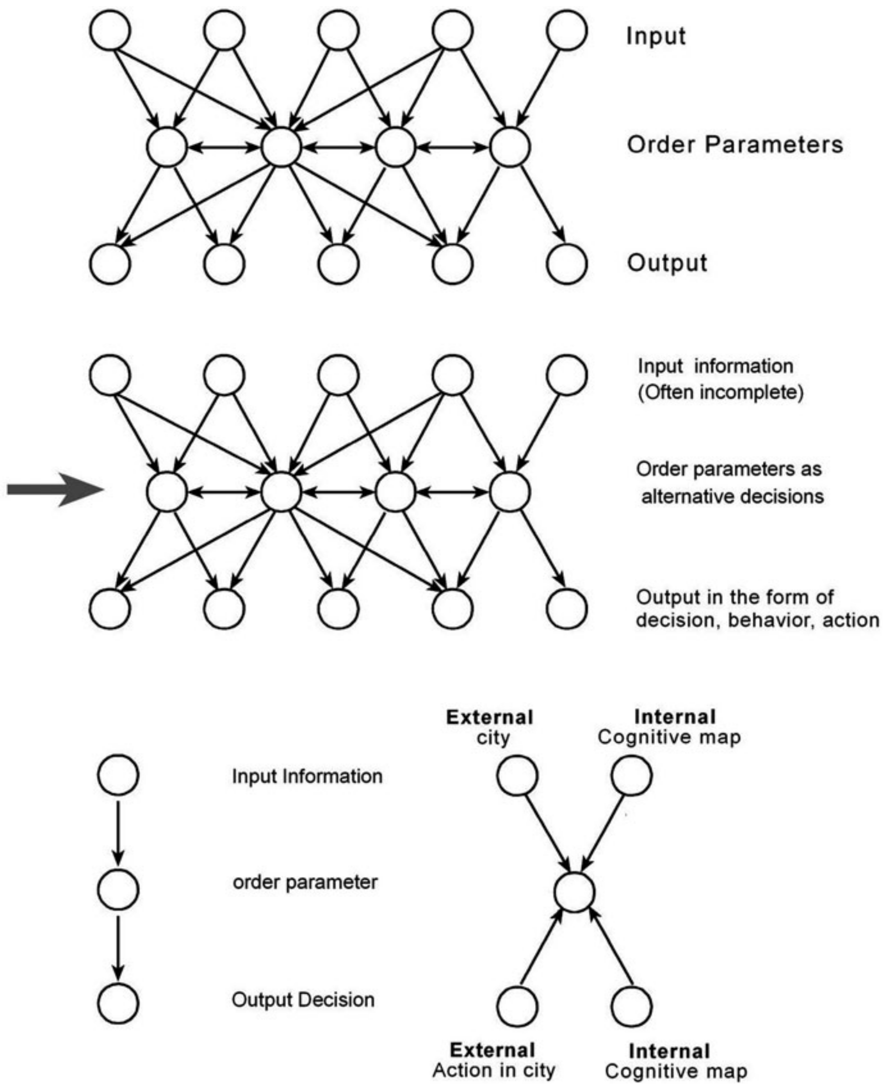


Fig. 7.10 The derivation of the SIRN model. *Top*: Haken's (1991/2004) 'synergetic computer'. *Center*: The first step is to look at this network from the side, as indicated by the *arrow*. The result is shown at *bottom, left*. Adding to the latter external inputs and outputs, we arrive at our basic SIRN model (*bottom, right*)

Bartlett scenarios, as well as to several individuals collectively reproducing large-scale artifacts. In an analogous fashion, the 'feedback information flow' refers to the formation of internal representations, such as images or learned patterns. The order parameters are determined by a competition in line with the synergetics' pattern recognition paradigm noted above. It is important to note that all the steps

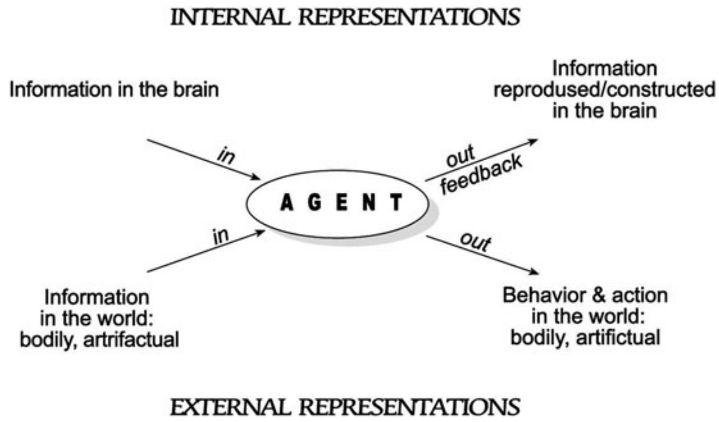


Fig. 7.11 The basic SIRN model symbolizes a self-organizing agent that is subject to two forms of information: internal and external, and is actively constructing two forms of information, again internal and external. Graphically, Fig. 7.11 corresponds to Fig. 7.10 (*bottom, right*) turned 180° on its NW-SE axis

indicated above (and in the submodels below), can and have been, performed by a computer so that the approach is entirely operational.

In order to apply the basic SIRN model to specific case studies, Haken and Portugali (ibid) reformulated it in terms of three prototype submodels corresponding to the three paradigmatic case-studies elaborated in the context of Proposition two (Figs. 7.2–7.7). They are the *intrapersonal*, the *interpersonal collective*, and the *interpersonal with a common reservoir* submodels.

7.4.2 Intrapersonal Subjective Submodel

Apply, first, the above SIRN model to the exploratory behavior of the rat in Fig. 7.3. The animal starts by performing a forward movement the input to which is twofold: internal information coming from the brain (‘drive’, intention, motivation . . .) and external information coming from the environment (shape, size . . .). The interaction between the two gives rise to a highly patterned behavior: *a forward movement* with stable distribution of number of stops (4–15) and a scale-dependent spatial distribution of them – the distance between the stops depends on the size of the arena. The forward movement entails the construction of several stops/bases as an output that re-shapes the environment. Once produced, these stops become externally represented artifacts that enfold information in the world (arena) and they also feedback to the animal’s memory and re-shapes its internal representation (cognitive map) of that world. The latter becomes the external and internal input for the backward movement and to the next excursion that once again re-shapes the externally and internally represented worlds and so on in an iterative process that is graphically described by Fig. 7.12 (*top*).

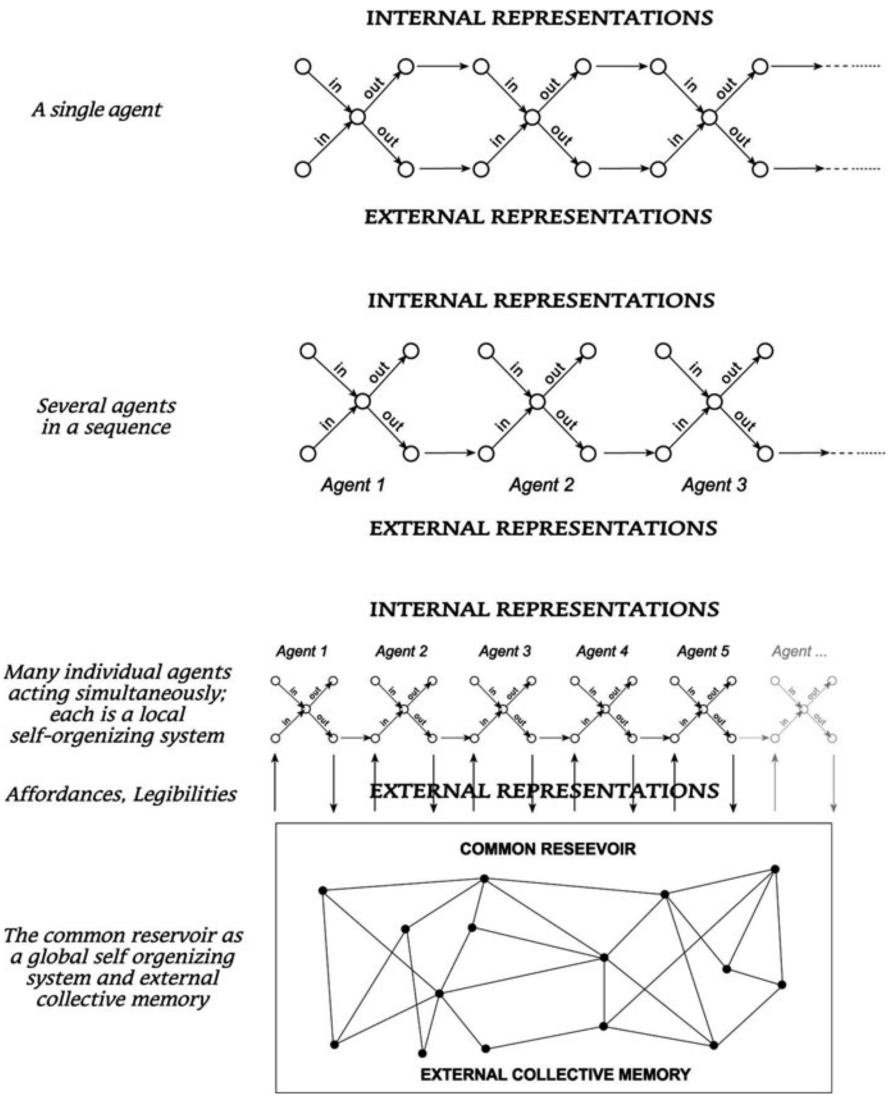


Fig. 7.12 *Top*: The intrapersonal submodel of a single person. (Examples: Figs. 7.2, 7.3, 7.5, 7.6). *Center*: The interpersonal submodel: serial reproduction of several persons. (Example: Fig. 7.4). *Bottom*: The interpersonal with a common reservoir submodel (Examples: Fig. 7.7). Note that in the intrapersonal submodel information is transmitted via external and internal outputs, in the interpersonal via external output only (action and behavior), while in the third submodel information and interaction between the agents are mediated by the common reservoir (e.g., a text, a city, Internet, etc.)

Figure 7.12 (*top*) can also be regarded as a graphical model of the person that comes to a new city and performs an exploratory behavior in order to learn its structure (Proposition two, first paradigmatic case). Starting from a home-base (hotel or apartment...) our human agent moves ‘forward’, *landmarking*, *edging*, *pathing* ... on the way various elements. By doing so s/he subjectively changes, firstly, the external environment – from now onward it will enfold information (Shannonian and semantic); secondly and simultaneously, by means of feedback, also his or her cognitive map of it. These elements will become the input for the next excursion and so on until s/he learns the entire city to some satisfactory level.

As can be seen, according to SIRN a cognitive map is a construction: Tolman assumed his rats to passively absorb an environment out there. According to SIRN, the rats in the above exploratory behavior experiments, actively construct two environments: internal and external. In analogy, the standard Information Processing Approach view on the person who comes to a new city is that s/he passively learns what is out there. According to SIRN s/he constructs anew his or her own subjective and personal cognitive map. In a way this view resembles Chomsky’s view on learning a language, as well as the pragmatist-ecological perception-action approach (Gibson 1979b; Freeman 1999). Chomsky contends that learning a language is an act of creation – the child constructs his or her own language. According to action-perception, animals perceive the environment and objects in it by acting on them. But note the difference: in both Chomsky’s and the ecological approach the outcome is a constructed internal information (termed internal representation, cognitive map or intention). In SIRN the outcome is two information fields: one internal and one external. Each of these information fields is affordable or legible to its creator (the exploratory behaving rat, our human agent as a newcomer...). However, only the externally represented field is affordable or legible to other animals and/or humans.

Figure 7.12 (*top*) models also Bartlett’s serial reproduction experimented with a single person. Such an intrapersonal process of interplay between internal and external representations is typical, in fact, of many sequential thought processes and creative work. Multiplication aided by pencil and paper, developing an idea by means of writing it down, painting, architectural design, sculpturing (Figs. 7.7a-c, above), carpentry and the like, are cases in point.

7.4.3 Interpersonal Collective Process

This is the classical Bartlett scenario, as illustrated above in Fig. 7.5. A typical experiment starts, as we have seen, with a given external input and proceeds with a sequence by which each person’s externalized reproduction of the remembered input becomes an input to the next person to remember and externalize, and so on. As in the intrapersonal case, after several initial steps that exhibit major changes from one reproduction to the other, the story or the drawn figure stabilizes and does not change significantly from iteration to iteration. In the language of synergetics we would assert that a certain order parameter has enslaved the system and brought it to a steady state. This interpersonal process implies that several persons, with their individual-subjective cognitive systems, participate in producing an externalized collective cognitive product, without being aware of their collective enterprise. As this sequential process evolves, and its collective product is constructed, each individual's externally represented reproduction gradually becomes "more" collective and so does each individual's internally represented remembering. The individuals engaged in the process are thus being 'enslaved' by the collective order parameter that emerges in the process. A good illustration for this process comes from Couclelis' (1996) study that follows the process by which persons engaged in a 'way directing task' construct an ad hoc common language. Figure 7.12 (*center*) graphically describes this interpersonal scenario by means of our SIRN model.

7.4.4 Interpersonal with a Common Reservoir

According to the intrapersonal submodel the person is learning a route/area by actively constructing it – internally and externally. This subjective side of the process is only one facet of it, however. The other facet is collective (i.e. cultural, social, etc.) in two respects. First, the semantic information employed in the process of landmarking, edging, pathing, etc. is to a large extent culturally dependent. Second, every agent's act in an environment such as a city, for example, participates in re-shaping the information the city affords to other agents: journey to work, moving to a new house, shopping, constructing a new building, road, etc. The city, in this respect, can be regarded a *common reservoir* – the collective product of many individual acts.

In the previous submodels the process depends fully on the biological memories of individuals. Here the process depends partly on biological memories, as before, but partly also on externalized nonbiological memory that we term a *common reservoir*. This common reservoir of external, artificial and nonbiological memory, might take the form of texts, Internet, buildings or whole cities. The paradigm case study, as noted, is our city game experiments (Fig. 7.7). It is typical in such games that after a few initial iterations an observable urban order emerges, the participants internalize this emerging order and tend to locate their buildings in line with it.

Figure 7.12 (*bottom*) illustrates graphically this public-collective SIRN submodel. Another way to look at this submodel is in terms of Fig. 7.13 that can be seen as an abstraction of the city game as described above and in Fig. 7.7. Each individual player/agent is subject to internal input constructed by the mind/brain, and external input which is the legible information coming from the common reservoir. In the above city game it is the virtual city on the ground; in real life, it is the real city. The interaction between these two forms of input gives rise to a competition between alternative decision rules that ends up when one or a few decision rules "wins". The winning rule(s) is/are the order parameter(s) that enslave(s) the system. The emerging order parameter governs an external output, which in the city game is the player's location action in the city, and an internal output, which is an information feedback loop back to the mind/brain.

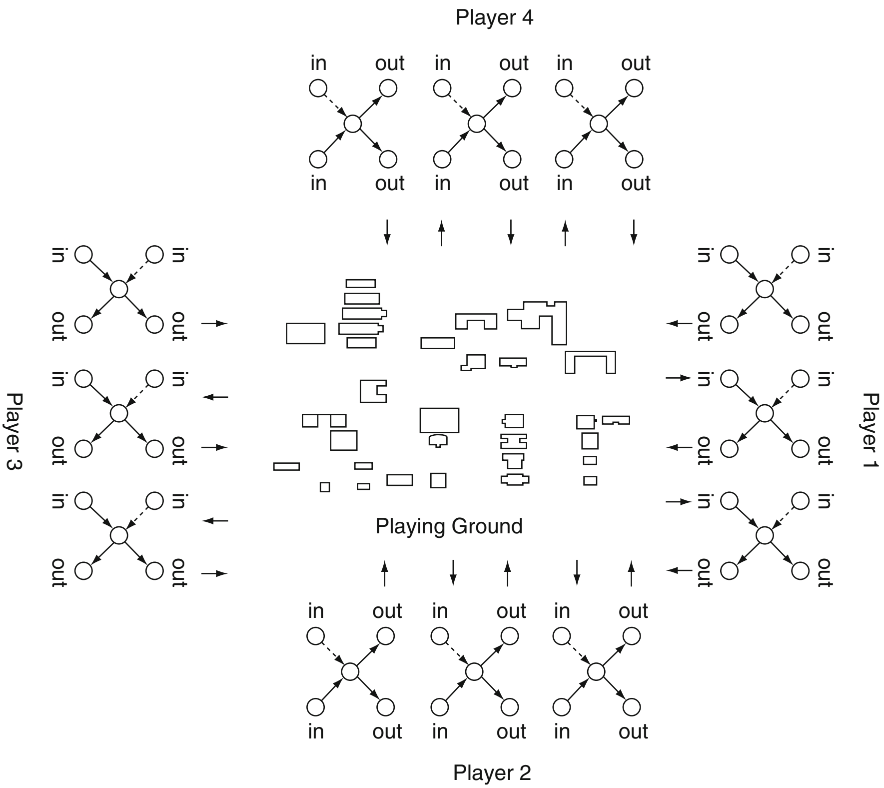


Fig. 7.13 An abstraction of the city game as described above and in Fig. 7.7

Both the previous submodel and the present one involve a dual, two-scale, self-organization process: an individual-local scale referring to each individual agent as a self-organizing system, and a collective-global scale, referring to the whole city as a self-organizing system. The individual agents by their action and behavior determine the city, which by means of its emerging order parameter(s) enslaves the minds of the individual agents. In the language of synergetics this process is termed *circular causality*. In terms of social theory it is close to notions of socio-spatial *reproduction* and *structuration*. As illustrated in the past (Portugali 2000; in particular Chaps. 5–8, 11, 14), the common reservoir might be a nonbiological externalized memory such as a city, a planning textual report or an urban planning policy emerging out of a discourse among the members of a planning team (Chap. 13, below). Note that as in the previous model, here too, due to circular causality, as the process evolves the subjective cognitive maps of the individual agents are becoming more similar to each other and an inter-subjective, collective cognitive map emerges. Both private–subjective cognitive maps and public-collective ones are thus *constructions*.

7.5 Concluding Notes

This chapter has re-introduced the notion of SIRN in light of progress made since Haken and Portugali first proposed it in 1996. As could be seen, SIRN suggests a new view on cognition that allows a smooth interaction between cognitive processes, on the one hand, and socio-cultural processes, such as city dynamics, on the other. Subsequent chapters in Part II will further elaborate on SIRN's notions of Shannonian and semantic information, will suggest a SIRN approach to categorization with respect to cities and will elaborate on the role of artifacts as implied by SIRN. The chapters of Part III and IV will suggest a SIRN approach to planning and urban simulation models.

Chapter 8
Shannonian Information and the City*

8.1 Introduction

The question of 'what it is in the externally represented face of the city that makes it imaginable' was one of the two pillars upon which the domain of cognitive mapping was founded (Chap. 6). The other pillar concerned the nature of internal representation, in the case of cities – of the image of the city. Lynch's (1960) *The Image of the City* as we've seen above (Chap. 6) was an attempt to answer the first of the two questions. Today, five decades later, Lynch's work is still the authoritative response to this question. How is that possible? One reason is the ingenuity and abundant intuition that typifies Lynch's study. Another reason, however, is the fact that there has been relatively little research on that issue since the appearance of Lynch's book. Following mainstream cognitive science most students of environmental and urban cognition have focused their research efforts on the nature of internal representations such as cognitive maps, putting aside the very face of the city as uninteresting or irrelevant.

This chapter focuses on the issue of the external face of the city, approaching it from the perspective of *Information Theory* as originally formulated by Shannon in the first half of the 20th century (Shannon 1948; Shannon and Weaver 1949) and as elaborated by Haken (1988/2000) in the context of his synergetic approach to cognitive and brain processes. Our motivation in this endeavor is the notion of *SIRN (Synergetic Inter-Representation Networks)* as presented in the previous chapter that suggests that many cognitive processes and tasks evolve as an interaction between internal and external representations that emerge in the process. This, in turn, raises the issue, already addressed above in Chap. 7, of the status of artifacts (that is, external representations) in the overall process of cognition. In the next two chapters it is shown that the various artifacts that make up the face of the city are perceived, remembered and imagined by virtue of, and according to, the information they embrace – the Shanonnian 'objective' information and the 'subjective' semantic information: The present chapter elaborates on Shannonian information and the city, while the next (Chap. 9) on semantic information and the city.

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*by Hermann Haken and the author.

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The discussion starts with three introductory sections. Section 8.2 discusses the various aspects that make up the face of the city and defines the basic questions. Section 8.3 points out their connection to the notion of SIRN as developed above, while Sect. 8.4 introduces Shannon's theory and the relatively few previous attempts to explicitly apply Shannonian information in cognitive studies. Section 8.5 that follows comprises the core of the chapter. It further introduces Shannon's information theory and shows, both intuitively and mathematically, how it can be employed to define the amount of information contained in different elements that make the face of the city. Section 8.6 concludes the chapter by emphasizing the new light it sheds on Lynch's urban elements and on the dynamics of cities.

8.2 Faces

8.2.1 The Face

In his famous experiments with eye movement Yarbus (1967) showed, first, that several "landmarks" of a photographed human face, notably the eyes and mouth, attract our attention more than other areas of the face's landscape (Fig. 8.1). Second, that this pattern of eye movement also typifies the visual scanning of photographs referring to other forms of natural and artificial landscapes such as a photographed forest (Yarbus, ibid, Fig. 117 – reproduced as Fig. 8.5 below), complex scenes inside a room (ibid, Fig. 109) etc. Yarbus' experiments indicate that both geometry and task (invoked by priming) participate in determining subjects' eye movements and by implication in attracting their attention to particular elements of a given picture. [Figure 117 in Yarbus (ibid) is an example illustrating how the geometry of a photographed environment affects eye movement, while Fig. 109 (ibid) illustrates the effect of a primed task.]

8.2.2 The Face of the City

As we've seen in Chap. 6, in *The Image of the City*, Lynch (1960) suggested five elements (*landmarks*, *nodes*, *paths*, *districts* and *edges* see Fig. 6.7) that according to him are specifically significant in shaping people's image of the city and in making the city *legible*. By legibility, we've further seen, he meant a particular visual quality of the cityscape that refers to the ease of recognizing the city as a whole and the elements of which it is composed.

As also discussed in Chap. 6 above, Lynch's notion of legibility is close in nature to Gibson's notion of *affordances* elaborated in his rather controversial study *The Ecological Approach to Perception* (Gibson 1979b). In that book, Gibson claims that different elements in the environment afford different activities to different

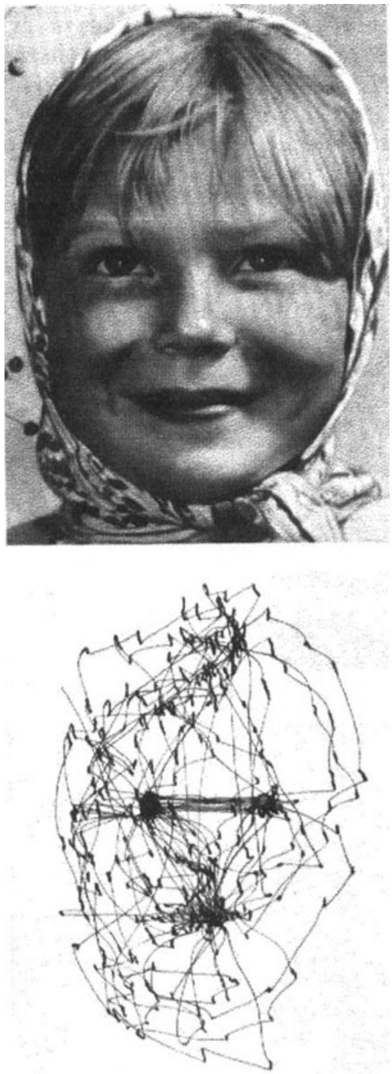

Fig. 8.1 Record of the eye movement during free examination of a photographed face. The eyes and mouth are the face's most prominent "landmarks" (*Source*: Yarbus 1967, Fig. 115)

animals. A terraine is thus walkable, a tree is climbable (for a cat, but not for a dog), a chair in a room or a rock in the field are seatable for an adult human, a ball is grabable, and so on. These properties of the terrain, the tree, the rock ... that afford certain activities to certain animals are termed by Gibson *affordances*. In a similar manner one can say that a certain element in the city that because of its geometry or symbolic value affords remembering will become a landmark in Lynch's term, for example.

Lynch's five elements and Gibson's affordances refer, as one can see, to the geometrical appearance of elements in the environment or the city. Subsequent studies (Appleyard 1969, 1970; Golledge and Spector 1978) indicate, however, that there are other elements – symbolic, cultural, personal etc. – that afford remembering and orientation and as such, also participate in making cities legible. [Further discussion on this and related issues can be found in the following collections: Portugali 1999; Golledge 1999; Kitchin and Freundshuh 2001; Kitchin and Blades 2000]. Looking at such elements from the point of view of Shannonian and semantic information, we suggest referring to Lynch-type elements as *geometrical urban elements* and to the second type – the nongeometrical one – as *semantic urban elements*. Some intuitive examples might illustrate the nature of this distinction: Rabin's memorial stone, located in Tel Aviv at the spot where he was murdered is not a very prominent geometrical element – it is neither a tower, nor an edge nor a major node (Fig. 8.2). And yet for Tel Avivians and Israelis it is an important reference point in the city. The *Balcone di Giulietta* in Verona, on which, according to Shakespeare's play, Juliet stood and talked to Romeo, is a major reference point in Verona, not because of its prominent geometry or even because of its history, but because of the story associated with it (Fig. 8.3). The same can be said about the Via Dolorosa in the Old City of Jerusalem or Bodhgaya in north India; the *Bo Tree* growing there is said to be a direct descendant of the original tree under which Buddha sat when he was first enlightened (Fig. 8.4). Each of these elements, of course, has geometry: Rabin's memorial and Juliet's balcony are points, the Via Dolorosa is a path, while Bodhgaya is geometrically what Lynch called a 'district'. But what makes such elements landmarks, paths, edges districts and nodes is not their geometry and external appearance, but the meaning attached to them – their semantic appearance if you wish.

Fig. 8.2 Prime minister Itzhak Rabin's memorial stone located in Tel Aviv on the spot where he was murdered in November 4, 1995

Fig. 8.3 The *Balcone di Giulietta* in Verona

Fig. 8.4 Bodhgaya is a town and a place where monasteries representing all major Buddhist nations and traditions are located. It is also the home of one of the world's newest and largest statues of Buddha

8.2.3 Two Questions and Two Answers

What is it in the eyes and mouth of the face in Fig. 8.1 that attracts our attention more than other elements of the face? What is it in the "face of the forest" (the vertical lines of the trees in Yarbus' ibid, Fig. 117 – reproduced here as Fig. 8.5) that attracts our attention more than other elements of the forest? What is it in the geometrical and semantic elements in the face of the city that make them landmarks, edges, districts,

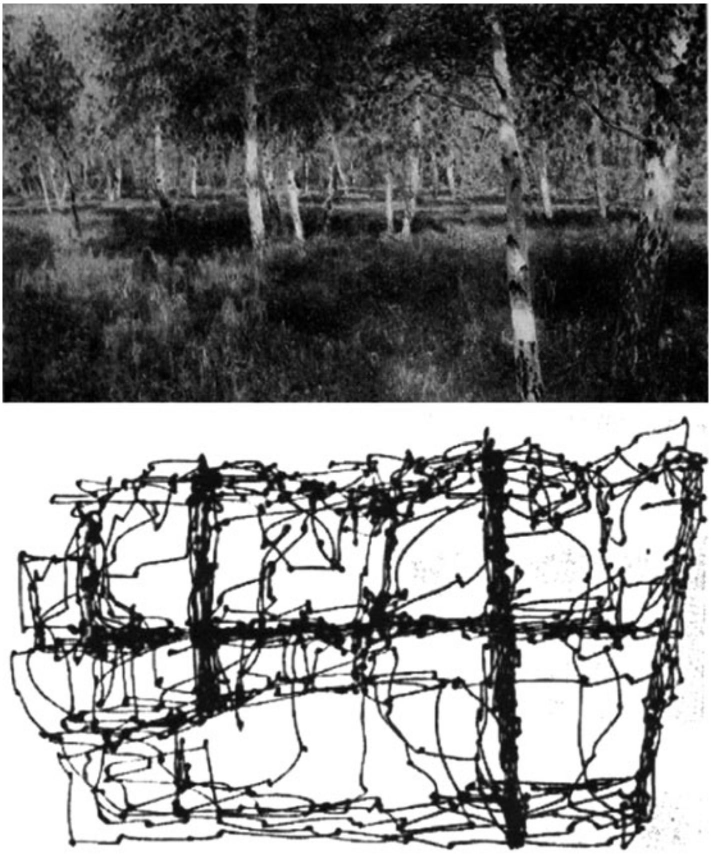

Fig. 8.5 *Top*: Reproduction of Isaak Ilyich Levitan's painting "The Birchwood" from 1885–89. *Bottom*: record of eye movements during the free examination of the reproduction with both eyes for 10 minutes. *Source:* Yarbus ibid, p 182 Fig. 11.7

paths and nodes – so much so that they afford remembering, city imaging and orientation more than other urban elements? The first answer we would like to offer is that *all* the elements that make up the human face, *all* those that make up the face of the forest and the face of the city are external representations by virtue of the property that they enfold and transmit information. In the case of cities, this includes in addition to the Lynchian elements, all the buildings, roads, parks as well as their various configurations (piazzas, neighborhoods or the city as a whole). Furthermore, some of the elements transmit more information than others and are therefore more significant in making the city legible.

The second answer is that the human eyes and mouth, as well as the geometrical and semantic urban elements (but not the forest!), are all *external representations* in yet another respect: The eyes and the mouth tell us about the internal state of mind of a person. We quite often hear a sentence such as "I can see in your eyes that you are happy/sad/bored . . . " etc. The same is true for the mouth – a slight change in its shape might transform a facial expression from anger into a smile. In a similar manner, buildings in the city externally represent something about the internal state of mind of their designers and dwellers.

Both answers raise the issue of the role and status of external representations in the overall process of cognition and cognitive mapping; both imply that like the eye, nose and mouth in the face, some elements in the forest and some elements in the city contain the highest degree of information. Both answers thus take us to the domain of information. The issue of external representation and the notion of information are introduced briefly below.

It must be emphasized that we are fully aware that the long process of evolution has made face recognition a highly specialized mind/brain domain and function, so that animals and humans tend to focus specifically on the eyes and mouth. Superficially, this might cast doubts on the analogy we make between the human face and the face of the city. On the other hand, however, looking at this phenomenon from the point of information theory, it turns out that mouth and eyes have the highest content of information, because of the pronounced variations of brightness, etc. over short distances. Thus when a computer is trained to look for places of the highest information content – and that is what we are also propagating for the recognition of the face of a city – it too looks for such places of high information content. Therefore, at a sufficiently high level of abstraction, there is, indeed, such an analogy irrespective of the fact that this pattern recognition by humans and animals has developed over millions of years. In addition, nature quite often applies skills that have been developed in the long course of evolution to situations that have come into existence only recently.

8.3 Legitimizing Artifacts in the Process of Cognition

8.3.1 Artifacts

The notion of *representation* stands at the heart of the classical approach to cognition. The basic assumption is that humans (and most animals) are born with an innate capability to internally represent the external environment. The standard question is, thus, 'how does the mind/brain represent'? The standard answer is 'it does so by means of computation, and information processing hardwired into the brain'. The exact structure of this process is a matter of debate among proponents of modular, holonomic, connectionist neural network and similar views on the operation of the mind/brain. More recently, however, there is 'a second thought' about the whole notion of internal representations. As we've seen in Chap. 6 above, there are increasing views suggesting that the brain does not work by manipulating symbols but by means of self-organization (Varela et al. 1994; Haken 1983a; Freeman 1999). Whatever one's stand on that issue, the general (and often implicit) consensus is that cognitive processes are implemented by the brain, and that as a consequence, the skull marks the boundary of the cognitive system. All that exists outside this boundary is an environment composed of nature-made elements or of artifacts. It is further agreed that the environment, with its natural and artificial elements, functions as stimuli to the operation of the brain and the cognitive system.

External representations are, by definition, artifacts. This applies to the product of our mimetic or lexical capabilities as well as to the human capability to produce stand-alone objects, that is, artifacts in the literal sense. Yet in cognitive science, as in many other sciences, the notion 'artifact' comes with an air of reservation. As we'll see in Chap. 11 below in some detail, this is also the view of Chomsky (1986, pp 26–27) in his discussion of external and internal languages (E- vs. I-languages, respectively): Chomsky writes that "*because E-languages are mere artifacts...* [they appear] *to play no role in the theory of language...*" (italics added).

The notion of SIRN elaborated above in Chap. 7 suggests a different view, namely, that in many cases the cognitive system extends beyond the skull and must include also external representations that by definition are artifacts. In other words, SIRN legitimizes artifacts as genuinely cognitive.

As claimed in previous Chapters, the construction of cognitive maps evolves in line with the above SIRN process. Thus, for example, the intrapersonal submodel is typical of a person coming to a new city and learning its structure/face by means of navigation, while the interpersonal with a common reservoir is typical of a person living in a city who learns its face (that is, constructs its image or cognitive map) by participating in its dynamics. (This includes the first case as a special case). In the various cases studied, the process involves a dynamic interaction between internal and external representations.

In the context of an artificial environment such as a city, every urban element (building, park, road network) and the city as a whole is, by definition, an artifact – that is, an external representation of its architect, designer, dweller, users, their culture, socio-economic status etc.. Yet, the various urban artifacts differ in the role they play in shaping the face of the city and by implication in the way people remember and imagine the city. We are thus led back to the two questions posed above: First, by virtue of what property the various urban patterns that make up the face of the city are its external representations; second, by virtue of what property the various urban patterns that make up the face of the city are active in shaping people's image (cognitive map) of the city. An intuitive answer to both is 'by virtue of their information content': artifacts are external representation by virtue of the fact that they are 'information carriers' and they differ from one another and thus in the role they take in shaping people's image of the city by their information content.

8.4 Shannon's Information and Cognition

8.4.1 Shannon's Information

The notion *information* is a frequently used word in everyday language and in scientific language. On the other hand, however, the notion also refers to a formal concept and a theory – Shannon's *information theory* (Shannon and Weaver 1949).

In every day language, information is used in the sense of message or instruction. A letter, a television transmission, a telephone call or an email, all carry information informing us, for instance, about events, facts, and the like. Shannon's concept of information is somewhat different, however. Let us consider a very simple example, namely the rolling of a die. There are six possible outcomes, but only one is realized. Quite clearly, the higher the number of possibilities of an event, the lower the probability that a specific event – in the case of a die falling on a specific number will be realized. The concept of Shannonian information refers simply to the number of possibilities Z, which in the case of a die is six. As we shall see later, a proper measure of information is not the number Z itself, but rather its logarithm, where usually logarithm to base 2 is taken, i.e. information is defined by

$$I = \log_2 Z \tag{8.1}$$

As can be seen from this definition, Shannonian information is not related to any meaning. Concepts, such as meaningful or meaningless, purposeful, etc. are not present in it. In a way, it is a measure of the unexpectedness of a particular event out of a fixed number of possible messages whose number is Z. It is surprising, therefore, that despite this Shannonian information plays an important role in recognition processes and has even been credited as one of the theoretical developments that gave rise to the new cognitive science (Gardner 1987). A seminal work that pointed out the relevance of Shannonian information to cognition and psychology is Miller's (1956) "The magical number seven, plus or minus two: some limits on our capacity for processing information". Another though less known application concerns attempts to develop a quantitative measure for figural goodness (Attneave 1959). Let us have a short look at both.

8.4.2 The Magical Number 7

If Tolman's (1948) notion of the 'cognitive map' indicates that the brain is capable of processing incoming information and transforming it into internal representations, then Miller's 'magical number' defines the constraints of this capability. Our short-term memory, he showed, is constrained in its capability to process one-dimensional information to 'plus minus seven', that is, to about 2.5 bits of Shannonian information (Fig. 8.6). He further showed that our mind/brain has several "tricks" to overcome this innate limitation, for example, to increase the dimensionality of the data, to re-arrange it into groups, 'chunks' or a hierarchical structure, or in a sequential order. In the previous chapter it has been suggested, first, that hierarchical organization of stored information might be the 'trick' responsible for systematic distortion in cognitive mapping due to hierarchy (e.g., Tversky 1996). Second, that there is another 'trick' that the mind employs, but that has not as yet been studied – the trick of externalization and inter-representation. Taken in conjunction with the above-noted sequential re-ordering it can be shown that

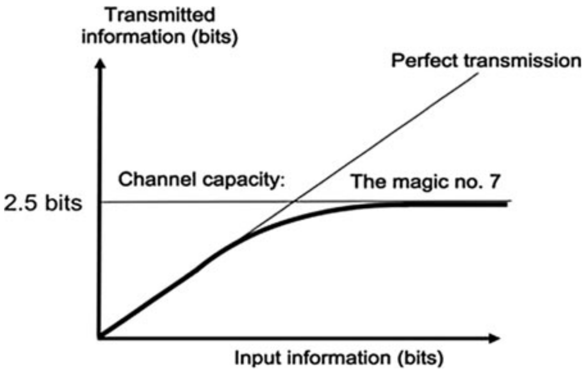

Fig. 8.6 Miller's (ibid) Magical Number Seven, Plus or Minus Two. The relations between input information and transmitted information: up to about 2.5 bits of information there is perfect transmission; beyond that threshold, transmitted information levels off

many cognitive tasks that involve a long sequence of steps depend on the capability for externalization and inter-representation.

8.4.3 Figurative Goodness

Another channel through which Shannon's information theory was introduced into psychology and cognitive science was the attempt to provide a quantitative measure for figural goodness (Attneave 1959) – an issue that was studied, qualitatively, mainly by Gestalt psychologists. Applying Shannon's theory it was possible to show, firstly, that "..*much of the information received by.. organism is redundant*" (Attneave, ibid, p 183), and, that "*redundant visual stimulation results from . . . an area of homogeneous..'color'.. or direction*" (ibid 184). Secondly, that "*Information is concentrated along contours.. and at points.. [where] direction changes.. rapidly*" (angle, peaks, curvature) (ibid). One example is Attneave's sleeping cat (Fig. 8.7); another example that has yet to be elaborated in this context is Lynch's elements (Fig. 6.7 above): His elements *landmark*, *node*, *edge* and *path* are cases in which contours or points change their direction rapidly, while his element *district* is a case of "an area of homogeneous. . . color. . . or direction".

From Shannon's information theory further follows, thirdly, that good Gestalts are redundant, containing little information (that is, little uncertainty). Fourthly, as indicated by Palmer (1991), that the Shannonian information definition of the goodness of forms fully conveys the original Gestalt notions of simplicity, order and singularity (Zabrodsky and Algom 1994, p 463). Fifthly, and related to the above, that 'information is a function not of what the stimulus is, but rather of what it might have been' (Garner 1974, p 194, quoted in Zabrodsky and Algom 1994, p. 463). This, according to Zabrodsky and Algom (ibid) is the major contribution of information theory to psychology. It means that in perceiving a shape, one perceives not only the observed form, but also the potential or extra/alternative information enfolded in it. Both properties show up in Fig. 8.8. This latter figure that was specifically devised for the present study, illustrates and compares the

Fig. 8.7 "Drawing made by abstracting 38 points of maximum curvature from the contours of a sleeping cat, and connecting these points appropriately with a straightedge" (Attneave ibid Fig. 3)

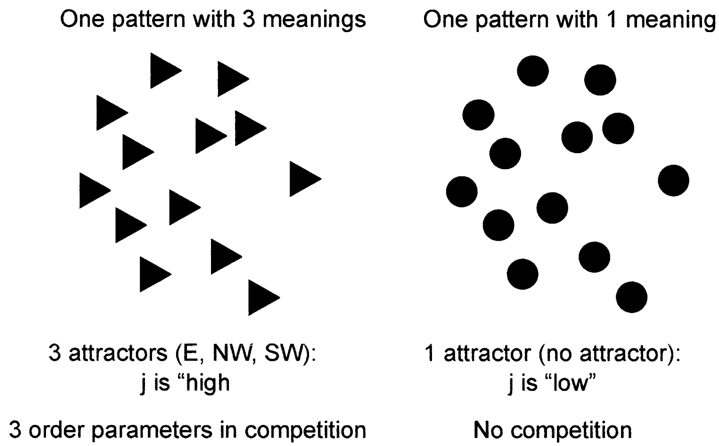

Fig. 8.8 A pattern of triangles ($I = 1.5$) vs. a pattern of circles ($I = 0$)

Shannonian information conveyed by two similar patterns. On the right-hand side, we see a pattern of dots that can be perceived in one way only, that is, one out of one possibility. Its Shannonian information I is thus:

$$I = \log_2 1 = 0.$$

On the left-hand side we see the same spatial distribution, but of triangles instead of dots. Here, however, there are three different ways to perceive that pattern, that is, one out of three possibilities. Its Shannonian information is therefore:

$$I = \log_2 3 \approx 1.5.$$

A second example is illustrated in Fig. 8.9.

Shannonian information applied to the issue of figural goodness, as above, sheds a new and surprising light on the notion of external representations and on the

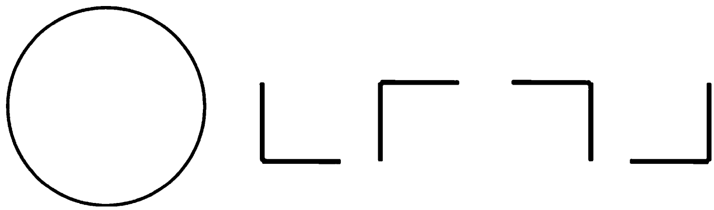

Fig. 8.9 "The *good gestalt* is a figure with some high degree of internal redundancy" (Attneave 1959, p 186). Example: 90 degrees rotation of a circle (a good gestalt; $I = 0$) vs. 90 degrees rotation of an "L" shape ($I = 2$) (based on Algom 1986, p 115)

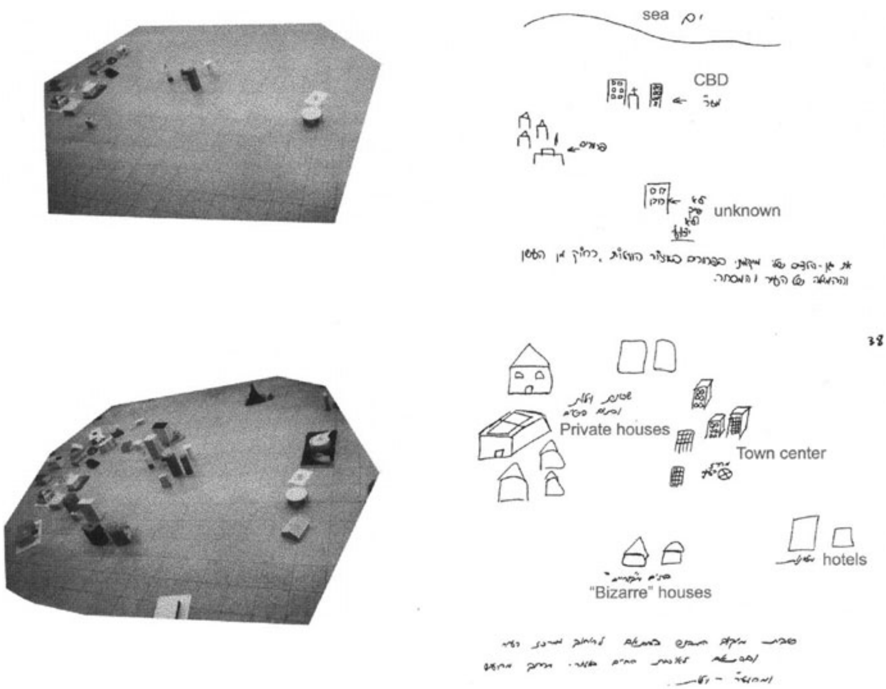

Fig. 8.10 A city game exemplifying the interpersonal with a common reservoir SIRN submodel. *Left*: two stages from the evolving real "city" as developed on the floor. *Right*: the same "city" as imagined by the decision-making players at the corresponding two stages. Note that the information conveyed by the configuration on the ground includes an imagined sea that does not exist on the ground

various elements that make up the face of the city. An external representation can now be defined as the information contained in an artifact or a pattern, as measured by Shannon's information bits. It is a function of, and thus indicates, not only what the pattern/artifact is, but also what it may be or have been, that is, its potential. This property, by which a pattern is perceived as containing information both about its observed and potential form, emerged independently from our experimental city games (Chap. 7 above, Fig. 7.7), of which Fig. 8.10 is yet another example. The participants in these games tend to take location decisions not only on the basis of the pattern observed, but of what it could have been – its potential. The pattern on the ground thus externally represents a potential for a few or many possibilities. The same holds true of the various elements that make the face of the city. Their properties as elements that shape people's image of the city can, at least potentially, be measured by means of Shannon's concept of information. The realization of this potential is the task of the next sections.

8.5 How Many Bits to the Face of the City?

8.5.1 Houses

To get a feeling of what we are aiming at, let us first simplify our considerations by concentrating our attention on a city composed of houses only. If all houses are similar to each other, as in Fig. 8.11 row 1, the city will be boring and we expect practically no information content. If, on the other hand, all houses are different from one another, as in row 2 of Fig. 8.11, we are dealing with a most interesting case and we expect high information content. The concept of Shannonian information provides us with a rigorous mathematical formulation of the statements we just made. To this end, we must discuss a few prerequisites.

We first introduce an index j that distinguishes among the different objects we are considering, in the present context the kind of houses. Thus, if the houses are different (Fig. 8.11, row 2), the index j is different, if they are the same (Fig. 8.11, row 1), the index j is the same. Though this statement seems trivial, it has far-reaching implications, as we shall see in the next chapter, namely in this case, the fixation of this index means: we are using semantic information, or in other words, that we are implying the process of pattern recognition. The choice of the indices j, which means a categorization, partly depends on objectively given data, partly on the way we are selecting and interpreting them. Once this index j, which may run for instance from 1 – M, is chosen, we may attribute to each index j the relative frequency of the occurrence of the corresponding object. Thus, p_j is given by

$$p_j = \frac{N_j}{N} \tag{8.2}$$

where N is the total number of houses in a city, and N_j the number of houses of the same kind according to the selection and recognition process just mentioned. We assume that the houses are distributed over a fixed grid of building sites.

After these preliminaries, we remind the reader of the definition of Shannonian information i that is given by

$$i = -\sum_{j=1}^{N} p_j \log_2 p_j \tag{8.3}$$

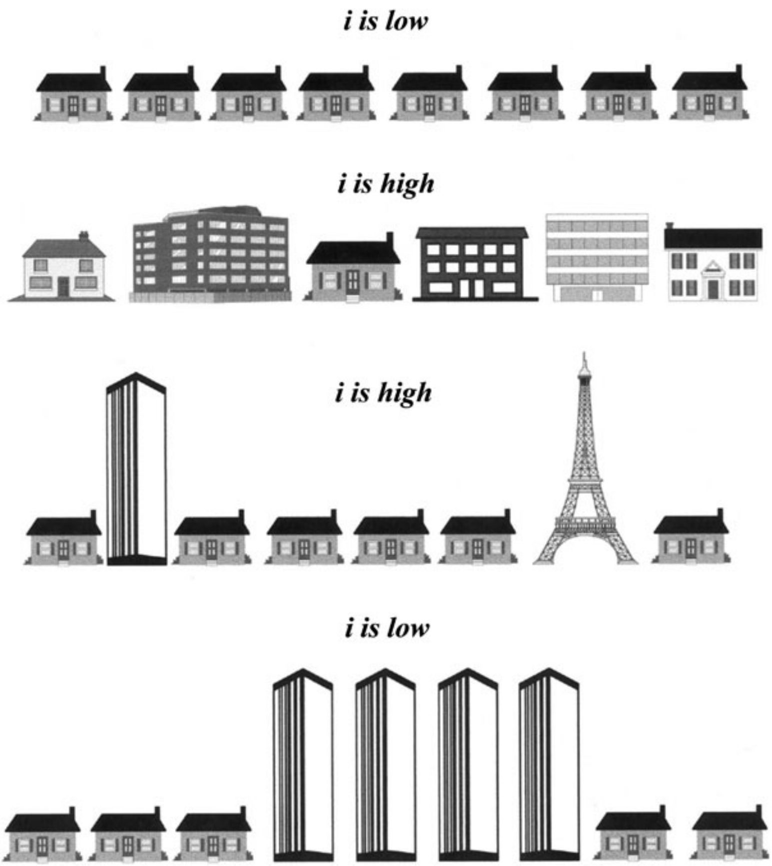

Fig. 8.11 Different configurations of buildings convey different quantities of Shannonian information

when the relative frequencies p_j are subject to the normalization condition

$$\sum_{j=1}^{N} p_j = 1 \tag{8.4}$$

The details concerning the transition from the definition of Shannonian information in terms of Eq. 8.1 to that of Eq. 8.3 are given elsewhere (Haken and Portugali 2003, Appendix B). An important remark should be made here. While I (8.1) increases with the number N of houses, i.e. the mere size of a city, i (8.3) is the information per house, i.e. $i = I/N$ in the limit of large N (i.e. > 100). Thus, i is independent of the *size* of a city, but reflects the variety of its houses, i.e. its character.

Let us discuss the meaning of Eq. (8.3) by means of the extreme cases we just discussed qualitatively. If all houses are equal (Fig. 8.11, row 1), then there is only one kind and only one value of the index j, namely $j = 1$, and N_1 is equal to total number of houses N. According to the definition of Eq. (8.2), $p_1 = 1$, and $i = 0$. In other words, there is no information at all if all houses are equal.

Let us consider the case that all houses are different. Then we have as many values for index j as there are houses, i.e. j runs from 1,2... till N. Since there is only one house of a specific kind, $Nj = 1$. Thus

$$p_j = \frac{1}{N} \tag{8.5}$$

and the information becomes

$$i = \log_2 N \tag{8.6}$$

In the case of Fig. 8.11, row 2, i is about 1.5, but for a sizeable city of thousands of buildings, all different, i might be a rather large number. Note, however, that what counts here is not the size of the city per se, but the great diversity of its houses (i.e. the number of indices j). As one may mathematically demonstrate, the choice Eq. (8.5) corresponds to the maximum of the information Eq. (8.3) under the constraint Eq. (8.4).

For a specific city, we are dealing just with a single case. What has this single case to do with the great number of different realizations? To answer this question, imagine cities with the same grid of building sites, but with different distributions of houses (buildings) over them. If all houses are different, there are a large number of realizations of such distributions. Because, in principle, there are so many realizations possible, when we find a *specific* realization, this represents a highly valuable information. In fact, if all the houses are different, a specific city offers us just one specific arrangement of these houses. Quite clearly, this specific arrangement is a perfect means for us to orient ourselves in such a city or to find buildings of specific interest to us. However, there is a catch in this consideration if we ask ourselves how many different buildings we then should memorize. In a large city this may lie between ten thousand to one hundred thousand buildings. Quite clearly, this will require an enormous amount of memory. As noted in Sect. 8.2, we can memorize only a limited number, forcing us to drop the distinction between originally different houses. In other words it means that we must collapse the selection of indices $j_1, \ldots, j_M$ again into single index $j = 1$. In this extreme case we would arrive at a situation in which all houses are no more distinguished so that $p_1 = 1$ and the information drops to zero. Evidently, an optimal solution will lie in between the extreme cases, all houses different and all equal. It is here where the concept of *landmark* in the broad sense of the word – to be distinguished from its specific usage in Lynch (1960) – comes in, that is, buildings or other objects that are well distinguished from all other buildings and can thus be both easily memorized and recognized.

But then again we can ask the question: what can information theory tell us about the choice and distribution of landmarks? Again, we introduce the concept of relative frequency of a landmark and use the index *j* to distinguish between different kinds of landmarks. If all landmarks are the same (Fig. 8.11, row 4), we would have $p_1 = 1$ and the corresponding information will be zero. Note that all the other houses will act as a background that is unimportant for counting information. On the other hand, if all landmarks are different from one another (Fig. 8.11, row 3), we obtain a maximum of information. But information theory is able to tell us much more, namely about the *spatial distribution* of landmarks.

Again let us start with an intuitive argument. Let us assume a city with landmarks that are all very close together, versus a city with landmarks that are distributed over the city (Fig. 8.11, row 4 vs. row 3). Intuitively we would clearly assume that in the first case the information content is low, while in the second it is high. To cast this problem into its mathematical form, we now have to introduce somewhat more complicated relative frequencies, or in other terms, probabilities. Because we wish to deal with correlations between different buildings with respect to their location, we have to supply the relative frequencies with two indices, *j* and *k*, referring to the buildings *j* and *k*, respectively, and two further indices with respect to the location of these buildings, i.e. *x* and *y*. More precisely, *p{jx, ky}* is the relative frequency of finding buildings of type *j* at site *x* and building of type *k* of site *y*. In the original formula of Shannonian information Eq. (8.3), the index *j* must be now replaced by the combination of all these four indices. However, the argument can proceed as before. If *p{jx,ky}* is strongly peaked, i.e. if the buildings are strongly correlated in space, the information Eq. (8.3) will be low. If the relative frequencies *p{jx, ky}* indicate a pronounced *distribution*, we expect high information. These results are summarized in Table 8.1.

In conclusion we may state that in the sense of information theory, landmarks should be well distinguishable and distributed over a city in an uncorrelated fashion.

This conclusion can be exemplified by a comparison between the tower house of Piazza del Campo at Siena and the tower houses of San Gimignano, both in Italy (Figs. 8.12 and 8.13). In Siena (Fig. 8.12), the city tower acts as a landmark that clearly indicates the center of town. In San Gimignano (Fig. 8.13), the height of tower houses served as a symbol of the wealth of their owners and due to competition, there are quite a number of such tower houses. At the same time, however, because the tower houses are too many and rather similar to one another, they lose their meaning as a landmark within the city, though as a group they can be considered as a symbol of the whole city.

The distinguishability of houses need not be provided only by their exterior appearance, but also by their interior or purpose. An example is the Synagogue in Prague, which at the time it was built was not allowed to be higher than any of the buildings

Table 8.1 Information when the spatial distribution of landmarks is taken into account

if $j = k$	$x \approx y$	peaked:	low i
if $j \neq k$	$x \approx y$	*peaked:*	*low i*
if *i, j, x, y*	*uncorrelated:*		*large i*

Fig. 8.12 The tower house of Piazza del Campo at Siena

Fig. 8.13 The tower houses of San Gimignano

surrounding it. Consequently, the Jewish Community dug much deeper foundations for the synagogue and erected a building whose interior is quite impressive and commemorable, although its exterior obeys the law imposed on it. Similarly, other buildings can become our landmarks because of their purposes, such as banks, post-offices, etc., or theatres, opera houses, concert halls, and so on. This may serve as an illustration of how the indices j in the fundamental formula of Shannon may be interpreted. If forms of houses or of the interior of buildings, are similar, for instance, we easily lose our orientation. This may be substantiated by the hexagonal forms in the Hebrew University of Jerusalem and the construction of some modern German Universities, where even the different coloring of corridors, etc. does not contribute to our orientation.

8.5.2 Streets

In the above considerations, we left aside streets and other elements along which buildings are spatially distributed. For instance, houses may be located along a street, as in street villages, or on a square grid. Clearly, the face of a city is not only determined by the variety of its houses but also by the streets, rivers, seashores, squares, or mountains that often surround the city. In principle, we may apply similar criteria to streets and other urban elements as we did for houses.

Seemingly, if all streets are similar to one another, as in Fig. 8.14a, as typical in many North American cities, very little information can be gleaned by looking at a street map, for example. In other words, high symmetry bears little information. For example, in Fig. 8.14a there are 8 identical streets, whereas in Fig. 8.14b, some 16–20 different streets. Note that when all streets are different, there is difficulty in determining what constitutes a single street and as a consequence more than one way to count the number of streets. As in the case of houses, one might conclude that in Shannonian terms, the information of the streets in Fig. 8.14a is: $i = 0.0$, while in the case of Fig. 8.14b $i = 4.0$. But here an interesting property enters, which results from the fact that unlike houses that are perceived, geometrically, as zero-dimensional points, streets are perceived as one-dimensional entities. As a consequence when looking at a street map, for example, we immediately divide the streets into two groups: vertical vs. horizontal. Thus, in the case of Fig. 8.14a, we have 4 vertical and 4 horizontal streets and as a consequence here $i = 4$.

The above shows up in New York City and many other American cities where the vertical streets are termed ‘Streets’ and the horizontal ones ‘Avenues’. In a large city such as New York the high symmetry of the road system still bears little information and for orientation in a city it might be important to break such symmetries. This can be elucidated by the Fifth Avenue in New York, which, to a good deal, represents a symmetry axis. This avenue is distinguished from the others by its precious shops, specific land uses and most importantly, the human activities that take place there. Quite generally, broken symmetries may help our orientation. This is particularly true for seashores, such as in Tel Aviv that constitute a boundary line for the city and also helps our orientation with respect to direction.

Streets in a city, in fact, create more categories such as ‘intersections’ and ‘city blocks’ and in this respect even more information that again can be measured in Shannonian terms. For example, in Fig. 8.14 there are 4 horizontal and 4 vertical streets that entail 16 ‘+ junctions’, 16 ‘T junctions’ and 25 ‘blocks’. As the reader may find independently, the Shannonian information of the city changes accordingly.

As in the case of houses, when all streets are different from one another, the information is high, but memorization becomes difficult. Such a situation is typical to an old city such as Venice, for example, with its thousands of little streets, canals and allies, as well as to many cities in Europe, South America, Africa, and Asia. As shown in Fig. 8.14e and as in the case of Venice and many other cities, piazzas and other large open areas play a role similar to the role assigned above to landmarks in the context of houses.

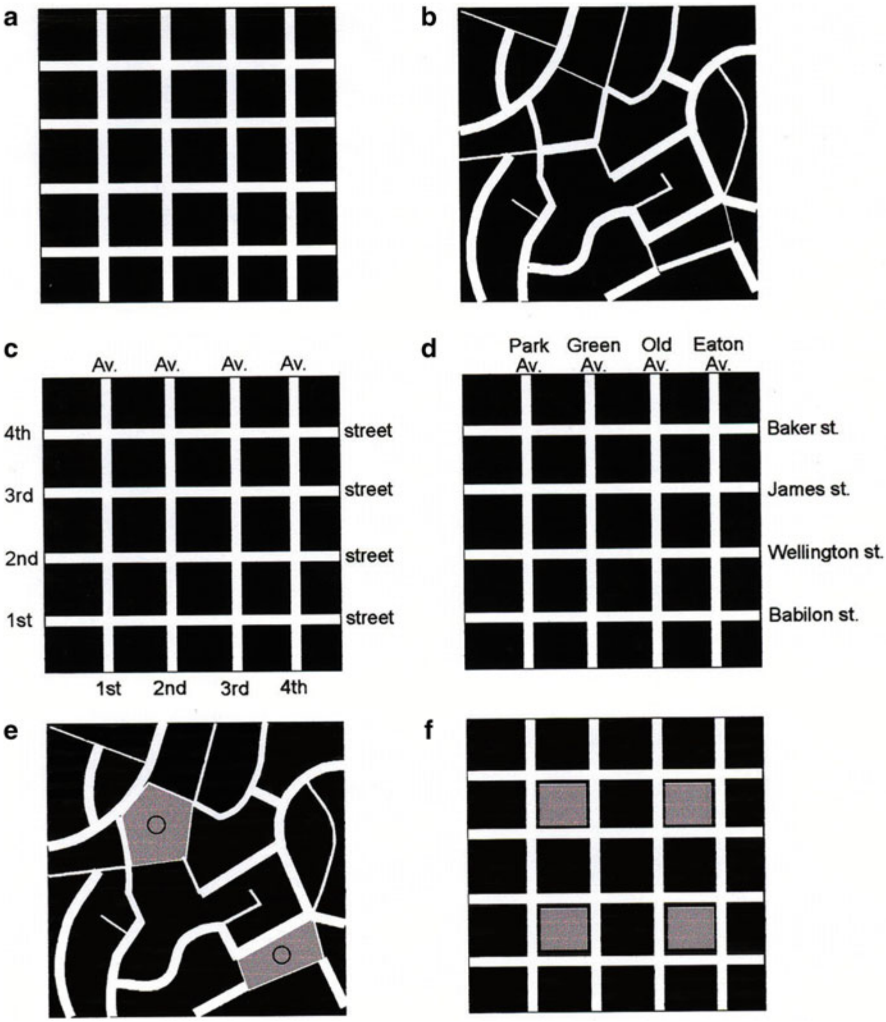

Fig. 8.14 Different configurations of streets convey different quantities of Shannonian information

8.5.3 Local vs. Global Information

High symmetry bears little information with respect to local urban elements such as buildings or streets. However, it bears a high level of information with respect to the global, or overall, structure of the city. For example, in New York City one *knows* how to get, say, from 5th Street to 95th without having ever been there, which is hardly the case in a city like Paris, for example. This leads to a distinction between *local information*, referring to the properties and spatial distribution of the many elements that together form the face of the city, and *global information*, referring to some general principles according to which these elements are organized. The spatial organization of these elements is of specific importance here. Another type of global information is *symbolic information, which* refers to a single or several urban elements that symbolize the city and thus distinguish it from other cities. This distinction is further elaborated in the next chapter.

8.6 Concluding Notes

From the point of view of SIRN an external representation is an artifact that transmits information. As we've just seen, Shannon's theory of information allows us to measure the quantity of information transmitted by the various urban elements (buildings, roads and so on) as well as by the city as a whole. This finding in its turn sheds a new light on Lynch's elements in his *The Image of the City*: Lynch's elements are urban entities that convey a lot of information relative to their surrounding or background.

One of Lynch's aims was to find out what is in the face of the city that makes the city legible. In more general terms his question was 'what makes *a good city form* (which is the title of his less known book from 1981). The answer suggested above is: the quantity of information the city and its various elements convey. As we've seen, this information is determined, on the one hand, by the morphology of the various elements of which the city is composed and also on their spatial distribution.

The above findings have far reaching implications, namely, that agents' behavior in a city is determined by their cognitive maps that in their turn are determined by the information content of the city and its many urban elements. The next question is how exactly this happens? The general answer is: by means of self-organization or more specifically by means of SIRN. This issue is discussed in the next chapter.

Chapter 9
Semantic Information and the City*

9.1 Introduction

This chapter should be seen as "Part Two" of the discussion on information theory in the previous chapter. In both chapters we discuss Shannonian and semantic information and as we'll see immediately, these two kinds of information are interdependent. However, while in Chap. 8 the emphasis was on Shannonian information and the city, here the emphasis is on semantic information and the city. The discussion below starts by showing the way these two notions of information are interdependent (Sect. 9.2). Next, Sect. 9.3 looks at several processes that are associated with semantic information, namely, at pattern recognition, grouping, categorization and self-organization. Section 9.4 that forms the core of the whole chapter examines the implications to information theory, cognition, pragmatic information, urban elements, SIRN and the notion of information adaptation. Finally, the concluding chapter looks at what has been achieved and indicates future research directions.

9.2 Semantic information enters in disguise

An important achievement of Shannon's theory is the definition of information as a quantity that is "free of meaning". This achievement, however, implies a dissonance between the purely quantitative notion of information as defined by Shannon and the term information as employed in everyday language, namely, a message that conveys meaning. In his study *Information and Self-Organization* – his top-down approach to complex systems, Haken (1988/2000) suggested a distinction between *Shannonian information* and *semantic information* that refers to the meaning conveyed by a message.

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*by Hermann Haken and the author.

J. Portugali, *Complexity, Cognition and the City*, Understanding Complex Systems,
DOI 10.1007/978-3-642-19451-1_9,

On the face of it, Shannonian and semantic information diametrically oppose each other. However, as shown by Haken and Portugali (2003) this is not exactly the case. To see how, let us briefly recapitulate what has been said above (Chap. 8): Shannonian information serves to define a quantitative measure for the information content, for instance of the buildings of a city. Semantic information enters into this definition in a rather disguised fashion, namely via the choice of the indices *j* (in Eqs. 8.2 to 8.4 in Chap. 8) that distinguishes among the different kinds of buildings. Thus, if the buildings are different from each other (Chap. 8, Fig. 8.11, row 2), the index *j* is different, if they are the same (ibid, Fig. 8.11, row 1), the index *j* is the same. This statement has far-reaching implications, namely, the fixation of this index means that *we are using semantic information*: The choice of the indices *j* is implemented by the cognitive process of categorization, which is a meaning giving process. In other words, semantic information is contextual.

The implication is rather surprising: In order to determine the objective Shannonian value of a certain building or street – their information content or how many bits each of them transmits – that specific building or street must first be a member of a group. That is, one among many instances that were given a single identity and meaning termed ‘a building’ or ‘a street’. Without that contextual group or category, the Shannonian value of a specific building or street cannot be determined.

The logic behind this somewhat surprising property is that Shannonian information makes sense only with respect to *closed systems*. There must be “a fixed reservoir of messages, whose number is Z” that will allow one to count the relative frequency of objects (Haken 1988/2000, p 16). On the other hand, however, cities like many of the systems that we encounter in life are *open systems* in the mathematical sense: their number of objects is indefinite. Here is where the process of pattern recognition of categories and its entailed semantic information comes in – it closes the system, distinguishes between objects, and allows one to count their relative frequency of appearance. The question, then, is ‘how this is implemented’? The answer we suggest is twofold: First, our cognitive system does it by itself, by virtue of the fact that it is a *self-organizing system* and a synergetic inter-representation network (see Chap. 7 above). Second, operationally speaking, the question here is ‘which comes first?’ namely “*i*” or “*j*”. In other words, the choice of “*i*” and “*j*” condition each other. Our answer to this problem is that they are found by an iteration procedure. Under a certain assumption, for instance on the choice of “*j*”, “*i*” is calculated, then a better choice of “*j*” is made, and so on. It is assumed that this procedure converges after a few steps that quite often are made subconsciously.

Needless to say, a great deal of work must be done after the values of “*j*” and “*i*” are calculated as above. High/low “*i*” levels are not necessarily linearly related to dimensions such as legibility, memorability, livability or some omnibus scale of quality. The latter would probably require even more complex functions. Such functions can, indeed, be obtained if we differentiate “*i*” with respect to specific urban artifacts, for instance, if we calculate “*i*” with respect to restaurants, sightseeing spots, entertainment places, or whole streets and so on. Hereby we may pick up several parts of the city and look for those parts that have the highest values of "*i*" with respect to these artifacts.

9.3 Aspects of Semantic Information

9.3.1 Pattern Recognition – The Process that Gives Rise to Semantic Information

Consider first Fig. 8.1 (Chap. 8). One can easily pattern recognize it as a face of a human female. According to the SIRN approach this recognition process is implemented in the following way (Chap. 7, Fig. 7.12 *top*): The pattern that is externally represented in the world (in this case the drawing) generates an intensive interaction between internal and external representations. In this interaction, the eyes of the observer scan the pattern, and generate a repertoire of internally represented schemas. The latter, in their turn, interact with the external pattern by actively scanning its more informative elements (the eyes and mouth in Fig. 8.1). This interaction between the internal and external representations eventually gives rise to an order parameter that then enslaves the parts of the system so that recognition is established.

It is important to note that the present application of 'categorization by means of pattern recognition' differs somewhat from 'classical' pattern recognition. In the latter the task is to recognize a specific offered pattern – say a face of a known person – out of a repertoire of stored patterns. In the present case the task is to recognize the *category* to which the offered pattern belongs. It can thus be compared to stored schemata, prototypes or other exemplars of the relevant category. As we'll see below (Chap. 19), this process is close to Haken's (1998) synergetic approach to decision making, as well as to its extension by Haken and Portugali (Portugali 2000, Chap. 14).

In mathematical terms that, at least in principle, can be implemented on a computer, the process can be represented as follows: An external pattern v_{ext}, encoded as pixel-vector with gray-values as components, is decomposed under the hypothesis "face", i.e., by the internal order parameter x, into components $v_{\text{int},j}$ according to the positions of the most remarkable features. This is an iterative process, eventually leading to

$$v_{\text{ext}} \Rightarrow P_\xi v_{\text{ext}} \begin{array}{l} \nearrow v_{\text{int},1}(eyes) \\ \vdots \\ \searrow v_{\text{int},n}(mouth) \end{array} \tag{9.1}$$

In the next steps, a learning procedure builds the internal order parameter q_{int} that has to be compared both with v_{ext} and $x = x_{\text{int}}$

$$L_\xi \left\{ \begin{array}{c} v_{\text{int},1} \\ \vdots \\ v_{\text{int,n}} \end{array} \right\} \Rightarrow q_{\text{int}} \Leftrightarrow v_{\text{ext}} \tag{9.2}$$

Processes (9.1) and (9.2) can also be applied in an intermixed iterated fashion. A first step into the realization of this approach has been done by the synergetic computer: A random sequence of partly hidden faces was shown to the synergetic computer, which could restore the "pure faces".

A similar process takes place with respect to the pattern of circles in Fig. 8.9 *right*, in the previous chapter, but not with respect to Fig. 8.9 *left*. Incidentally, this example shows how delicate the concept of a pattern can be. Following Norbert Wiener, we can define a pattern as an arrangement of objects. Adopting this definition, the patterns of Fig. 8.9 *right* and *left*, respectively, are the same. We may describe them by the same pattern vector q. When we proceed to the level of the individual objects, however, we must proceed to a more detailed pattern vector q, which we may write as

$$\overline{q} = qv\upsilon,$$

where v means: insert v at the corresponding positions of q. Clearly, in the case of circles, there is only *one* v, and thus only a single q. On the other hand, triangles can be oriented differently; in the case of Fig. 8.9 *left* all triangles to the east, all to northwest and all to south west. Mathematically:

$$\upsilon = \upsilon_e, \upsilon = \upsilon_{nw}, \upsilon = \upsilon_{sw}$$

Thus we find the three order parameters

$$\overline{q}_e = qv\upsilon_e, \; \overline{q}_{nw} = qv\upsilon_{nw}, \; \overline{q} = qv\upsilon_{sw}.$$

Note that the result of the recognition process of the face in Fig. 8.1 and of the pattern of circles in Fig. 8.9 *right*, is a single order parameter, that is, $j = 1$ and $i = 0$, whereas in Fig. 8.9 *left*, there are three competing order parameters, that is, here $j = 3$ and $i \approx 1.5$.

Let us now follow two more examples concerning semantic and Shannonian information. First, imagine an Israeli and an English town planner coming to an Israeli town of 100 buildings. Both recognize that there are 80 four-story buildings and 20 ten-story buildings. Both observe Hebrew signs on the buildings and both properly interpret them as street-names. But only the Hebrew-speaking Israeli can see that half of the names are Ashkenazi and half Sephardi. The result: For the English person the town will consist of two groups of low and high building, while the Israeli will further subdivide each of the groups to Ashkenazi and Sephardi, and so on. The indices j will be determined accordingly and the very same town might thus afford different quantities of Shannonian information to the two persons (in ways that are further described below).

Second, consider two persons approaching the same city. One from the outer space, by means of a spacecraft, in a top-down fashion, and the other from below, in a bottom-up fashion, by means of an underground train, directly to the center of the city. Each has in his/her long-term memory a set of urban schemas (c- and s-cognitive maps) and artifacts, ranging in scale and size from pavements or streets to neighborhoods and the whole city. These internally represented artifacts are not 'stored' as static symbols, but rather emerge out of the person's interaction with externally represented information. As a consequence, even when their long-term memories are at the start identical, the cognitive map that each will produce will be different. The map of the top-down person will include more elements that refer to the global structure of the city, while that of the bottom-up will include more small-scale/local urban elements. This will entail different indices j and as a result different quantities of Shannonian i.

As elaborated below, each of the above case studies refers to a different aspect of semantic information: The cases associated with Figs. 8.1 and 8.9 in Chap. 8 above, refer to innately determined semantic information, the story about the Israeli and English persons illustrates the effect of culturally determined semantic information, while the last one the effect of pragmatics, that is, the specific action with which the task/act of cognition is associated.

This interconnection between Shannonian and semantic information doesn't terminate here, however – the two notions intermingle in yet another way. Remember Miller's magical number 7. One way our brain overcomes this constraint, writes Miller, is by *grouping*. But grouping, once again, implies categorization, that is, giving a single meaning to several separate phenomena. Once grouped, a large number of individual urban entities suddenly acquire an identity and become a house, an office tower, a condominium, etc. In what follows, we will take a closer look at this process of grouping and categorization.

9.3.2 Grouping and Sequential Processing

Let us start with an example: How can we efficiently memorize a number composed of several digits, e.g., one out of ten thousand numbers and how is this related to Shannon's information? We wish to study this example as it relates to memorizing the number 7638. When we want to memorize a 4-digit number, each numbering from zero to nine, the Shannonian information for one digit is

$$i_1 = -\log_2 p_1 = -\log_2 \frac{1}{10},$$

and for the whole configuration

$$i_4 = -\log_2 p_1^4 = -\log_2 (1/10)^4 = 4\log_2 10$$

Does Shannonian information change if we group the digits, e.g., two by two?

Then the first group has

$$p_{12} = 1/100,$$

and the second group has

$$P_{34} = 1/100,$$

and the Shannonian information for the total configuration is

$$i = -\log_2 p_{12} p_{34} = -\log_2(1/10000) = 4\log_2 10$$

i.e., precisely the same as without grouping.

$$i = -\log_2 p_{12} p_{34} = -\log_2(1/10000) = 4\log_2 10$$

But now consider this in view of sequential learning. Without grouping, we have to learn one event out of 10,000, but with grouping we have to learn 2 events out of 100. Or seen from a different viewpoint: In the first case we must scan through a memory with 10,000 items, in the second case, two out of 100 items. That this grouping is essential for pattern recognition can be substantiated by experiments with the synergetic computer (that was introduced above in Chaps. 4 and 7). When it was shown a *scene* of several faces, it recognized one face after the other rather than simultaneously (Fig. 9.1).

Having recognized that sequencing is important, Miller's experiments and conclusions on the channel capacity of the human brain appear in a new light. While it is true that in a single scene – within a short time window – the processed information does not linearly increase with the amount of information offered but rather levels off – when a large window is offered, e.g., by reading a book or listening to a talk, time is chopped into windows – each responsible for the

Fig. 9.1 Sequential pattern recognition by the synergetic computer. The computer first recognized one face. When the corresponding attention parameter is set equal to zero, the computer recognized the next face, and so on

"elementary" limited information take-up. Note that this is very typical of the way we learn a city in general and the face of the city in particular: because of its size we can never see the entire city and we therefore scan and learn the city "window by window". Note further that this sequential process is the essence of the SIRN approach. As elaborated in Chap. 7 above, in this process we do not passively perceive and memorize the entire information offered by a "window", but rather we actively "select" the elements that convey the highest value of information as defined here. We are actively "landmarking", "edging" elements in the environment as they enter our "window".

One might argue that the limited information channel capacity arises from limitations of the short-term memory, which then has to be shuffled – step by step – into the long-term memory.

9.3.3 Semantic Categorization and Shannonian Information – The Gaudi Effect

As we've just seen, semantic information (created by pattern recognition) determines the indices j and through them the Shannonian i. But the process doesn't terminate here. In this section, we will show how changes in the composition of Shannonian information in the city feed back and bring qualitative changes in the city's semantic information. In other words, we show that the relations between semantic and Shannonian information are not causal and unidirectional, but rather, that they are characterized by circular causality. As before, we'll start with an illustrative example.

Consider, first, the evolution of an imaginary city. It starts with one building, then another one is added, then another and so on in a sequence. Assume that the first building is of type-1, the second of type-2, the third type-3, etc. Assume, further, that after a few iterations, most of the new buildings that are added to the city are similar to type-1, 2, or 3. What would be the effect of this? Clearly, according to what has been said above, every new type-1 reduces the information content of each of the type-1 houses.

But here a new dimension enters to the process. As the number of type-1 buildings increases, suddenly (or gradually – but this is a matter for a separate study) the many buildings that are similar to 1 will be "pattern recognized" as a single, identifiable group. That is to say, *they will become a category*. In terms of synergetics such a change can be interpreted as a phase transition in the semantic information content of the city. Once this has happened, the marginal effect of every new similar building to the group will be to reduce the information content of each single building in it, but *at the same time it will increase the information content of the category as a whole*. The individual members of the category will now be recognized not by their individuality, as at the beginning, but by their membership in their respective categories.

Note that the vast majority of artifacts in the city, at all scales, are of this nature: pavements, traffic lights, houses, condominiums, office-buildings and so on. One thus has a play here between *unique artifacts*, on the one hand, and *redundant artifacts*, on the other. This play is commonly experienced when we come to a new city for the first time. From the start we intensively compare the new patterns as they come to our view with the categories stored in our mind. In other words, we pattern recognize what comes to our view. In this pattern recognition process, houses that look familiar to us will not provide us with a surprise. However, if we encounter a building with a totally new and unfamiliar form, it will surprise us, or in other words, it will be related to a high Shannonian information. If we see a second building with that form the additional surprise will be smaller and so on. After having seen a number of such buildings, we (or rather our brain) will form a category out of them as described above. The increment of surprise, or information, has thus levelled off.

A nice illustration of the above process is what one might call the *Gaudi Effect*. When one encounters Gaudi's *Sagrada Familia* in Barcelona for the first time (Fig. 9.2), the effect is one of a great surprise. A typical reaction is "it doesn't

Fig. 9.2 Gaudi's Segrada Familia

Fig. 9.3 Gaudi's Casa Mila (La Pedrera)

Fig. 9.4 A building in Tel Aviv, known also as "The Crazy House", designed by architect Leon Gaignebet but "looks like" a Gaudi's building. "Gaudi was a genius while I have perhaps a little talent", says Gaignebet in an interview (Jerusalem Post 15 March 2006) and adds that his source of inspiration was fractal theory

belong to anything". But then, when one sees the *Casa Mila (la Pedrera)* and a few of his other projects (Fig. 9.3), one starts to pattern recognize the rest of Gaudi's buildings. His architecture has been categorized. So much so that when encountering a bizarre building not designed by Gaudi (Fig. 9.4), a common reaction might be "it looks like one of Gaudi's".

Let us start by casting these intuitive observations into the precise mathematical forms of Shannon's theory of information. Let the number of type-1 houses be N. Now we add to this group a house of type-2. The relative frequency of houses of type-1 is

$$p_1 = \frac{N}{N+1} \tag{9.3}$$

In order to evaluate the corresponding information explicitly, we must proceed from log_2 to the natural logarithm ln

$$\begin{aligned} & i = -\log_2 p_1 = -K \ln p_1, \;\; \textit{where} \\ & K = 1/\ln 2, \\ & \textit{i.e.}, \\ & i = -K \ln\left(\frac{N}{N+1}\right) \approx \frac{K}{N} \end{aligned} \tag{9.4}$$

From now on we drop the factor K, which amounts to measuring the information in *nits* instead of *bits*.

For large N, Eq. (9.2) is small, i.e., very small information – practically no surprise. But when we consider a type-2 house we have

$$p_2 = \frac{1}{N+1}$$

And

$$\begin{aligned} i_2 &= -\ln p_2 = -\ln\left(\frac{1}{N+1}\right) \\ &= \ln(N+1) \end{aligned} \tag{9.5}$$

which is a large number: great surprise.

If we include two additional houses of type-2 we have relative frequency of houses of type-1

$$p_1 = \frac{N}{N+2},$$

and the corresponding information:

$$i_1 = -\ln\left(\frac{N}{N+2}\right) \approx \frac{2}{N} \tag{9.6}$$

which again is a small number for N large. On the other hand, for

$$p_2 = \frac{2}{N+2},$$

we obtain the information:

$$i_2 = -\ln\left(\frac{2}{N+2}\right) = \ln(N+2) - \ln 2 \tag{9.7}$$

Generally, when we have N houses of type-1 and M houses of type-2 we obtain

$$\begin{aligned} p_1 &= \frac{N}{N+M} \\ i_1 &= -\ln\left(\frac{N}{N+M}\right) \\ p_2 &= \frac{M}{N+M} \\ i_2 &= -\ln\left(\frac{M}{N+M}\right) \end{aligned}$$

If $N \approx M$, the two values of i_1 and i_2 become practically the same.

Let us study the change of information when the distribution of houses changes for the case of N houses of type-1 and M houses of type-2. We consider a change of $M \to M+1$ and $N \to N-1$ so that the total number of houses remains constant. According to information theory we calculate the information gain that is defined by

$$G = p_1' \ln\frac{p_1'}{p_1} + p_2' \ln\frac{p_2'}{p_2} \tag{9.8}$$

where for example

$$p_1 = \frac{N}{N+M},\ p_1' = \frac{N-1}{N+M} \tag{9.9}$$

$$p_2 = \frac{M}{N+M},\ p_2' = \frac{M+1}{N+M} \tag{9.10}$$

Inserting these expressions into Eq. 9.7 leads to

$$\begin{aligned} G &= \frac{N-1}{N+M}\ln\left(\frac{N-1}{N+M}\,\frac{N+M}{N}\right) + \frac{M+1}{N+M}\ln\frac{M+1}{N+M}\,\frac{N+M}{M} \\ &= \frac{1}{N+M}\left((N-1)\ln\left(\frac{N-1}{N}\right) + (M+1)\ln\left(\frac{M+1}{M}\right)\right) \end{aligned}$$

For $N >> 1$, $M >> 1$ we can simplify G to obtain

$$G \approx \frac{1}{NM} \tag{9.11}$$

According to Eq. 9.10 the information gain decreases with the number M of the different houses. To get still more insight, we introduce the total number $N(total) = N + M$ houses. Then Eq. 9.10 reads

$$G = \frac{1}{(N(total) - M)M} \tag{9.12}$$

If M is much smaller than $N(total)$, G decreases with increasing M and reaches its minimum if $M = N(total)/2$.

Two questions arise at this stage: First, when will categorization start? That is, at what stage will the individual single buildings that we've termed above as type-2 be given a single identity and will thus be treated as a category? Second, what is the cognitive process responsible for this process and how does it develop? The answer to the first question is that this is essentially an empirical matter. And indeed, one aim of our city game described in Chap. 7 above (Fig. 7.7) is to shed some empirical light on that issue. The answer to the second question is that the process responsible is captured by SIRN and that it develops by means of an interaction between Shannonian information as a control parameter, and semantic information as an order parameter. This occurs in the following way:

Assume a person living in a city that is cognitively dominated by a certain order parameter(s) with implied building types, categories and their Shannonian information bits. Adding a new (type-1) building to this city triggers (for our person) an interaction between internal and external representations. This interaction gives rise to a control parameter that in the above case-study is measured by means of Shannonian information. As the control parameter crosses a certain threshold, a phase transition occurs: the many hitherto similar individual buildings are being pattern recognized as a unique, single, urban category. In the view of synergetics, this specific cognition of many separate buildings as a collectivity, that is to say, as a single and unique entity, is the product of an *order parameter* and the process leading to it is guided by the so-called *slaving principle*. It is as if the perception of the various buildings as individuals is being enslaved by their perception as a group – a single entity.

What exactly is the threshold beyond which a phase transition occurs and re-categorization starts? This, as noted above, is an empirical question that has yet to be investigated. As a working hypothesis and an illustration of what such a threshold might mean, consider the following two definitions:

Definition 1: Categorization starts, if i_1 and i_2 become of equal magnitude.

Definition 2: Categorization starts if additional information becomes unimportant, or, more precisely, if information gain becomes smallest, i.e., for

$$M = \frac{N(total)}{2}$$

This is, of course, a most reasonable result!

9.3.4 Central Place Grouping and Categorization

As we have just seen, single or unique urban elements can be transformed into a category when the number of urban elements identical or closely similar to them grows. But there is another way by which single elements are related to the process of categorization. In certain situations, which are quite common in cities, their alienation to their urban context causes other city elements to become an identifiable category. For example, when there is a large residential area with similar houses it would be hard to distinguish among them and by implication, between subareas in it. If, however, in such an area a few buildings essentially alien to this residential area are located, such as prominent landmarks or even 'ordinary' shops, restaurants etc., they become marked or labeled and thus distinguished. But not only that, they quite often will become central places that define subareas, or neighborhoods, within the larger homogenous residential area. For example, the 'shopping center area/neighborhood' vs. 'the school area/neighborhood'. The Shannonian logic of this effect is as follows:

If the large and continuous residential area has similar houses that are essentially indistinguishable, we expect as information:

$$i = 0$$

Adding two central places to the above uniform residential area will form two distinguishable neighborhoods and the relative frequency of finding one specific neighborhood will now be

$$p_1 = 1/2$$

and the corresponding information

$$i_1 = -\ln 1/2 = \ln 2 = 1 \; nits$$

Thus by distinguishing, that is to say, by means of landmarks, the information increases, though not dramatically. If one added M central places, the result would be M distinguishable neighborhoods (e.g., residential areas) and their information would now be

$$i = \ln M.$$

9.3.5 Semantic Information and Self-Organization

As we've just seen, semantic information is created by means of self-organization and depends on the receiver's specific memory and action. In *Information and Self-Organization* Haken (1988/2000) provides examples that show that the notion of semantic information applies not only to “thinking creatures” such as humans (that can consciously and unconsciously pattern recognize and categorize) but also to very basic organic systems. One example refers to DNA. When we throw a strand of DNA into a heap of sand, nothing will happen. When, however, such a strand is inserted into a bacterium, it can lead to the production of a new substance in that bacterium. In both cases the Shannonian information of the DNA is the same, but its meaning for the receiver is quite different. This illustrates in yet another way that any sensitive definition of semantic information must contain the action of the message on the receiver causing the observer’s reactions.

As already noted, the above is, in a way, reminiscent of the concept of Gibson’s *affordances*, but in the synergetic approach, it can be cast into a mathematically precise form. This was shown above with respect to the face of the city and in a more general way in Haken (ibid). In the latter it was further shown that the responses of an observer can in general be characterized by specific attractor states. A message serves to initialize the observing system in such a way that a corresponding attractor state can be realized. The example of the strand of DNA nicely illustrates the distinction between Shannonian and semantic information, while our present study illustrates the role of pattern recognition and associative memory. From here on links have been established to decision theory as was outlined elsewhere (Haken 1996, 1998; Portugali 2000, Chap. 14) and as will be illustrated below in Chap. 19. In the present context such decisions may refer to buying or renting houses or flats, or more simply, to choosing restaurants, theatres, performances, and so on.

The second example concerns information and the self-creation (or self-organization) of meaning in the context of biological systems. One of the most striking features of any biological system is the enormous degree of coordination among its individual parts. In an animal, for instance, myriad neurons and muscle cells cooperate in order to bring about locomotion, heartbeat, breathing, or blood flow. Recognition is a highly cooperative process, too, as are speech and thought in humans. As shown in synergetics, this coordination in self-organizing systems is brought about by the action of order parameters (Haken 1996). The individual parts of a system generate such order parameters that, in turn, act on the individual parts and regulate their behavior. Although from a formal point of view, the order parameters play a similar role in physical and biological systems, there is a profound difference with respect to their meaning. Namely as has been shown elsewhere (ibid), in biological systems the order parameters serve specific purposes that, eventually, lead to the survival of the individual. The order parameters serve a specific purpose in a biological context at the very least. In this way, order parameters may be called "informators" that carry semantic information. For instance, in amoebas, an order parameter is the field of chemicals that guides the motion of the individual amebas to a center, where they form a body in order to survive when nutrition becomes scarce. As usual, this order parameter is brought about by self-organization (Haken 1988/2000).

Our present study on information and the face of the city belongs to the domain of culture. Here the property of self-organization and the interplay between Shannonian and semantic information is quite clear. As an example take language that is regarded by many as the utmost sign and property of humanity. All human languages came into being by means of self-organization, that is, by means of a complex and spontaneous interaction between a large number of individuals that gave rise to a highly structured set of principles that form the order parameter of the language. The order parameter(s) of a language can be seen as an "informator" that carries the semantic information enfolded in the lexical components of a language.

As shown in *Self-Organization and the City* (Portugali 2000), the order parameters that govern the dynamics of the city can be regarded as "informators". That is, they carry semantic information about the content of single buildings, neighborhoods and the whole city. One aim in the present chapter was to study the way self-organized semantic urban information is related to and enters the Shannonian information content of urban elements. As we've seen above, semantics enters in disguise.

9.4 Implications

9.4.1 Information Theory

From the point of view of information theory, the face of the city is a *message*. As a message it conveys and transmits different quantities of Shannonian information. The latter, as we've seen above, depends on the city's semantic information. That is to say, on the specific way we cognitively and actively give meaning to the city and the many elements of which it is composed. This view, which concerns the relations between Shannonian and semantic information is probably the most interesting general result coming out of our work, as elaborated in the previous chapter and the present one. That is, on the one hand, Shannonian and semantic information fundamentally differ from each other: Shannonian information is information regardless of meaning, while semantic information refers to meaning and is thus dependent on the receiver. On the other hand, however, the two notions are intimately interrelated: the existence of categories (that is, semantic information created by means of pattern recognition, for instance) is a pre-condition for the very possibility of applying the Shannonian measure in the first place. Shannonian information, in this respect, measures the quantity of information embodied in a certain semantic structure. As we have seen and will further emphasize below, changes in the Shannonian quantities might, under certain circumstances, introduce change to the semantic structure of the city.

9.4.2 Cognition

Two interrelated cognitive capabilities are active in shaping the semantic structure of cities: pattern recognition and categorization. One pattern recognizes the information that flows from the environment by dividing it into meaningful categories and entities. A nice illustration is provided by the colors that we see. As shown by Rosch and coworkers (1976), the continuous stream of light-rays that flow from the environment to our senses is divided/categorized by our brain into discrete colors. Such processes of categorization and their resultant semantic information can be the outcome of four processes: processes based on the innate properties of humans (color categories, towers as landmarks in the city, etc.); processes based on culture (the categories of a language – voice or letters; our example of the Hebrew and English speakers above); processes derived from the very subjective experience of the individual (a personally important spot in the city); and processes associated with action (our example concerning the top-down/bottom-up approaches to the city). The first might be termed *innate semantic information*; the second *culturally semantic information;* the third *personally semantic information;* while the fourth, *pragmatic semantic information* or in short: *pragmatic information* (see below). Note, first, that the distinction between innate properties and those based on culture parallel the distinction made in sociology and sociobiology between genetic inheritance and cultural transfer. Second, that the notion 'pragmatic information' falls in line with the notions of 'embodied cognition' and 'action-perception' that currently dominate the study of cognition.

9.4.3 Pragmatic Information

Pragmatic information is an aspect of semantic information. This view is the starting point of a study entitled "Shannonian, semantic and pragmatic geoinformation" (Portugali 2004a). More specifically, the paper shows that while semantic information refers to the meaning conveyed by a message or object, pragmatic information refers to the action it affords, in other words, to its action-related meaning. For example, the semantic information conveyed by a certain object in the environment might be that it is a rock, a tree, a river, a road, etc., while the pragmatic information afforded by these objects is that the rock is seatable (or not), the tree is climbable (or not), the river is swimmable and crossable (or not), the road is drivable, walkable, seatable (or not) and so on. Pragmatic information is intimately related to Gibson's (1979b) notion of *affordance*.

Now, take Lynch's second element – *path*, or to be more specific, take roads in the city of Tel Aviv-Yaffo (Fig. 9.5). As can be seen, all roads afford the action of driving, some roads afford also moving in between focal points in the city, while only a few afford driving or moving between focal points and crossing the city from one side to the other. As a consequence, when we wish to categorize the road network of a city (Tel Aviv in this case) by means of the index j, we'll have an index (category) $j1$ that consist of a large number of relatively short roads, a much smaller number of $j2$ roads, and a few $j3$ roads. As in most cities, in Tel Aviv each road is unique and different from all other roads by its specific location, landscape and

Fig. 9.5 The road network of Tel Aviv-Yaffo

name. However, while people will not be able to memorize all the short roads that were categorized as index *j*1, they will have no problem memorizing each of the roads that were categorized and indexed as *j*2. and *j*3. This was confirmed by an empirical study conducted by Omer et al. (2005) and by Omer and Jiang (2008).

From the above follows that, compared to the roads of *j*1, the roads of category *j*2 afford less Shannonian information but a higher level of pragmatic information. There is a process of circular causality here: Drivers' action in the city is influenced (determined) by the pragmatic information afforded by its road network – they drive more on the *j*2 and *j*3 roads. As a consequence, they are exposed more to the specific structure and uniqueness of these roads and consequently remember them better, and so on in circular causality. Such roads thus become *paths* in Lynch's sense. The same can be said on the rest of Lynch's elements: landmarks, nodes and junctions.

To generalize: in a landscape (or any set of geographical objects) where all objects are different, the Shannonian information is very high, but the pragmatic information (the action afforded by this landscape or data) is low. A possible solution is to compress the information by means of categorization and the indices *j*. It is common in such a process that the number of objects in one (or few) of the categories *j* is small to the extent that it affords high pragmatic information. Such objects then become *elements* in Lynch's sense. This is illustrated in Chap. 8 above in Figs. 8.2 and 8.11 (rows 3, 4) and in Fig. 9.6.

Fig. 9.6 The gray-colored buildings indicate urban objects that due to their structure convey high pragmatic information and thus have the potential to function as landmarks. Black buildings refer to the same effect on a walking person
(*Source*: Portugali 2004a)

9.4.4 Urban Elements

Our study of information in the city sheds new light on urban elements as external representations, and by implication on the classical Lynchian elements. First, it can be said that all the artifacts that make the face of the city are, by definition, external representations. To this we can now add that urban artifacts are representations also due to the fact that they embody information – Shannonian, semantic and pragmatic – and that this property can be given precise mathematical content. Looking at Lynch's five elements from this new perspective, it may be seen that landmarks, nodes, paths and edges are significant in forming the image of the city due to the fact that their information content is high. On the other hand, districts (to which we can also add road networks) convey information due to their nature as urban spatial categories with the implications discussed above.

Lynch's elements refer, as can be seen, to what we've just termed as 'innate semantic information'. A more complex examination of the face of the city must include the other forms of semantic information. One way to do so is to examine the face of the city in terms of a play between two dichotomized classes of urban artifacts: *unique artifacts* versus *redundant artifacts*. In Table 9.1 we suggest a typology of urban artifacts based on this dichotomy. As elaborated in Table 9.1, unique artifacts refer to urban patterns that because of their uniqueness have a high value of Shannonian information and are therefore better remembered than other

Table 9.1 Two dichotomized classes of urban artifacts: *unique artifacts* vs. *redundant artifacts*

Redundant artifacts	**Outdoor furniture**	These include pavements, benches, streets' lights, telephone booths, bus stops, underground/ Metro/S-band/Subway, signs, trees and also moving elements such as buses, trams, trains, etc. Thus one can talk about a typical London bus or underground station and so on.
	Buildings	Buildings are among the most redundant and repetitive of the urban elements. And despite the fact that they are not all identical, they still form categories to the extent that one often speaks of a typical Parisian building or a typical Tel-Avivian residential house.
	Urban scenes	Here we refer to a configuration of buildings, "urban furniture", roads, etc. that together form a scene typical to a certain city.
	Road network	New York, for example, is typified by its 'iron grid' road network, while the Old City of Jerusalem by its winding streets and alleys. In both cases one might find it difficult to recognize one street from the other, but the general character of all streets is easily recognized and remembered.
Unique artifacts	**Geometrically unique**	The five elements suggested by Lynch (Fig. 6.7) provide a good example here. Their uniqueness and prominence in the city result from being geometrically and thus visually different from their environment.
	Symbolically unique	Here we refer, on the one hand, to geometrically unique elements that have become a symbol of their city. Eiffel Tower in Paris has become a symbol of its city (but not Tokyo Tower which is a "copy" of its Parisian brother), the Empire State Building and the Statue of Liberty have become symbols of New York, while the Corcovado with the Statue of Christ the Redeemer, the symbol of Rio de Janeiro. On the other hand, complexes such as Westminster with its Big Ben in London, the Arc de Triomphe in Paris and the Copa Cabana in Rio de Janeiro, have become a symbol of their cities despite the fact that geometrically and visually they are rather common and not very distinguished.
	Legendarily unique	This sub-class refers to elements such as the Balcone di Guilietta in Verona (Fig. 8.3), the Via Dolorosa in the Old City of Jerusalem, that we've mentioned above, or the Synagogue of Prague that is associated with the story about the Golom of Prague. What makes these places significant urban artifacts is the legend associated with them

patterns. As a consequence, these unique urban patterns are more intensively employed in shaping people's images of the face of the city. The distinction just made between the various forms of semantic information is of direct relevance here. Unique urban elements can be further subdivided into *symbolic* and *legendary*. The result gives us three subclasses differing with respect to the source of their uniqueness. On the other hand, redundant artifacts would refer to urban artifacts that, because of redundancy and repetition, form a category with the properties noted above. A convenient way to distinguish between the various categories here is by reference to their scale. Thus in Table 9.1 we identify four such subtypes: *outdoor furniture, buildings, urban scenes*, and *road networks*.

An interesting implication of the above typology is that information in the city is scale dependent. First, as we've just seen, one can study information at various scales as above. Second, an information decline at one scale (i.e., a building) might imply an information gain at the global scale of the neighborhood or the city.

9.4.5 SIRN: A New View on Categorization and Pattern Recognition

In terms of SIRN's 'public with common reservoir' submodel, the city's semantic and Shannonian information provide the basis for people's further action in the city. Such action might be taken within the frame of the city's existing categories, but it might also extend beyond them and re-categorize the city. In the first case, the result will be a process of reproduction that perpetuates the prevailing semantic and Shannonian information structure of the city. In the second case, it might have the effect of a mutation, that is, it might bring a change or even a phase transition in the face of the city. Sections 9.2.3 (The Gaudi effect) and 9.2.4 (concerning the role of central places in urban categorization) refer to such cases, that is, to situations where changes in the quantitative (Shannonian) information structure of the city have the effect of a control parameter that beyond a certain threshold gives rise to a phase transition, a new order parameter, and a qualitative change in the city's semantic structure.

From the above follow interesting implications for the general theories of categorization and the synergetic paradigm of pattern recognition. With respect to the first, our study of the face of the city indicates the potential of looking at categorization from the conjunction made here between information and pattern recognition in a spatial context (the city). This gives rise to a whole set of new general questions that have been raised above with respect to the more limited issue of information in the face of the city.

With respect to synergetics, as already noted, the SIRN model suggested above for semantic information in the city differs somewhat from synergetics' standard paradigm of pattern recognition. The conceptual and mathematical frameworks that we develop in Chap. 8 and in the present chapter can thus be regarded as a starting point for a synergetic theory of categorization in general. Figure 9.7 compares the original paradigm of pattern recognition with the process of categorization by means of pattern recognition developed above and shows how the first might be transformed into the second. As can be seen in Fig. 9.7, the process of pattern recognition starts when a part of a pattern is offered to the brain/computer. In categorization, per contra, the brain/computer is offered a complete pattern. In both pattern recognition and categorization, the process proceeds when the offered pattern is being complemented. In pattern recognition, however, it is complemented in a specific way according to one of several complete patterns that are stored in memory. In categorization there is no stored pattern so that the pattern is being complemented in a

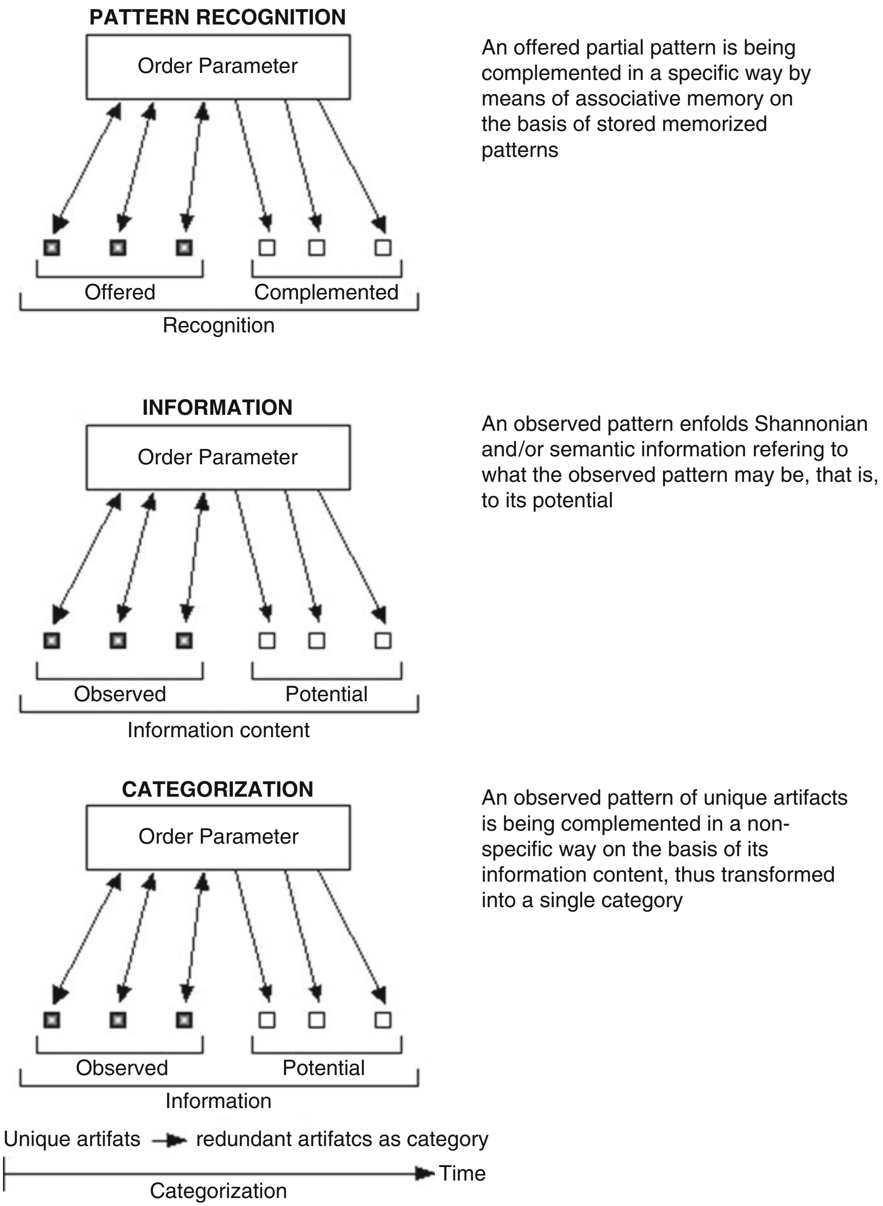

Fig. 9.7 Pattern recognition, information and categorization

nonspecific way by reference to internally represented schemata that emerge in the process. Such schemata are related to the nature of figural information noted above. That is, that information refers to and measures the potential of patterns.

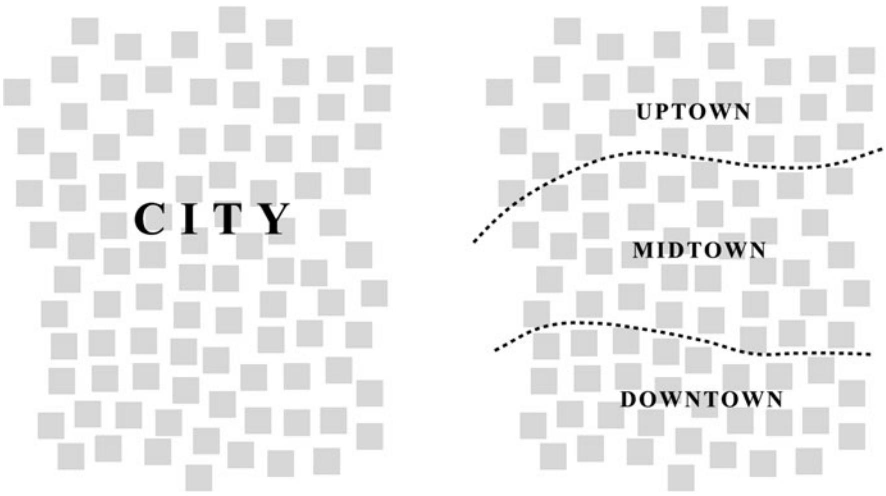

Fig. 9.8 Imagine a city (*left*) where all buildings are different from each other. In such a city information is very high and categorization (*right*) will entail information compression. Now imagine a city (*left*) where all buildings are identical to each other. In such a city information is very low (zero) and categorization (*right*) will entail information inflation

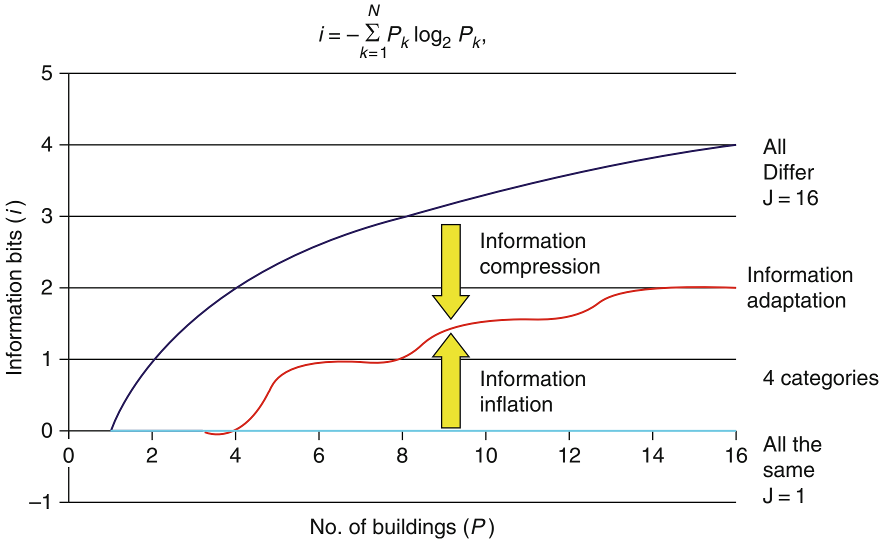

Fig. 9.9 The interplay between information compression and inflation entails information adaptation

Needless to say, a full discussion of categorization and synergetics extends beyond the boundaries of the present chapter. Both will have, therefore, to await subsequent studies that we intend to develop in the future.

9.4.6 Information Adaptation

Following the findings in the previous and the present chapters, we (Haken and Portugali, in preparation) started a study that goes deeper into the relations between Shannonian and semantic information. This study shows that in addition to the above finding that Shannonian information cannot be defined independently of semantic information, Shannonian and semantic information are interrelated as two interacting aspects of a single process that we term *information adaptation*. We further show that information adaptation involves an interplay between processes of *information compression* and *information inflation*.

Consider the process of pattern recognition as interpreted by synergetics: information-wise, a pattern recognition task starts when a person (or computer) is offered partial information about a pattern and is asked to produce the whole information about it. As illustrated above, according to synergetics, such a task is implemented by means of *associative memory*, a process of self-organization, competition between order states, the *slaving principle* and the emergence of an *order parameter*. In our new paper we show that pattern recognition can in certain circumstances entail information compression (as in the case of face learning), while in others information inflation (as in the case of interpretation of caricatures, for instance). We further show how this applies to cities: As shown in Fig. 9.8 in certain circumstances categorization of the city might lead to information compression, while in others to information inflation. These two processes as noted are two aspects of information adaptation – a process that by means of self-organization adapts the structure and form of the city to humans' (its inhabitants') information processing capabilities. Figure 9.9 illustrates this interplay between information compression and inflation that end with information adaptation. [See discussion on the implications to the notions of space and place in Chap. 11 below.]

9.5 Concluding Remarks

Our aim in this chapter was to open a discussion on the nature and role of external representations in the overall process of cognitive mapping, that is, of objects and artifacts in the environment. This issue, which was one of the founding questions of Lynch's (1960) *The Image of the City* and by implication of cognitive mapping studies, has since been neglected. We have discussed this issue by reference to 'the face of the city'. By so doing we have given our study a specific focus and have forged a link to Lynch's original study. But the issue is of general nature as may be understood.

We have approached this study of the face of the city from three perspectives: Shannon's information theory (Shannon and Weaver 1949); Haken's (1988/2000) study on *Information and Self-Organization* with his notion of semantic information; and SIRN, which emphasizes the role of external representations in the process of cognitive mapping (Chap. 7, above). We were able to show that externally represented city elements that are specifically important in constructing the image of the city are also those elements that enfold and convey the highest quantity of Shannonian information.

Despite the preliminary nature of our study, its implications are already rather surprising – as can be seen in Sect. 9.3 above. These preliminary results open several new predictions and research directions. For example, the relationship between the degree of information afforded by urban elements (measured as suggested above) and the degree of their memorization by subjects; the implications of the link we suggest between information theory and processes of categorization in the city to issues such as systematic distortions in cognitive mapping, spatial learning and way-finding behavior; the relationship between our theorization of the face of the city and urban dynamics; the possibility of integrating information measures in geographical information systems, and so on. In fact we have already started to develop these and other issues that are implied by our present study. We have done so in several ways: first, by further theorization; second, by making our information measures in the context of real cities operational; third, by empirically testing our predictions with subjects in real urban situations; fourth, by integrating some of the principles found in the present study in models that simulate urban dynamics as suggested in Part IV below.

Chapter 10
Notes on the Category 'City'

10.1 Introduction

Cities are huge artifacts – among the largest artifacts ever produced by humans. Each city is also an environment – an artificial environment (see next chapter). For about half the world's population, the city is the environment within which they live, act and behave. Through their action and behavior, people constantly reproduce and change that environment. The city is also a category – a cognitive construct in the mind of people that refers to the many city instances that exist in the world.

This chapter examines the entity 'city' from the perspective of cognitive science's discourse on categories. The motivation to do so follows our research projects *Self-Organization and the City* (Portugali 2000) and *SIRN* (*Synergetic Inter-Representation Networks*). The latter was introduced in the previous chapters as an approach to cognition, cognitive mapping and urban dynamics. Both projects suggested interpreting the city as a *dual* self-organizing *system*. Dual in the sense that each agent operating in the city is a local, cognitive, self-organizing system, while the city as a whole is a global, urban self-organizing system. Treating the city as such raises a twofold question regarding the boundaries of the system under investigation: the boundary of the city as a global urban system; and the boundary of the cognitive system used in the categorization of cities.

In the domain of cities and urbanism, the first aspect of the above question was often discussed under the title "What is a city?" On the face of it the question is trivial – cities have existed for more than 5000 years, most people in today's world live in cities, cities of today have representative governments and clear-cut municipal boundaries, and so on. The fact is, however, that the various attempts to answer this question ended in confusion. Consider, on the one hand, Gordon Childe's (1950) ten-point definition of a city in his seminal paper "The Urban Revolution" in ancient Mesopotamia. On the other hand, take the attempts in the 1960s to standardize and define metropolitan areas (see details in Haggett 1975, pp 352–356), or more recent discussions of 20th century cities. "Again and again,". writes Harvey (1996) in "Possible Urban Worlds" – the concluding chapter

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of his book – "I am struck . . . by the difficulty of designing an adequate language . . . to grasp the nature of the problem", (ibid, 416), that is, of cities and urbanism.

In several subsequent studies, it has been demonstrated that the above difficulty can be alleviated if we approach the city from the perspective of cognitive science's recent discourse on categories and categorization (Portugali 1996c, 2000). Section 10.2, "Cities from the point of view of cognition", summarizes the main points of the above approach.

While the application of cognitive science's categorization research to the domain of cities helped clarify the nature of cities, it has, at the same time, exposed some limitations of cognitive science's approach to categorization. In particular, the fact that it tends to treat the production and dynamics of cities as external to, and independent of, the process of categorization, and to overlook the implications of the relative large size and age of cities, compared to small objects that are normally referred to in cognitive studies. Section 10.3 on "The city – a peculiar category" elaborates on these issues.

Some of the above limitations are a matter of disciplinary attention and research interest. Others, however, are rooted in the major paradigms of cognitive science, that is to say, in the second aspect of the question previously mentioned – the boundary of the cognitive system used in the categorization of cities. Section 10.4 – "The boundary of the cognitive" – discusses *classical cognitivism* that dominated cognitive science since its emergence in the mid-1950s, and *embodied cognition* that has dominated the discourse on categories in the last three decades. From the discussion it follows that the limitation of both in dealing with the peculiarities of the category city is a result of their tendency to exclude artifacts and the process of their production from the domain of cognition and categorization. The discussion then concludes by suggesting SIRN as an approach to cognition and categorization that in certain tasks and contexts treats the behaving human agents, and the city that is being reproduced by their action and behavior, as a single cognitive system.

10.2 Cities from the Point of View of Cognition

10.2.1 The City as a Classical Category

From the point of view of cognition, the city is first and foremost a category (Portugali 2000, Chap. 1). Looking at cities from this perspective, it has been shown that students of cities and urbanism tend to look at cities in terms of the so-called approach of *classical cognitivism*. That is to say, they tend to assume implicitly that cities form a category by virtue of a set of shared necessary and sufficient conditions that differentiate the members of the category 'city' from nonmembers (such as villages, or farms, for example). This perception of cities can be termed "the city as a classical category". Much of the confusion regarding the nature of the city and questions such as "What is a city?" are, to my mind, due to a misconception of the nature of categories – that is, due to the fact that students of cities and urbanism tend to adopt the classical view of cities as if it was an absolute truism, not being aware of cognitive science's findings that 'classical categories' are one among several types of category.

10.2.2 The City of Wittgenstein

Instead of looking at the cities in terms of "classical categories", I've suggested (Portugali 2000) examining them in terms of Wittgenstein's (1953) notion of "family resemblance" as described by him in paragraph 66 of his *Philosophical Investigations*. In that paragraph, Wittgenstein uses the example of the category "game" in order to demonstrate that the members of many categories do not share common properties and, by implication, do not form categories by virtue of some necessary and sufficient conditions. Games still make a category, however, by forming a *family resemblance network*. If you look at the various proceedings that we call "games", writes Wittgenstein,

> "You will not see something that is common to all, but similarities, relationships and a whole series of them at that . . . Look for example at board-games, with their multifarious relationships. Now pass to card games; here you find many correspondences with the first group, but many common features drop out . . . when we pass next to ball games, . . . And the result of this examination is . . . a complicated network of similarities overlapping and criss-crossing: sometimes overall similarities, sometimes similarities of detail".

The same applies to the category city (Portugali 2000, pp 11–12). If one looks, for example, at

> "North American cities, with their high-rises, down town, suburbs etc. and specific architecture", and then at European cities, one finds "many correspondences with the first group, but [also] many common features [that] drop out and others [that] appear. When [one passes] next to the cities of South America, much that is common is retained, but much is lost. And we can go through the many other groups of cities in the same way; can see how similarities crop up and disappear. And the result of this examination is that we see a complicated network of similarities overlapping and criss-crossing: sometimes overall similarities, sometimes similarities of detail".

This view of the city as a family resemblance network has been termed (Portugali, ibid) "The city of Wittgenstein".

10.2.3 The Embodied Cities of Experiential Realism

Wittgenstein's "family resemblance" was adopted by cognitive scientists, to a large extent due to studies by Rosch and coworkers (1976) on categorization and concept formation, and also due to Johnson's (1987) and Lakoff's (1978) approach of *experiential realism*.

Rosch and coworkers have added to Wittgenstein's family resemblance the notions of *prototypicality* and *basic-level*. That is, that some instances in the family resemblance category are more typical or prototypical, so that an orange, for instance, is "more" of a fruit than a melon. Johnson and Lakoff have taken these views on categorization to their logical conclusion. They have done this in two (largely coordinated) studies: *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason*, by Johnson (1987) and *Women, Fire and Dangerous Things: What Can Categories Reveal About the Mind*, by Lakoff (1987). From both it follows that nonclassical categories challenge the information processing approach that has been the mainstream of cognitive science since its birth in the mid-1950s: that cognition is essentially an algorithm executed on the hardware of the brain, principally independent of the body and its environment, and that likewise syntax is independent from semantics and the language faculty from any external cognitive influence (Lakoff 1987, p 182). In contrast to this view, Johnson and Lakoff have developed the notion of *experiential realism*, according to which cognition is *embodied*. Note, that a short introduction to these views was already given in Chap. 6 Sect. 6.1.4 under the title of "embodied cognition". This view originated to a large extent out of the discussion about categorization – which is the context of the present discussion.

Johnson and Lakoff did not invent the notion of embodied cognition. As we've seen in Sect. 6.1.4, since the 1970s theories of embodied cognition have been developed – independently and in parallel – in several domains of cognition. Gibson's (1979b) ecological approach to psychology is an early example, Edelman's (1992) TNGS (Theory of Neural Group Selection) has developed an embodied cognition approach in the context of neurology, Kelso (1995), Thelen (1995), and Freeman (1999) represent a self-organization interpretation of embodiment in the domains of behavior, development and the olfactory system, respectively. In all the above examples, the emphasis is on embodiment in the sense of *action-perception*, that is, that contrary to the classical view, in which action and perception are treated as two independent faculties (Varela et al. 1994; Tschacher 2003), here the suggestion is that bodily action is part of perception. Note that Johnson's and Lakoff's embodied cognition is explicitly related to categorization, whereas in the other theories embodied categorization is implicit.

According to Johnson's and Lakoff's "linguistic embodied cognition", a person's basic bodily experience in the environment entails *image schemata* that by means of imagination (metaphors metonymy, etc.), are then used to relate to the world and to categorize it. One of the more dominant experiential image schemata that is derived from our basic geographical experience in the world is *center-periphery*. It shows up in many categories that have a radial structure with the prototypical best exemplars at the core, from which they are related to other peripheral instances of the category through similarities, metaphors and family resemblances.

As can be seen, there is a tension here between geographical experience of center-periphery phenomena on the level of tokens (individual instances) and center-periphery phenomena on the level of the categories themselves. Methodologically, the two should be clearly distinguished. However, as will be shown below, in the case of cities, they run together. This view is in line with Johnson (1978, p 125) who writes that the center-periphery schema

> "*... shows itself not only in the structure of my perceptual field, but equally important as a structure of my social, economic, political, religious, and philosophical world. Those 'objects' that stand forth as significant in my experiential field are both concrete and abstract entities ...*"

To the above quotation I would add that from the point of view of SIRN, the center-periphery schema shows itself not only in one's perceptual field and as a structure on one's social, economic etc., worlds, but also as a structure of one's *urban world*. As a result, the city too is a category typified by a core-periphery structure. It should thus be perceived as a huge family resemblance network of connected similarities. In this evolving and diffusing network, one can identity core and periphery: cities, images, and urban phenomena, which in a certain space-time moment capture the central area of the net as the most typical or prototypical exemplars as well as cities that form the periphery. They are all related to each other by means of imagination, that is, similarities, metaphors and family resemblances. Cities looked upon from this perspective have been termed "*The cities of experiential realism*" (Portugali 2000, Chap. 1).

10.3 The City – A Peculiar Category

Cities are very large, complex, self-organizing artifacts that have existed as a category for more than 5,000 years. None of the above properties that concern *size*, *complexity* and *self-organization*, the production of *artifacts* and *time*, appears in cognitive science's research on categories. And yet, they are central to the category city. As will be shown below, however, their exposure and study in the context of cities feeds back, firstly, on categories at large and thus contributes to a general theory of categorization, and secondly, on other geographical categories that share some or all of the peculiarities of cities. For example, 'continent', 'country' or even a geographical category such as 'Mediterranean' (Portugali 2000a). Five such peculiarities are discussed below. The first two are related to size, while the others to artifacts, self-organization and time, respectively.

10.3.1 Cities Are Very Large Objects

Cities are very large objects, yet the cognitive science discussion of categories has concentrated almost solely on small, "table-top" objects, as Smith (1999) calls them. As discussed elsewhere (Portugali and Haken 1992 and in Chap. 6 above) with respect to pattern recognition of large-scale geographical objects and to the construction of cognitive maps, this quantitative size difference entails qualitatively different cognitive processes. This difference shows up also in the domain of categories and categorization. In small-object categorization, the central question is "What makes an entity a member in a category?" and "What makes a specific instance of a category prototypical, or best exemplar, of the group?" We've seen above that these questions are important also with respect to cities. However, the more interesting and relevant question in the domain of cities concerns what Lynch (1960) has called *legibility* and what Gibson has termed *affordability* – the extent to which *some urban components* are more legible, information affording, prototypical or best exemplar of a certain city and of the category city as a whole.

Having said the above about cities, one can now realize that the same also applies to small-scale objects: Some components of an object are more informative than others about the object and the category of which it is a member. For instance, a shard of the rim of a pottery vessel is usually more informative of the whole vessel than a shard from the base or the body – a fact well known to archaeologists when they sort pottery shards. In cognitive science, it is commonly assumed that categorization is implemented by reference to the properties of the whole pattern of objects – Smith's et al. (1998) study on alternative strategies of categorization is an example. The implications are that when we categorize, not just cities, but entities in general, we rely not only on the properties of whole exemplars of categories, but also on the properties of the components of exemplars. The new dimension that the study of cities can contribute to the general discourse on categorization thus concerns the conjunction between pattern recognition and categorization. Its central question is therefore this: "What *components* in a specific instance of a category are best exemplars, or prototypical of, the instance and the category?"

10.3.2 Each Single City Is Itself a Category

This is a corollary from the above. In small-size categories, there is a clear distinction between the category and the many instances that make it. The category 'chair,' for example, refers to a family resemblance network of actual chairs. The situation is different, however, with respect to cities and other large-scale categories. Here, there is a back and forth movement between city categories, and the associated object, and inhabitant-categories. Paris, New York, London and the like are, on the one hand, instances of the category 'city' (or 'metropolis') but on the other, each is so big that it is also a category unto itself. Thus, the many instances that constitute the category 'Paris' include, in addition to its specific 'Parisian' pavements, 'Parisian' coffee shops, restaurants, typical 'Parisian' street corners, its famous quarters, monuments, museums and so on, also millions of people that regard themselves, and are regarded by others, as 'Parisians'. "The fact that a category like 'New Yorkers' can make sense to the polyglot millions who occupy that place", writes Harvey (1996, p 323), "testifies precisely to the political power that can be mobilized and exercised through activities of place construction in the mind as well as on the ground".

This is indeed so. But before the category 'New Yorker' testifies to the above political power, it testifies to the cognitive processes that enable it in the first place – to the peculiarity of many geographical categories - that because of size, each is cognized, on the one hand as an instance of a category, while on the other, as a category unto itself. It further testifies to the intimate connections between cognitive processes associated with the categorization of big objects (like cities), place construction and Self. Can the same be said about categories at large? The answer is positive, at least partly: Each 'nature-made' entity can, in principle, be regarded in this way even though we do not tend to apply this potential to all entities. This leads to a hierarchical view on categories and to a distinction between two types of categories: On the one hand, there are large and complex categories, such as cities, countries, continents, the members of which are themselves cognized as categories. On the other hand, there are small and simple categories (pen, chair, fork, etc.), the members of which are cognized as 'instances' of a group but not as independent categories. [This distinction is similar, but not identical, to the distinction between 'basic level' and super ordinate categories].

10.3.3 Cities Are Artifacts

As discussed above and as will be further elaborated below (Chap. 11), cities are artifacts and as such are a product of human labor and imagination. Yet the discourse on categorization in cognitive science fails to appreciate the consequences of that fact. That is, that many categories are not just objects out there in the environment that the brain/mind has to recognize and categorize, but that a lot of categorization is implemented by *practically making* the categories. The carpenter or the architect are not producing some shapes that other people then categorize as 'chair' or 'building,' but they are producing, intentionally, specific instances of a chair and a building. If their products are exact copies of existing chairs/buildings, then nothing dramatic has happened in these two categories. But if, for some reason, their new instances differ from previous ones in some way, they have changed the family resemblance network of their respective categories, and have opened new possibilities for entities to be categorized as 'chair' and 'building'.

Artifacts are, by definition, external representations of imagined or planned artifacts, themselves internal representations of artifacts as they appear in the external world. Categorization with respect to artifacts thus involves an ongoing SIRN interplay between internal and external representations; that is to say, on the one hand, perception and pattern recognition while on the other, pattern formation and production in the environment. As first suggested by Haken (1979, 1996) and later by Portugali (2000 and above Chap. 4) with respect to cities, pattern formation and pattern recognition are two aspects of a single process.

10.3.4 Cities Are Self-Organizing Systems

Cities are very large artifacts. In *Self-Organization and the City* (Portugali 2000) as in the present book, the suggestion is to see the artifact city as the *collective* product of a synergistic process involving thousands and millions of participants, each acting locally in a relatively independent manner. The amazing outcome of these, seemingly chaotic, processes are highly ordered and organized artifact: Cities are genuine self-organizing systems. Despite the enormous amount of planning that is invested in cities, in the last analysis, their global pattern emerges spontaneously "by itself" – by means of self-organization. The city belongs in this respect to a class of large-size artifacts/categories that includes 'writing', 'E-languages' (see definition in the next chapter) and other categories that together form culture and society.

As in previous cases, here too, the suggestion is that while the property of self-organization is prominent of cities, it is, in fact, a property of artifacts/categories at large. What is specific to cultural self-organizing categories such as cities, languages and the like is that their elementary parts are human agents, each of which is itself a self-organizing system. The result is the dual self-organizing process noted above, by which the agents participate in the self-organization process of the city as a whole, which in its turn participates in the specific self-organization process of each individual agent. As elaborated in some detail above (and in Portugali 2000), in the domain of social theory, this process is often termed 'reproduction', whereas in the domain of self-organization – 'circular causation'.

From the above follows two types of artifacts and categories: *engineered artifacts/categories*, the final form of which can be intended, planned, engineered and thus controlled, versus *self-organized artifacts/categories*, the final form of which can indeed be intended or planned but in the last analysis emerges by means of self-organization.

10.3.5 The Category 'City' has a 5,000 Year-Long Life Span

Cities – the artifacts that constitute the category 'city', and urbanism – the self-organization process that makes them, have been with us for more than 5,000 years. Despite the fact that the city is not the only category of this nature, the discourse about categories tends to ignore the time dimension and the often-long life span of categories. During their long life, cities have changed to the extent that there is no common denominator between the 'first' and the 'last' city aside from the name. From this observation alone, it follows that the city is not a classical category, but rather a special kind of a Wittgensteinian family resemblance network of entities – a complex network of connections, extending in time and space – that at a certain space-time point were perceived as cities by virtue of some features they shared with other entities, which at their time and place were perceived as cities by virtue of some properties they shared with other such entities, and so on.

It further follows, however, that the notions of 'prototype,' 'best exemplar' etc., are limited in their scope: the prototype, or best exemplar, city of 5000 years ago is different from today's and from the prototypes and best exemplars of many urban cultures in between. The implication is that like the many instances of the category city, its notions of prototype, basic level, best exemplar and the like, are themselves subject to an evolutionary/self-organization process too. In *Self-Organization and the City* (Portugali 2000) the suggestion was thus to interpret the process of urbanism in terms of a sequence of urban revolutions that bring about a new urban culture with a new city form, a new prototypal cities, basic level, best exemplar and the like.

10.4 The Boundary of the Cognitive

The first part of this chapter has demonstrated how a cognitive science approach to categories can enrich our understanding of cities. The second part of the chapter, "The city – a peculiar category", was designed to demonstrate how a study of the category city can add insight to cognitive science's understanding of categories. We have seen, firstly, that the peculiarity of the city as a large-scale spatial object exposes a new form of categorization hitherto overlooked in the study of mind – categorization by means of the more informative parts of objects that constitute the category. Secondly, that from the peculiarity that "each single city is itself a category" emerges a hierarchical view on categories and a novel distinction between categories that humans tend to categorize as having a singular identity and categories that are treated by the mind as having only a group identity. Thirdly, that the "cities are artifacts" peculiarity reveals that a lot of categorization is implemented by practically making the categories. The implication is that in certain tasks/contexts, artifacts and the process of their production are integrative to the cognitive process and system. Fourthly, from the 'cities are self-organizing systems' peculiarity follows two types of artifacts: artifacts the form of which can be "engineered" and artifacts whose form emerge by means of self-organization. Fifthly, from the peculiarity, "the category city has a 5,000 year-long life span", it follows that "prototype", "best exemplar", "basic level" etc. of categories are subject to a temporal self-organizing evolutionary process.

The above properties of mind have escaped the attention of mainstream cognitive science because of its tendency to overlook large-scale/size entities/categories, not to study artifacts, the self-organizing property of categories and the long life span of many of them. The result is that it cannot say anything significant on a phenomenon such as a city. It is out of its terms of reference – out of its domain of study. The same applies to other categories such as "cultural group", "cultural area", "urban ghetto" and the like. As discussed in the previous chapter, the majority of cognitive studies on large-scale entities such as cities (e.g., cognitive mapping studies) tend to follow cognitive science in this respect. They too do not deal with the dynamic and production of cities and other geographical artifacts. They start with the individual and his/her brain in order to theorize about the individual's image of, or behavior in, the city, but here they stop. The question of how this brain-derived behavior or image takes part in the city's dynamics remains with no answer.

Can there be a cognitive approach that will explicitly consider the size of cities, the fact that they are artifacts and self-organizing systems, their long life span? With respect to size and long life span the answer is, to my mind, positive: This is essentially a matter of disciplinary attention. There is no conceptual barrier preventing cognitive scientists extending the notions of "family resemblance", legibility or "affordances" to large categories and/or to categories with long life span. On the other hand, however, the city as an artifact is a complicated matter. "The contingency of artificial phenomena", writes Simon (1996, XI) in the preface to the second edition of his *The Sciences of the Artificial*, "has always created doubts as to whether they fall properly within the compass of science". Cognitive science has followed this approach and has traditionally treated artifacts as external to the cognitive system and as such 'not cognitive' [see further discussion on this issue in the next chapter]. Any deviation from this view thus implies a conceptual or paradigmatic change regarding the nature and boundaries of the cognitive system.

The question of the proper boundaries of the system under investigation is central to all system theories – theories of self-organization included. The peculiarity of the city as a self-organizing cognitive category is therefore directly related to the question of the boundaries of the cognitive system. As we've seen above (Chap. 6), according to the classical approach to cognition, self-organization is a property that typifies the brain/mind and is thus confined to the skull. Artifacts, according to this view, are external to the cognitive system and as such are "not cognitive". According to the embodied cognition view, cognition is task-specific and context-dependent and, as a consequence, self-organization might also be a property of the acting body (Varela et al. 1994; Kelso 1995; Freeman 1999). From this view follows that bodily artifacts (lexical, mimetic, etc.) might in certain circumstances be an extension of the mind (Donald, ibid), while stand-alone artifacts such as tools, an extension of the body (Gibson 1979b, p 40, Fig. 6.4 in Chap. 6 above). A third view is SIRN. As elaborated above in Chap. 7, according to SIRN, in certain contexts/tasks cognition and self-organization are confined to the skull, in others to the whole body and in yet other tasks/contexts, the cognitive system as a self-organizing system includes the brain, the body and stand-alone artifacts in the environments. The latter might be small artifacts like a lamp and large artifacts such as a city.

10.5 Concluding Notes

The study of cities, together with urban planning, design and other behavior-environment domains, belongs, at least partly, to what Simon (1996) has defined as "The sciences of the artificial". Many, if not most, of the objects studied by these sciences are artifacts – products of human thought, imagination, action and production. Thought processes and imagination are commonly regarded as cognitive. In recent years 'action' has been treated as part of perception and as such is also cognitive. The city as a peculiar category indicates that it might be useful to reconsider the status of production and stand-alone artifacts in cognitive processes and vice versa – to interpret the urban process and the dynamics of cities as SIRN processes of categorization and re-categorization.

Chapter 11
Complex Artificial Environments

11.1 Introduction

As we have seen above, complexity theories have developed in the sciences and with respect to natural phenomena and then at a later stage were applied to cities. We have further seen that the various applications to cities are based on analogies that can be made between natural phenomena and processes and urban phenomena and processes. But the validity of these analogies is only partial as cities are not natural entities; they differ from the latter in a fundamental twofold respect: first, each city is an *artifact*. Second, the parts of cities and of similar artificial systems at large, cannot be likened to the atoms and molecules of the Bénard experiment, not to light waves in the LASER, nor to the sand grains of self-organized criticality: each has mind, brain, memory, aims, plans and each is acting and behaving as a result of these aims in an unpredictable way; in short, each of the parts of cities is itself a complex self-organizing system. This latter property implies a fundamental difference: the parts of material systems are simple whereas the parts of the artifact city are complex – the city in this respect is a *dual complex artificial system*. In Chap. 6 above I've elaborated on the uniqueness of the urban agents and the duality of cities as complex systems in some length.

From the above follow three issues. The first issue concerns the ontological status of the city – what kind of artifact it is? The second issue concerns epistemology, namely, how knowledge about the artifact city is created by cognition (perception, behavior etc.), by production (self-organized, planned and designed) and by the study of cities. The third issue concerns the implications of the above two issues to the relations between the study of cities as a complex artificial environment and the main body of urban studies that in the last three decades is dominated by the social theory oriented approaches to the study of cities.

The above three issues are discussed in the following three sections. Section 11.2 focuses on the relations between cities and languages. The choice of language is first due to the fact that several students of cities have made an analogy between language and cities and second, because in linguistics there has been a debate on whether language is a natural or artificial entity. Section 11.3 commences from Simon's (1966/1999) book *The Sciences of the Artificial* that as the name indicates,

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deals with the difficulties and possibilities of developing a science of artifacts. Section 11.4 puts CTC in between two notions: *space* that has been the key concept of the positivist quantitative first culture cities and *place* that has played a similar role in the SMH approaches to cities.

11.2 Cities and Languages

11.2.1 Chomsky's E- vs. I-Languages

In *Knowledge of Language: Its nature, origin and use*, Chomsky (1983) makes a distinction between external and internal languages (E- vs. I-languages, respectively). E-languages are the spoken languages (Hebrew, English, French, Chinese, etc.), while I-language is the innate universal language with which, according to Chomsky, every human being comes to the world, and by means of which he or she acquires specific E-languages. Evaluating these two concepts of language from his cognitive scientific approach to the study of language he writes the following:

> *The notion of E-language has no place in this picture. There is no issue of correctness with regard to E-languages, however characterized*, **because E-languages are mere artifacts**… **the concept appears to play no role in the theory of language**… *The technical concept of E-language is a dubious one in at least two respects. In the first place …* **languages in this sense are not real-world objects but are artificial**, *somewhat arbitrary, and perhaps not very interesting constructs. In contrast … statements about I-language … are true or false statements about something real and definite, about actual states of the mind/brain and their components...* (1986, pp 26–7, bold added).

Chomsky here suggests that E-languages are artifacts and therefore "*somewhat arbitrary, and perhaps not very interesting constructs*". I agree with the first part of his suggestion, namely, that languages are artifacts; but I disagree with the second – that they are "not very interesting constructs" – not only because artifacts, in general, and the artifact "city" in particular, form our topic of interest in this book, but mainly because I see the production of artifacts as part of cognition – this is one of the main implications from the notion of SIRN that provides the theoretical foundation for this book (for details, see Chap. 7 and in particular Sect. 7.3.6.4 and Fig. 7.9). Two additional reason are the following: firstly, because, the association between Chomsky's theory of language and the study of cities has already produced some interesting results; a second reason is that very much like cities, the artifacts E-languages are *complex systems*. Let us start with the first reason.

Possible links between Chomsky's theory of language and urban theory have already attracted students of cities. Two prominent examples are Hillier's *space syntax* (Hillier and Hanson 1984; Hillier 1996) and Alexander's *pattern language (*Alexander et al. 1977). Both employ the association to language to shed light on the nature of artificial environments in general and of cities in particular.

11.2.2 Space Syntax

Space syntax is an approach to cities and architecture developed by Hillier and coworkers (Hillier 1996; Hillier and Hanson 1984) suggesting that *space* can be employed as a common language of buildings, settlements and cities. This common language, they claim, has the potential to give rise to a theory of the built environment capable of dealing with the interrelations between structural and functional relations of cities in themselves. Such a spatial theory can then be related to other theoretical domains that are active in cities. In *The Social Logic of Space* Hillier and Hanson (1984, p 50) write:

> *In natural languages a syntactically well-formed sentence permits meaning to exist, but neither specifies it nor guarantees it. In a morphic [architectural] language ... a syntactically well-formed sentence ... guarantees and ... specifies ... the meaning of a pattern.*

Hillier and Hanson further suggest three sets of laws, according to which artificial environments such as cities evolve: Laws regarding the relations between spatial objects, "laws from society to space" and "laws from space to society" (Hillier and Hanson, ibid).

11.2.3 Alexander's Pattern Language

Alexander et al (1979, pp 49–50) make the link to Chomsky's theory of language even more explicit. The patterns of doors, buildings, neighborhoods and whole cities, they write, are natural entities that are "actually there in peoples' heads and are responsible for the way the environment gets its structure". And in an interview with Grabow (1983, p 184–5), Alexander emphasizes the difference between "his" pattern language and Chomsky's language:

> *A natural spoken language ... has a set of elements (words), a set of rules defining the possible relations between words and "the complex network of semantic connections, which defines each word in terms of other words". The pattern language of artificial environments is still more complex in the sense that "each pattern is also a rule which describes the possible arrangements of the elements – themselves again other patterns".*

11.2.4 Complex vs. Simple Artificial Systems

The second reason, as noted, is that cities and languages are complex systems. Chomsky's conceptualization of I- and E-languages is founded on the distinction between the "natural" and the "artificial" discussed above – in his words: between "real-world objects" and "artifacts". I-Language, claims Chomsky, is a natural, real-world object and thus lent itself to scientific inquiry, while E-languages are artifacts, and as a consequence their study must take place outside the realm of the sciences (probably in the Humanities and other hermeneutic, nonscientific disciplines). This view of Chomsky echoes, of course, Snow's (1964) thesis (above Chap. 1) that the "sciences" and the "humanities" form two unbridgeable scientific cultures and is related to our discussion above regarding "the science of cities".

Chomsky's view is based on the distinction between natural and artificial. This distinction is a commonplace in the philosophy of science. But complexity theories add to this distinction a finer distinction between simple and closed and complex and open systems – natural as well as artificial. An example of a closed and simple natural system is a crystal; examples of open and complex natural systems have been given several times in the text above. In a similar way we should distinguish between simple and complex artifacts. A machine is a simple artifact and as such subject to the first and second laws of thermodynamics. A human language, society, culture . . . are all artificial complex systems and cities too. As we've seen above in Chaps. 4 and 5, in order to convey the difference between closed and open systems, Prigogine with Stengers (1997) compare the natural crystal to the artifact town contending that while a crystal "is an equilibrium structure that can be maintained in a vacuum", a city is not and if you isolate a city or a town "it would die".

The interesting discovery stemming from the various theories of complex systems is that, as we've seen above, they apply to natural and artificial complex systems alike. Not because natural and artificial systems are identical, but because, despite the genuine differences that exist between them (Haken 2006), they share the property of complexity. E-languages and cities are thus similar to each other in that both are complex self-organizing systems; both are open to their environment, both have emerged as highly ordered systems out of a spontaneous complex interaction between a huge number of human agents and as complex systems both lent themselves to scientific inquiry – just like I-language.

Cities and languages as complex systems resemble each other in yet another way: both are *dual complex systems*. This is because the elementary parts of both are human agents and because each agent is itself a complex system. Historically, complexity theory was developed in light of phenomena in physics – the Bénard experiment, for example – which acted as paradigmatic case studies. In the Bénard experiment, for example, the local parts are simple entities (atoms, molecules etc.) and complexity is the property of the emerging global system. Furthermore, complexity theory's main focus of interest has always been in the processes of emergence that take place in the global system. As a consequence, only little attention was paid to the intricacies of the circular causality phenomenon that typifies complex systems. Namely, to the way emerging properties in the global system react and trigger changes in each of the local parts. The main exception here is Haken's (1983) notion of the slaving principle, which is central to his theory of synergetics.

Haken and coworkers have studied processes of slaving that typify individual agents – with respect to pattern recognition and planning, for example (Haken 1996, 1998), and also processes of slaving that are typical of whole cities and societies (Haken and Portugali 1995; Weidlich 1999). The challenge is to combine the two processes and theorize about them as two facets of a single system. The notion of SIRN introduced above (Chap. 7) is an attempt to meet this challenge.

But cities are not languages. For one thing, their products are stand-alone objects such as buildings, roads, bridges, etc. that can exist and survive independently of their producers. The products of languages are humans' voices and gestures that have no existence independent of their producers. Cities, in this respect, are akin to writing and texts – the external, stand-alone, representations of languages. The appearance of cities, some 5,500 years ago, hand in hand with writing, is, to my mind, not accidental.

A second difference concerns planning. To the best of my knowledge, there are no language planners (the attempt to "plan" the international language of Esperanto ended in failure), but there are many city planners. Moreover, unlike language, the city is full of planners and planning: professional planners and official/formal plans as well as nonprofessional and nonofficial planners and plans. Every agent operating in the city (person, family, company) is a planner on a certain level. But not one of the many planners can fully determine the final form and structure of the city. They are all *participants* in a big city-planning game (see below Part III).

11.3 Cities and the Sciences of the Artificial

11.3.1 Methodology

Methodology is often considered *the* unbridgeable gap between Snow's two cultures and by implication between CTC and social theory oriented urban studies. The gap seems clear and sharp: The methodological tools of the 'hard' sciences are reductionism, mathematical formalism, statistical analysis and explanation, while those of the 'soft' humanities and social theory the exact opposite: anti-reductionism, understanding in place of explanation, and hermeneutics in place of analysis. The gap is specifically distinguished with respect to the natural versus the artificial domains, but also inside the artificial domain, for example, with respect the specialized social sciences versus social theory approaches that reject the fragmentation of the social whole into independent disciplinary domains.

The notion 'natural sciences' is founded on the (often implicit) assumption that one can clearly differentiate the natural from the artificial. Given this assumption, the aim of the natural sciences is to reveal the laws of nature that by virtue of being natural are universal and thus objective. In the sciences, therefore, "the term 'artificial' has a pejorative air about it" (Simon 1969/1999). One doesn't want artifacts in one's data or results. All this is in sharp contrast to research domains that deal with artifacts that by their very nature are the products of human thought, labor, action and imagination and as such are influenced by social norms, politics, culture and social structure.

The apparent success of the natural sciences in revealing the properties of nature and in transforming theoretical knowledge into 'hard' technology has made them a model for a 'genuine science'. This, in turn, entailed a situation of permanent crisis, or at least tension, in the human and social disciplines that by their very definition deal with artifacts: On the one hand, we find the view that in order to qualify as genuine sciences these disciplinary domains have to adopt the methodological approach of the sciences – the so-called *scientific method*. On the other hand, we find the view that the artificial domains are fundamentally different from the natural and hence should develop their own specific methods. The disintegration of the social domain into specialized 'social sciences' such as economics, sociology, linguistics, psychology, politics, human geography and so on, follows the first view, while the insistence of social theory to treat society as a single whole that is not reducible to independent social science disciplines, follows the second view. Marx, for example, has considered his theory of historical materialism the social equivalent of Darwin's theory of evolution (Meek 1971, p 193). Frankfurt School thinkers like Habermas and Marcuse were specifically active in fostering this second view. More recently, Giddens' (1984) *structuration* theory can be mentioned, and of course SMH and PPD scholars (see above Chap. 3).

This methodological debate is a permanent companion in the artificial domains; not only as above, between the social sciences vs. social theory approaches, but also in disciplines that deal with planning and design ('is planning or urban design a science or an art?') as well as within every social science. The study of cities is not an exception. The 'quantitative revolution' in human geography and urban studies followed, as we've seen above (Chap. 2), the first line of thinking, seeking to transform the descriptive *study of cities* into an analytical *science of cities*, while the 'SMH revolution' and its subsequent postmodernist approaches, the second (Chap. 3). [For a somewhat similar debate with respect to the "hard" sciences see Feyerabend's (1975) provocative work *Against Method*].

The question of how can, or should, a specific domain become science is thus common to all sciences of the artificial. An attempt to untangle this question was made by Simon (1969/1999) in *The Sciences of the Artificial*, whose 1999 addition takes into consideration complexity theories.

11.3.2 The Ant Hypothesis

Simon starts by noting that both the natural and the artificial domains are highly complex. The great achievement of natural science was twofold: to show, following Descartes, that every complex natural phenomenon can and methodologically should, be comprehended by means of *analysis*, decomposing the phenomenon into its simple elementary parts and reconstructing the causal relations between these parts; and to show that a few purposeless and thus natural laws govern the interactions between the few elementary parts that generate the enormous complexity of nature.

Unlike natural entities, artifacts *are* the products of aims, intensions, plans, design, and engineering. The latter, according to Simon, are different forms of rational adaptation to the specific environment, social and otherwise, within which people live. Now, unlike the few and simple natural laws that are the cause of the observed complexity of the natural world, the causes of the artificial world as we observe them in reality are complex. That is, human behavior as we observe it in reality is complex. But this observed complexity should not deceive us, says Simon, because it is only an external appearance of an innately simple behaving system. As an illustration he suggests the two-part "Ant Hypothesis":

Part one

"*An ant, viewed as a behaving system, is quite simple. The apparent complexity of its behavior over time is largely a reflection of the complexity of the environment in which it finds itself*". (p 52)

Part two

"*Human beings, viewed as behaving systems, are quite simple. The apparent complexity of our behavior over time is largely a reflection of the complexity of the environment in which we find ourselves*". (p 53)

Most CTC implicitly follow Simon's Ant. This is very convenient as most CTC have strong inclinations toward economic theory and Simon's Ant behaves very much in line with the *Homo Economicus* – this one-dimensional, selfish, rational, profit-maximizing, imaginary person that is implicitly or explicitly assumed in most economic models including location theory. In particular the Ant hypothesis underlies the bottom-up agent-based and cellular automata (AB/CA) models prevalent in the last two decades. These typically start with agents that, like the Ant, have one or a few simple aim(s) "in mind". These agents come to the city and enter into a local/simple interaction with a cell, its neighboring cells and agents. The interaction between the simple Ant-like agents gives rise to an urban system that in time becomes more and more complex. As the urban environment becomes more complex, so does the observed behavior of the urban agents; but essentially it is not. The complexity is thus a property of the global system as a whole, but not of its individual parts.

This apparently makes perfect scientific sense and indeed might provide a basis for sciences of the artificial that obey the two traditional principles of scientific explanation, that simple causes give rise to a highly complex reality and Occam's Razor principle that the simplest explanation is best. But there is a "little" problem in the above scientific scheme: the notion of cognitive maps, experiments with animal behavior, embodied view of cognition and most importantly the inner rationale of complexity theories in the life and human domains, all falsify Simon's hypothesis (Portugali 2003). Let me elaborate.

11.3.2.1 Cognitive Maps

Tolman's (1948) notion of *cognitive maps* and its implications to urban dynamics are discussed in some detail above (Chap. 6). Based on a set of experiments Tolman demonstrated that rats and humans have the capability and tendency to construct in their minds cognitive maps, that is to say, information referring to the global structure of the environment. Six decades of cognitive maps studies indicate, firstly, that humans conduct their behavior in cities on the basis of their cognitive maps of them. Secondly, those urban agents never come to a city *tabula rasa*. Rather, they come equipped with two types of cognitive maps (Chap. 6): *C-cognitive maps* that are category-like and refer to agents' perception of *a City*, and/or *s-cognitive maps* that refer to agents' perception of specific cities. Both c- and s-cognitive maps refer to the global structure of cities with the implication that a substantial part of agents' location decisions, behavior and action in cities is taken in a top-down manner. And yet, as we've seen above, the vast majority of CTC and their AB/CA urban simulation models are bottom-up in their structure.

11.3.2.2 Exploratory Behavior

Ethological experiments show that rats' exploratory behavior (Golani et al. 1999) is innately complex: rats perform the same complex exploratory behavior when put in complex as well as in simple environment. According to pragmatist and ecological approaches currently dominant among students of behavior, the evolutionary rationale for this is that the innate behavior of rats, as well as of other animals, was evolutionally shaped in the context of complex environments (cf. Gibson 1979b; Freeman 1999; Varela et al. 1994). And yet, as we've seen above, CTC and their AB/CA models are built on the logic of Simon's ant, namely, they postulate that agents' "innate" behavior is essentially simple and complexity is a property of the emergent urban environment. Studies in exploratory behavior indicate that this is not the case, namely, that agents' rules of behavior are from the start complex (above Chap. 7).

11.3.2.3 Embodied Cognition

The notions of *embodied* and *situated* cognition that are now prominent in cognitive science, and the notion of SIRN, that is, Synergetic Inter-Representation Networks (above Chap. 7), falsify the Ant Hypothesis.

Agents' rules of behavior in multi-agents simulation models can be derived in two ways: by postulating a certain behavior and by reference to empirical data. The latter usually come from cognitive science – the discipline that investigates the relations between mind, body and behavior. The first way is common in economics, while the second in AI and A-life. The practice in most AB/CA urban simulation models is to follow the way of economics and to postulate the behavior of urban agents. The consequences are the two problems described above. The suggestion here as in Part II as a whole, is to follow the practice in AI and A-life and to look at cognitive science.

As we've seen in Chap. 6, the two main ontologies that dominate cognitive science are the dualist *classical cognitivism* and the nondualist *embodied cognition*. The various embodied cognition approaches are challenging the classical view not only on philosophical grounds, but mainly on empirical grounds. These empirical studies indicate that "the ghost *is* the machine", that is to say, that perception is bodily action; that agents come to the world already complex; that agents' cognition is situated in the environment within which they act, and that their cognitive system is a network extending beyond their brains/bodies to include the artifacts they produce.

The attraction of the embodied cognition ontology to AI and A-life – the domains engaged in artificial minds, bodies and environments (Franklin 1997) – is apparent: building a robot, for instance, or an artificial VR city, literally forces the builder to be aware and sensitive to the intimate relations that exist between the structure of the body/machine and its perceptual-cognitive capacities, or between the specific properties of artificial VR (virtual reality) city and agents' perceptual-cognitive-bodily capabilities in it. (On the differences between cognition and action in VR environments vs. real environments see Portugali 2005b,c).

Complexity theories with their AB/CA simulation models are common also in the domain of AI and A-life. However, unlike CTC that tend to ignore the above and to postulate agent's behavior rather arbitrarily, in the domain of AI and A-life agents' rules of behavior are treated as embodied and situated, namely, they are neither fixed nor pre-determined. Rather, they are emergent forms of adaptation to specific tasks and the properties of the environment.

11.3.2.4 Self-Organization

As we've seen above and will further see below, *Self-Organization and the City* (Portugali 2000) is a project attempting to adapt – not just apply – the properties of complexity and self-organization that originated in the domain of the "hard" sciences, to the "soft" domain of cities. A central insight that emerges from this project/adaptation is that cities, like languages, are *dual self-organizing systems*: The city as a whole is a complex self-organizing system, and each of the many agents operating in the city is a complex self-organizing system by itself, too. As a consequence, unlike Simon's model in which the interaction between simple innate causes and the environment leads, or gives rise, to a complex system, in the dynamic of cities we find a situation by which the interaction between the many local complex urban agents that operate in the city leads, or gives rise, to the global city as a complex system. From the above follows a paradox, namely, urban simulation models that were originally designed as means to study the properties of cities as complex systems (characterized as they are by circular causality, dual self-organization and the like), are built as if cities are mechanistic systems characterized by simple causality.

11.3.3 Information Compression

The duality of the city and of complex human systems in general entails a major methodological problem that concerns both the core of scientific explanation – causality and simplicity – and the very essence of complexity. The initial conditions of simple systems are simple: relatively few independent parts, within a system that is itself isolated from its environment. The initial conditions of complex systems are complex: a very large number of interacting parts, linked by a complex network of feedback/forward loops, within a system that is open to and thus part of, its environment. As noted above, in social theory such initial conditions catalyzed the conclusion that the 'scientific method' is not applicable to such systems. The significant achievement of complexity theories is to show that even in such complex opening conditions a scientific approach is possible. The principle that allows a scientific treatment of complex systems is self-organization that takes the forms of *information compression*.

Chapters 8 and 9 above elaborated in some detail on information in relation to complex systems. From the discussion in Chap. 9 follows that complex systems 'self-organize', that is to say "interpret", the information that comes from the environment with the implication that the meaning assigned to the message depends on the receiving system and not just on the message itself as in Shannon's theory.

Self-organization is a process of information compression (Haken 1988/2000) in the sense that a large number of parts, each conveying its own specific message, enter into an interaction that gives rise to one or a few order parameters. Once emerging, the order parameter(s) enslave the many parts of the system with their many messages. Synergetics' *slaving principle* can thus be seen as 'information compression principle': the many potential messages enfolded in the system are being compressed/enslaved into the order parameter's message. Or, in other words, depending on the internal dynamics of the system a given external message or a set of messages, that can be interpreted and affect the system in a multiplicity of ways, is eventually being compressed in a unique way.

In complex physical systems the transfer of information from sender to receiver depends on the state of the receiving system: given a signal that transmits a certain message, its impact on a complex system is not causally predetermined: when governed by one attractor the message conveyed will affect the system ("will be interpreted") in one way, and when governed by other attractors in other ways. Fluctuations are thus important to the process of self-organization: they can push the system from one state/attractor to another and thus respond differently (self-organize) to a given signal.

In biological complex systems a given signal/message can be interpreted differently depending on the animal's biological (DNA) and experiential memories (e.g., conditioning). In the human domain we should add to the above list the agent's character, including personal life experience, values, cultural affiliation and social status.

The above applies to relatively simple cases where a given single message that can be interpreted in a multiplicity of ways is being self-organized and compressed in a unique way. It also applies to the really complex situation that concerns individuals under a bombardment of information, that is, under a multiplicity of messages from a multiplicity of sources and of all kinds. This is typical to the dynamics of cities: every agent operating in the city is continually subject to a multiplicity of messages in the form of views, noises, smells etc. In order to behave and survive, the agent (person, company, etc.) must make sense of all those signals and messages. In other words, the agent must interpret/compress the many messages in a way comprehensible by humans' cognitive capabilities and constraints.

In Chaps. 8 and 9 above it has been shown that different elements of the city transmit different quantities of Shannonian information that can be practically measured by means of information *bits*, for example, and, that this becomes possible only after the city was self-organized, that is to say, closed in a specific way. In other words, after information was compressed in a specific way. Such information compression is done partly individually by reference to an individual's personal experience in the city and partly collectively by reference to cultural and social entities shared by large groups in the city. The thesis to be elaborated in the next section is that *place* and *space* are two forms of information compression.

11.4 CTC as a Link Between Space and Place

Since the early 1970s, the notions of *space* and *place* are located on the two sides of a barricade that divides the study of cities in line with Snow's (1964) two cultures of science (above Chap. 1). *Space* has become a central concept in the attempt to transform the study of cities from a descriptive into a quantitative, analytic, and thus scientific enterprise. *Place*, on the other hand, is located among the "soft" humanities and social philosophy oriented social sciences as an important notion in the post-1970 attempt to transform geography and the study of cities from a positivistic into a humanistic, structuralist, hermeneutic critical science. More recently, the place-oriented scholars have adopted postmodern, poststructuralist and deconstruction approaches, while the quantitative spatial approaches were strongly influenced by theories of self-organization and complexity. As already noted, there are several structural similarities between complexity theories and social philosophy oriented theories. In what follows I'll first point to, and explore, these similarities and then elaborate the thesis that as a consequence of these similarities CTC have the potential to bridge the "cities" of space and place and by implication Snow's two cultures. Finally, I'll discuss in some detail conceptual and methodological implications.

11.4.1 CTC – The Deeper Messages

As noted above, the more influential theories of complexity originated in physics and chemistry – studying inanimate matter. This is significant for two reasons. First, physics has traditionally been regarded a "hard" science and a model for other disciplines. The first attempt at a science of cities (above Chap. 2), in the 1950s and 1960s, was directly associated with physics and with what Gregory (1994) has termed "physicalism". Direct analogies like the gravity/interaction model, as well as economically-oriented location theory, provided the foundation for quantitative urban studies (Chap. 2, above) and rational comprehensive planning (Chap. 12, below).

Second, like the two grand theories preceding it – relativity and quantum theory – the theories of complexity have found properties in matter hitherto assigned to the organic and human domains, including history, evolution, irreversibility and non-linearity (Portugali 1985). As a consequence, several of the notions that originated in the study of complex systems can be related to similar notions that originated in the domain of social theory. Here are some brief examples:

- Theories of complex systems and social theory are essentially systemic and even holistic. Complexity theories reject atomism, and social theory refuses to conceptualize society in terms of essentially independent disciplines (economics, sociology, politics etc.).
- Theories of complex systems and social theory oriented approaches prefer to conceptualize ‘development’ and ‘evolution’ in terms of abrupt changes rather than a smooth progression. As a consequence, in both we find an emphasis on structural changes. In social theory the common terms for an abrupt change is (social/political/cultural) ‘revolution’, while in the language of complexity theories one tends to speak about ‘bifurcations’ and ‘phase transitions’. It is interesting to note that Gould and Eldredge (discussed in Gould 1980) have suggested that biological evolution too proceeds as a sequence of abrupt changes – a process they have termed *punctuated equilibrium*. The complexity theories’ notion of ‘steady state’ is similar to social theory’s notions of ‘epoch’, ‘period’ or ‘mode of production’. The latter is similar to synergetics’ notion of ‘order parameter’. Furthermore, synergetics’ notions of ‘enslavement’ and ‘circular causality’ are close to social theory’s notions of ‘social reproduction’ and even more so to the notions of ‘socio-spatial reproduction’ as conceptualized by social theorists of space such as Lefebvre (1974/1995) or Giddens (1984).
- PPD’s recent emphasis on viewing reality as ever changing and transforming is close to the notion of ‘a far from equilibrium condition’ which is the basic characteristic of complexity and also the reason for the general popularity of notions such as ‘chaos’ and ‘butterfly effect’ that originated in the domain of complexity theories.
- Conceptualizations of space in both the sciences and social theory and humanities have converged, as discussed in the next section.

11.4.2 The Production of Space and Place

In the Newtonian world-view ‘space’ was essentially perceived as an independent container (independent of time) within which independent bodies coexists in spatial causal relations of attraction and repulsion (Bohm 1980). This view was adopted by the location theory that provided the foundation of positivist urban studies – the ‘first science of cities’. In the latter, complex reality was reduced to a large container, in which the spatial interaction between such bodies/entities as settlements, central places and demand or supply is governed by spatial forces such as mass measured by population, distance measured by transportation cost and so on (Portugali 1985b, 1993 and above Chap. 2).

Following relativity and quantum theory, this mechanistic world-view became seen as an abstraction from a subtler reality in which space is only relatively independent from time and the bodies in it (Bohm 1980). This is also the case in complexity theories in which space is, on the one hand, a landscape full of forces and on the other, a product – an order parameter that emerges out of the interactions that take place "on it", but that once emerging/existing prescribes the behavior and interaction of the parts. This view is partly implicit also in cellular automata/agent-based urban simulation models in which the cells – the parts of the system – are only relatively independent as their properties are essentially some function of their relations to their neighbors. (On the spatiality of CA/AB models see Couclelis 1991, 1997; Takeyama 1997; Takeyama and Couclelis 1997).

Such a world-view comes close to the perception of space as it appears in social theory in the writings of Giddens (1984), Harvey (1996), Castells (1989, 1996), Lefebvre (1995), among others. Unlike the abstract Newtonian space that provided the foundation to the first culture of cities (Chap. 2), these writers speak about *The Production of Space* (the title of Lefebvre's book), or more precisely about '*the social production of space'*, by which they mean 'social' in the wider sense of the word that includes also the economic, political and cultural. Thus space and by implication a city, is not a natural objective entity but an *artifact* – a product of the historically specific socio-spatial relations between humans. As a social product and an artifact, space and city feed back and participate in the process of socio-spatial reproduction (Soja 1989).

In both complexity and social theories space and city are thus products. In social theory the emphasis is on space and city as social products; in the domain of complex systems space might be seen as a social product – when one deals with complex artifacts such as a city, but it might also be seen as a natural product – when one deals with the space constructed in the organic world, for example. But the important contribution of complexity theories is in the view that space and city are not just products – end products, but also what in Haken's synergetics is called 'order parameter' – a collective variable that emerges out of the interaction of the parts, but once emerging, enslaves and prescribes the behavior of the parts by means of what has been defined above as 'information compression'. [A view that comes close to Lefebvre's *The Urban Revolution* (1970/2003) that was strongly rejected by Castells. See Smith's introduction to Lefebvre 2003].

The 'rebellion' against the quantitative first science of cities in the early 1970s started, as we've seen above (Chap. 3), by negating space and place. However, the above perceptions of space as a social product entailed several reinterpretations of place in similar terms. According to Casey, the discussion on space in social theory came associated with

> "*a renewed and rising interest in place … of … authors who think independently of …* [Heidegger's] *… Being. Common to all these rediscoverers of … place is a conviction that* [contrary to Heidegger] *place itself is no fixed thing … Instead, each tries to find place at work, … of something ongoing and dynamic …*" (Casey 1997, p 286).

This view of place is even more prominent in the writing of scholars of place and space that go beyond the phenomenological perception of these terms. Thus, writing from the perspective of his 'space of flows' Castells (1996, p 423) describes place by reference to the physical and social dynamics of "the Parisian *quartier* Belleville". The majority of people, he emphasizes, "live in places" and their perception of space is "place-based". Similarly, for Massey (1995, 1997), Kilburn in London is a typical place; its dynamics is at once local and global – local with respect to the political, economic and social interactions that bind its inhabitants into a community network and global due to their social, political and economic relations that stretch out over the global space. A similar view of place is portrayed by Sheppard (2002) but with respect to 'geo-economic places' in the context of the global space economy.

Unlike the notion of 'space', 'place' has not been intensively studied in the context of positivist quantitative urban studies and not in CTC. The natural context for a discussion of place was cognitive geography (or 'behavioral geography' as it is often called) and indeed in its early days there were interesting discussions concerning *sense of place* (Lowental 1961, 1985; Lynch 1960, 1991; see also Hubbard et al. 2002). But the bifurcation of the study of cities into two distinct cultures, as described above, put an end to these early beginnings: Cognitive behavioral urban geography joined the positivistic culture, concentrating on quantitative-scientific notions such as 'space' and 'spatial behavior' (Golledge and Stimson 1997; Kitchin and Blades 2002), leaving the study of 'place' to the "nonscientific" domains of SMH and PPD (cf. Hubbard et al. 2002, pp 16–18; Casey 1997).

As elaborated below, however, from the conjunctive perspective of theories of complexity and cognition, space and place are interrelated in the sense that space is an abstraction from the very experiential reality within which people live and act, that is to say, an abstraction of places. It will be further shown below that, similarly to space, place is an artifact that comes into being in the process of self-organized information compression.

11.4.3 The Differences

The above-noted similarities between complexity and social theories have not escaped the attention of writers from a variety of domains, and parallelling complexity theories, we see a steady stream of studies responding to these similarities from the perspective of the sciences (Capra 1982, 1996; Peat 2002), philosophy (Mainzer 1994) media/cultural critics (Johnson 2001), social theory and the so-called New Age (Thrift 1999).

Several attempts have also been made to explore the possible links between PPD and complexity. Thus, Kellert (1993) closes his nonmathematical introduction to chaos theory with a chapter that points to several similarities between PPD feminist theory and chaos theory. He suggests that feminist theory provides an explanation of Prigogine and Stengers' observation that chaos theory was neglected for many years. Cilliers (1998) emphasizes the similarities between connectionist interpretations of complexity and Lyotard and (to a lesser degree) Deridda. The collection edited by Rasch and Wolfe (2000), centers mainly around Niklas Luhmann's systems theory approach to society and postmodernity; in geography and urban studies, see Thrift (1999) and Portugali (1985, 1993, 2000).

It is important not to be carried away by the above similarities: theories of complexity and social theory oriented SMH and PPD, do differ from each other. First, while both refer to the chaotic nature of systems, they differ in the role they assign to chaos. PPD tends to portray chaos as a state of reality while complexity theories tend to describe it as the starting point for a process of self-organization that brings *Order out of Chaos* (Prigogine and Stengers 1984). Second, while both emphasize phase transitions/revolutions and processes of reproduction maintaining steady states, they differ in their view of how revolutions/phase-transitions are created. Social theories are more deterministic in this respect: Marxism emphasizes historical determinism, while Hegelien idealism stresses determinism of the human spirit. According to the complexity theory of synergetics (Haken 1983), for instance, the various forces acting on the system (materialist, idealist or others) are in principle not deterministic, that is, they cannot uniquely determine the evolution/fate of the system. Rather such forces are considered *control parameters*. When they are changed beyond a critical value the system state may become unstable and show strong fluctuations. Once this happens, they loose control and the system self-organizes itself, that is to say, by means of its internal dynamics it gets into a new state of a 'far from equilibrium' steady-state and order. A third difference concerns methodologies as we shall immediately see.

11.4.4 Place and Space as Two Forms of Information Compression

From the point of view of our SIRN approach to cities, place and space are two forms of information compression (Chap. 9, above and Portugali 2006a). As noted, information compression in general, and in cities, is implemented in two ways. The first entails grouping or compressing a large set of human activities, artifacts, emotions and interactions into singular entities with unique identity, that is to say, places. Social theory oriented (SMH and PPD) urbanists have elaborated and scrutinized in some detail the process of place creation and the shift "from space to place and back again" (Harvey 1996). They portray a process that is at once emotional and functional, related, on the one hand, to the subjective identity of individuals, while on the other, to their collective cultural, social, political and economic life (Hubbard et al. 2002). There is no room here for a detailed survey of these studies, but I would like to add to the rich literature on this issue that the process of place creation is nicely captured by Giambattista Vico's notion of *poetic geography*:

> *By the property of human nature that in describing unknown and distant things, in respect of which they either have not had the true idea themselves or wish to explain it to others who do not have it, men make use of semblances of things known or near at hand . . . The ancient geographers agree on this truth . . . they confirm that ancient nations, emigrating to strange and distant lands, gave their own native names to the cities, mountains, rivers, hills, straits, isles and promontories* (Vico 1744/1961, p 234).

Vico's process of poetic geography is in line with the pattern recognition paradigm as described by Haken's (1991/2004) synergetics and the process of information compression by means of grouping as discussed in Chap. 9: In all such processes, stored memories and sensations are used as means to solve an existing cognitive task – in the example described by Vico, to transform anonymous environmental spaces into unique familiar places.

Through this process each city gets a name (Jerusalem, Paris, New York) that immediately makes it singular, connected to specific memories, history, geography and mythologies. Each city is further subdivided into a hierarchy of unique singular places (Soho and Harlem in New York, Montparnasse and Quartier Latin in Paris), each with its own name, character, image, specific history or historical association, specific memory and identity.

As we know, there are geo-cultural differences in this process: in Europe naming goes down to the level of streets and only then it becomes technical, i.e. 'spatial', when each building gets a number. In Japanese cities it goes all the way down to the level of single buildings, while in the US there is a superposition: below the level of cities, we find 1^{st} St. 2^{nd} St. etc. but also a subdivision into neighborhoods (Soho, Harlem). Note, that despite the originally planned "placelessness" of the notions 1^{st}, 2^{nd}, 3^{rd}, . . . St/Av etc., the experiential urban dynamics has transformed such anonymous numbers into meaningful places, so that 5^{th} Av. or 42^{nd} St., in New York have become unique places that carry with them memories, symbols, images and the like.

In Sect. 10.3.2 I've quoted Harvey (1996, p323) that the fact that the identity 'New Yorker' "can make sense to the polyglot millions who occupy that place testifies precisely to the political power that can be mobilized and exercised through activities of place construction in the mind as well as on the ground". This fact also testifies to the intimate link between place construction as a collective process and the way each individual constructs his or her own personal self identity, which is among the most subjective of human sensations. This link and play between the local and the global, the individual and the collective, forms the core of synergetic and other theories of complex systems.

The second form of information compression is the process of categorization as conceptualized by embodied cognition scientists such as Rosch et al. (1976), Lakoff, (1987), Johnson (1987), and Varela et al. (1994), among others and as applied to cities in Chap. 10 above. These studies have shown that the various processes of categorization are implemented by means of humans' innate visual capabilities (e.g., color categories), capabilities for poetic thinking (e.g., categorization by means of metaphors, metonyms and the like), and capabilities for analogies and abstraction.

Studying the cognitive process of categorization from the perspective of complex systems, Kohonon's (1995) theory of *Self-Organizing Maps* demonstrates that categorization evolves by means of self-organization as a typical complex system (see above, Chap. 6). Subsequent studies have employed Kohonen's approach in conjunction with synergetics' paradigm of pattern recognition (Ossig et al. 1998; Daffertshoffer 1998). In Chap. 10 above we've seen that in the context of cities, the starting point for categorization might be one place or a set of unique singular places, each with its own name and identity that by means of the various processes of categorization are given a single identity and name. Thus, the places Paris, Jerusalem, New York, etc. become members of the category 'city,' and inside cities places such as Harlem and Soho in New York become 'neighborhoods,' and so forth. By means of this process of categorization places are being transformed into spaces.

In Chap. 3 above we've seen that humanistic urbanists, advocates of the second culture of cities, have emphasized the emotional and experiential-phenomenological dimensions of place creation, very much in line with Heidegger's notions of "being" and "dwelling". They have criticized the processes that create spaces as processes that create placelessnesses – nonhuman, alienated and alienating places. SMH and more recently PPD urbanists have further elaborated the notions of place and space, exposing their multidimensionality. In particular they have emphasized that place and space are first and foremost social products with the implication that their production is part of the overall process of socio-spatial reproduction.

Students of the first culture cities have tried to develop a science of cities among other things by transforming places into spaces (Chap. 2, above); proponents of SMH and PPD urbanism have gone to the other extreme by criticizing the very attempt to quantify the spatiality and "platiality", of human life and relations (Chap. 3, above). CTC to my view can integrate the two seemingly opposing views by portraying place and space as two forms and facets of a single process of information compression that complement each other. A purely spatial placeless city, neighborhood or even street, with no name, identity, history or mythology is surely not humane. But at the same time without transforming the humanly rich urban places into one-dimensional cities, neighborhoods or streets there is no possibility of counting how many cities there are, or how many rich or poor neighborhoods, and without transforming multi-dimensional human beings into one-dimensional persons (a process strongly condemned by Marcuse 1968), there will be no way to count the number of people living in a certain city.

Place and space are thus two forms of information compression. There are other forms of information compression that are, in fact, more prevalent in social theory. For example, the notion of 'mode of production' takes the complexity of social, economic, political and cultural life and compresses them into a single ordering principle. The same can be said of other notions of social theory. The difference is that social theory has arrived at this way of looking at reality mainly by means of hermeneutics, discourse and language, while CTC uses mathematical formalism (plus hermeneutics, discourse and language). The prevalent view in the study of cities is that quantitative and mathematical approaches and qualitative SMH and PPD approaches contradict one another. My view on this issue is in line with Sheppard (2001) who demonstrated that there is no logical contradiction between mathematical analysis and SMH/PPD views.

While methodology differs – mathematical formalism vs. hermeneutics – the deep structure of the two methodologies is identical. You start with a complex reality/system, identify its order parameters and modes of production, and show how the latter compress the complexity of reality while reproducing it, and so on in circular causality and socio-spatial reproduction.

11.5 The Two Cultures Once Again

The finding in Chaps. 8 and 9 above that Shannonian information in the city becomes possible only after information was self-organized and compressed in a specific way is rather surprising. It shows that, contrary to what was assumed before, the qualitative-semantic and the quantitative-Shannonian forms of information are interrelated and that the former preconditions the latter. A similar outcome emerged from the preceding discussion: in order to produce abstract quantitative space, one needs qualitative experiential places. As shown in Chap. 9, semantic information is created by means of humans' innate cognitive capabilities as well as by reference to politics, culture and society. In a similar manner places and spaces are created by reference to both innate cognitive capabilities (i.e. grouping people according to their age or gender) as well as by reference to politics, culture and society.

From the perspective of complexity theories the culture of place and the culture of space thus approach each other, like the two edges of an almost-closed circle: The line separating them is very long but the distance between them is short. Complexity theories have the potential to bridge this gap, if students of cities from the two cultures start taking the other side seriously.

Part III
Complexity, Cognition and Planning

Chapter 12
The Two Cultures of Planning

12.1 Introduction

Cities and planning are intimately related; so much so that the notion 'planning' is commonly employed as shorthand to the more longer term 'urban and regional planning' (which is not the case with economic or social planning, for instance). A possible reason for this is that cities were always regarded as signs and symbols for the existence of strong central authority capable of planned action – in antiquity, walls, roads, canals, castles, fortresses, temples and the like, indicated a central authority that is capable of planning. The same holds true for today's cities: their roads, pavements, highways, public institutions, civil centers, industrial zones and residential areas are often seen as the result of a dominant central authority that plans and controls the city.

Cities, as we've seen above, are similar to languages – both are artifacts and both are dual complex systems. What distinguishes cities from languages is, firstly, the fact that they are stand-alone artifacts and secondly, *planning*: unlike languages, cities are full of planning – each urban agent is a planner at a certain scale.

In Chapter 1, I described the study of cities in the last 60 years in terms of a conjunction between Snow's (1964) thesis about *The Two Cultures* (of science) and Kuhn's thesis about *The Structure of Scientific Revolutions* (Kuhn 1962); that is, as a pendulum that is moving between two poles that roughly correspond to Snow's two cultures when the moves from one pole to the other take the form of what Kuhn has termed "paradigm shifts" and what students of complexity call *phase transition*. At one pole, we see scholars that approach the city from the perspective of the sciences with their scientific methods, attempting to develop *a science of cities*, while at the other, studies that approach cities from the perspective of the humanities and social philosophy with hermeneutics as their major methodological tool.

The central thesis in Chaps. 1 and 11 is that complexity theory has the potential to bridge this gap. In Chaps. 1 and 11 the emphasis was on cities; in the present chapter the emphasis is on planning – urban, regional and environmental planning. More specifically, in what follows I show that similarly to cities the history of planning can be interpreted in terms of Snow's two cultures (Sect. 12.2). Next I explore the current and potential relations between complexity theory and planning

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(Sect. 12.3). Finally, I explicate hitherto implicit links between complexity theories and social theory oriented urbanism and planning (Sect. 12.4). The chapter concludes with a suggestion to reformulate planning theory.

12.2 The Planning Pendulum

12.2.1 Utopian Planning – The First Hermeneutic Culture of Planning

Similarly to cities, one can describe the history of planning in terms of a pendulum that is moving between two poles that correspond to Snow's two cultures: a qualitative descriptive *study* of city/urban/regional/environmental planning, versus a quantitative analytic *science* of (city/urban/regional/environmental) planning or *regional science* as it is often called. In the first half of the 20th century the domain of planning was dominated by the hermeneutic-descriptive culture of planning. Peter Hall (1975/2002) has described the style of planning during these years as *utopian planning*. By that he meant that influential planners such as Howard and Corbusier directed their energies to produce future visions, i.e. utopias, of cities. The notion of 'utopia' often comes with a negative connotation (specifically in Marxist thought) as something unrealistic; yet this was not the case with utopian planning. Some of its utopias, such as the 'garden city' or the concept of 'green belt' became rather influential and have shaped the form and structure of 20th century cities.

12.2.2 The 'Rational Comprehensive' as the First Scientific Culture of Planning

As just noted, the first quantitative-analytic-scientific culture of cities has developed in the 1950s and 1960s. Hand in hand with this development emerged also the "rational comprehensive" culture of planning, when the division of labor between the two is in line with Faludi's distinction between *theory in planning* and *theory of planning* (Faludi 1973a, b). The science of cities was to supply the theory in planning with an insight about the development and structure of the city and the way it should scientifically and rationally be, whereas 'the rational comprehensive' was the favorable theory of planning, that is, the planning procedure which will enable to plan and implement the good city in an efficient and rational way.

As illustrated in some detail by Camhis (1979), the rational comprehensive planning theory and practice was an attempt to apply the so-called *scientific method* to the domain of planning. At the basis of both was the positivist mechanistic logical-deductive scientific method. During the 1950s and 1960s planning has been transformed from intellectual-humanistic and somewhat utopian endeavor into a formal scientific university discipline that similarly to other such disciplines (engineering, economics . . .) produces researchers, theoreticians as well as practitioners. As with the first scientific culture of cities so with the scientific culture of planning, by the late 1960s and early 1970s came the disillusionment from both the first scientific culture of cities and its associated first scientific culture of planning. In *Self-Organization and the City* (Portugali 2000) we've referred to this process of disillusionment as the "first planning dilemma" and described it in the following words:

> *it became evident that "rational comprehensive planning" . . . is an irrational assumption, that planning is a political, incremental . . . and essentially 'nonscientific' and nontechnical process; it became apparent that . . . [the] spectacular scientific instruments we've developed fail to tame the city, the metropolis, the megalopolis, the environment. . .. that beautiful scientific instruments such as the gravity, interaction, or entropy maximization models . . . can hardly scratch the complexity of the urban scenario, and that so are the 'rent bid curves' of . . . urban land use theory, and the 'factorial ecology' of Chicago's 'urban ecology' and the 'location triangle' of . . . industrial location theory, and the hexagonal geometrical landscapes of . . . 'central place theory'. All this scientifico – mathematical arsenal seemed "incapable of saying anything of depth and profundity about [the real problem of society and]. . . when we do say something, it appears trite and rather indecorous* (ibid pp 225–6).

In retrospect it can be observed that the doubts about the rationality of the rational comprehensive started already in the late 1950s and early 1960s – during the high days of the first science of planning – when students of planning such as Lindblom (1959) or Davidoff (1965) started to criticize or at least question the approach. Theirs, however, was a "constructive criticism from within"; the aim of Lindblom with his *incremental planning* and Davidoff's with his *advocacy planning* was not to altogether reject the *raison d'être* of the rational-comprehensive approach to planning but rather to correct and improve it. Thus, Lindblom added to the rational comprehensive a politically more realistic twist, while Davidoff a more democratic one. It is therefore not surprising that their papers appeared as chapters in Faludi's (1973a) *A Reader in Planning Theory* – Lindblom in Part II entitled "Toward a comprehensive planning" while Davidoff in Part IV on "Bureaucrats, advocates, innovators". The all out attack on the first science of planning came at a later stage, in the early 1970s, when scholars such as David Harvey and Manuel Castells started to criticize it from a Structuralist-Marxist standpoint while others from a phenomenological-idealistic standpoint. Unlike Lindblom's and Davidoff's criticisms, they criticized its very foundations.

12.2.3 SMH Planning as the Second Hermeneutic Culture of Planning

The above disillusionment from the first science of cities and planning was one of the forces behind the "qualitative revolution" of the early 1970s that took place in the domains of urban studies, urban geography and urban and regional planning; a revolution that was dominated by social theory oriented approaches in particular by *structuralist-Marxist and humanistic* (SMH) critical views on urbanism and planning (above Chap. 3; Portugali 2000). Two lines of thought emerged out of the SMH approaches with respect to a 'theory of the city' and a 'planning theory of the city'. One was the humanistic approach whose central message was *awareness*: humanistic studies of cities, so it was believed, will expose the significance of cities to the subjectivity and individuality of people, will distinguish between *place and placelessness* (Relph 1976), between humane and ... nonhumane cities ... The cumulative effect of this discourse about the qualitative aspects of cities and landscapes will eventually enter the awareness planners and architects when they are practically working in and on cities.

The Marxist-structuralist stand was to altogether reject the distinction between theory of planning and theory in planning as ideological (false consciousness), with the implication that both the rational comprehensive planning theory and the above naive humanistic stand, are but part of the superstructure – integral element in the overall socio-spatial structure of the modern capitalistic city. Any genuine change in planning is thus conditioned by a total transformation – a revolution – in the structure of society. Despite their good will, claimed Marxist critics, the planners are structurally doomed to play into the hands of the politicians, the ruling classes and the multi-nationals that control *the system*.

No one can deny the important contribution of the SMH criticism of planning and the deep insight gained by the SMH approaches. On the other hand, however, it entailed a dilemma, as it was not accompanied by any practical suggestion to the practice of planning. In *Self-Organization and the City* we've termed this situation the second planning dilemma and described it as follows (Portugali, ibid pp 226–7):

> *... what are you to do with the SMH insight when as a planner you have to make a decision about urban renewal, or road networks; what would you say? start talking about base and superstructure? The labor-process? how this beautiful theoretical insight becomes praxis? Gradually it became evident that SMH planning discourse and research is remote from reality and social relevance even more than positivism. Thus, since the mid-80s, we hear once again the very same question: "how can we account ..."; but this time not only for the coexistence of great scientific achievements, on the one hand, and the failure to apply them to society, on the other hand, but also "how can we account for the failure of the alternatives.*

12.2.4 The Catch of the Kitsch

The result was a kind of a split in the domain of planning by which the practice of planning is dominated by the rational comprehensive approach while the theory of, and discourse on, planning by SMH planning approaches. This general state of dissonance between theory and practice and the inability of modernist SMH planning approaches to practically guide action, was one of the grounds upon which the postmodern view of cities and planning originated. As with postmodernism in general, so with respect to urbanism and planning, postmodern urbanism and planning have transformed the above dissonance and disillusionment from modernist ideologists, to an ideological platform as elaborated in Chap. 3 above.

On the face of it the new vision of postmodernism sounds highly desirable and creative: an ever-changing reality, ever changing and ever moving city. However, the reality of the postmodern condition shows that there is a catch here – *the catch of the kitsch*: The most prominent example is in architecture and the urban landscape: Indeed the postmodern city started with free and creative quotations from the ancient past and from futurist visions, but very quickly it turned into a uniform style – into a kind of neo-conservatism – into the very opposite of what postmodernism advocated for. This dissonance between the decided intentions and the daily praxis forms the deadlock of the postmodernist city of the 1990s and the first aspect of what we have described (Portugali ibid) as the third planning dilemma:

> *You can't tame, plan, engineer, the environment, since you are trapped in its chaos, and you cannot participate in its chaotic play since you are trapped in its structure, fashion and style.*

Planning in Crisis? is a recent book by Schonwandt (2008) in which he responds to the title of his book in the affirmative, suggesting that urban planning and design are in crisis as a consequence of a growing gap between theory and practice – very similar to what we've referred to above as the three planning dilemmas.

12.3 Planning and the New Urban Reality

While postmodernism had an immediate effect on architecture and urban design, its impact on city and urban planning started to be felt at a later stage when postmodernism was interpreted as a phenomenon of late capitalism associated with technological changes, on the one hand, and the social, economic and political processes of globalization, glocalization, the decline of the welfare state and the rise of civil society, on the other. Of specific influence here were the studies of authors such as David Harvey (1989) *The Condition of Postmodernity: An Enquiry into the Origins of Cultural Change*, or Castells (1996) *The Rise of the Network Society*.

These interpretations acted as an impetus to the emergence of several responses of social theory derived (SMH and PPD) planning approaches of which *communicative planning* (Healey 2007) is probably the most influential one. The latter together with other approaches, which are not specifically related to the SMH-PPD culture, such as *strategic planning*, the notion of *governance* and *New Urbanism*, currently dominate the discourse in the domain of planning. While the first three respond mainly to social changes of the last decades (globalization, civil society, . . .) and are thus more related to the process of planning and planning policies, New Urbanism is more related to urban design and architecture and the physical structure of cities.

12.3.1 The Collabative Planning Approach

The communicative, or collaborative, planning approach (CPA) can be seen as an attempt to respond to the challenges of the 'postmodern planning condition', which is planning in the reality of globalization, the weakening of the welfare state, privatization, the rising power of the various institutions of civil society, the fragmentation of society, the consequent emergence of multicultural societies and of course of the rising dominance of urbanism and cities. Its basic premise is that in this new postmodern reality, the old, centralized, top-down, rational comprehensive planning procedures simply collapse. Instead, planning is seen as a "governance activity occurring in a complex and dynamic institutional environments, shaped by wider economic, social and environmental forces that structure, but do not determine, specific interactions" (Healey 2003, p 104). Based on Habermas' notion of *communicative action* that refers to society at large, the communicative approach suggests a spatial/urban planning process in which the interaction and discourse between the various governmental and nongovernmental actors in the planning field function as the main regulator. Rephrasing Habermas' statement that "... reaching agreement [between the various social actors is the] mechanism for coordinating action" in society (Habermas 1990, p 184), proponents of the CPA suggest that '... reaching agreement [between the various planning actors should become the] mechanism for coordinating action in the field of urban planning'.

The CPA has recently been presented in a book by Innes and Booher (2010) entitled *Planning with Complexity: An introduction to collaborative rationality for public policy*. Innes and Booher present the CPA as a new *collaborative rationality* that is tuned with the new planning reality of the 21st century and as such must replace the old anachronistic rational comprehensive planning approach. The basics of collaborative rationality, write Innes and Booher (ibid p 6) "have to do with the process of deliberation":

> *A process is collaboratively rational to the extent that all the affected interests jointly engaged in face to face dialogue, bringing their various perspectives to the table ... all participants must also be fully informed and able to express their views ... Techniques must be used to mutually assure the legitimacy, comprehensibility, sincerity and accuracy of what they say. Nothing can be off the table. They have to seek consensus.* (*ibid*).

12.3.2 Strategic Urban Planning (SUP)

The notion *strategy* and with it the distinction between strategy and *tactics* goes back to Sun Tzu – the 6th century B.C. famous Chinese author of *The Art of War*, to Niccolò di Bernardo dei Machiavelli and his book *The Prince* published in 1532, and to Carl von Clausewitz and his book *On War* first published in 1832, to name a few famous "founding fathers". The modern usage of the notion of strategy is associated with Jon Boyd, still in the domain of war, and with Henry Mintzberg (1944) who applied the notion to planning in the domain of business. From here the way was short to what nowadays is termed SUP – *strategic urban planning*. According to Healey (2007) we need to distinguish between the "old" strategic planning that was dominant in the 1960s and lost its influence from the 1970s onwards, and the new strategic planning that similarly to communicative planning emerged as a response to the new urban reality of the last two decades. This view is in line with the "American-European . . . strategic planning" conference that took place in Barcelona in 1993. The central motive of SUP as emerging in this conference is a synergy between three sectors that in the last two decades seem to have been dominating Western society: the public-sector, the private-sector and the new *third sector* which is also called *civil society*.

In a recent paper entitled "The shift from master planning to strategic planning", Burgess and Carmona (2009) add a fourth player to the above three – the "knowledge industry" composed as it is by universities, research centers, and high-tech industries. Burgess and Carmona use the notion of "master planning" as a reference to the nature of planning in the 2nd half of the 20th century. The latter according to them was dominated by the "triumph of the Keynesian mixed economy model in capitalist societies" (ibid 23), and the modernist welfare state and its interventionist style of planning and design. The move from master planning to strategic planning is thus a move away from planning in the context of the welfare state with its Keynesian mixed economy toward planning in the context of neoliberalism and the global economy.

Burgess and Carmona's is the opening paper in a book on *Planning Through Projects: Moving from Master Planning to Strategic Planning* (Carmona et al. 2009). As can be seen, their paper explicates to the subtitle of the book. They use the subtitle in order to emphasis the difference between the old and the new, but in fact their title does the opposite – it emphasizes the similarities between the "new" strategic planning and the "old" master planning: during the 20th century the master plan was essentially an advisory document with no legal status (compared to land use/development plan the aim of which was to control development). Similarly to the old master plan, the new strategic plan is essentially an advisory document that emphasizes long-term "urban vision" and leaves the actual decisions and actions at the hand of the two strongest players in the planning game – the political and the market forces.

12.3.3 On the Conjunction Between Collaborative Planning and SUP

As can be seen, SUP and the collaborative planning approach and rationality are intimately interrelated: the first determines the city's strategies, whereas the second the process of their determination. More specifically, the city's strategic plan according to this view is determined by means of a collaborative planning process the major agents of which are representatives of the three sectors: the public, the private and the third sector composed as it is of the various nonprofit and/or nongovernmental organizations.

Strategies and tactics are commonly derived from the overall or global goal of the organization. For example, in the domain of warfare the overall goal might be preventing or winning the war, whereas in business, profit making or at least economic survival. However, unlike the domains of warfare and business where the global goal of the organization can be clearly defined, in the domain of cities the global goal is often unclear or at best a matter of debate. To overcome this difficulty proponents of SUP have suggested the notion of *vision* that is commonly used in strategic planning; in the case of cities this becomes the *urban vision*: this is the future state of the city as envisioned by the various planning actors involved in the strategic planning process. And who are these actors? In the past, these were the representatives of the first sector only; today, at the age of the postmodern condition, these are the three sectors: the public, the private and the third sector.

The basic assumption of the conjunctional communicative-strategic planning is that the more planning actors from the various sectors are involved, the more democratic and just the planning outcome will be. This is of course the bright side of the process. The dark side is that the more planning actors are involved in the process, harder to achieve becomes the communicative planning goal of reaching consensus; as a consequence, when it is reached, the outcome is a rather vague urban vision.

But this is not the end of the sequence: at the end, the vision and the strategies are meant to guide the city's administration with its executing bodies in their practical planning actions. But here is a catch: vague urban visions allow a wide spectrum of interpretations and that freedom of interpretation is given to the city's administration and its executing bodies. The result is a paradox by which a process that was meant to be democratic gives rise to its very negation, namely, a city administration that can practically do (almost) whatever it wants. Given the dependence of the first (political) sector on the capital of the second sector this situation invites corruption.

12.3.4 Governance

The term 'Governance' is derived from the Greek word 'kybernan' and 'kybernetes'. It means '*to steer and to pilot or be at the helm of things*'. While the term 'government' indicates a political unit for the function of policy making as distinguished from the administration of policies, the word 'governance' denotes an overall responsibility for both – the political and administrative functions. The notion of governance is of specific relevance to the new urban reality in which several of the actors involved in governing the city come from what we've defined as civil society. The notion of governance thus comes to emphasize the difference between the elected urban government and the processes of governing the city as described above, for instance.

12.3.5 New Urbanism

If the urban vision of specific cities is a central element of the strategic urban planning process, then *new urbanism* (NU) can be seen as a new urban vision related to cities of the late 20th and early 21st centuries at large. Unlike CPA and

SUP that referred to the processes of planning and governance, NU, as declared by "The Congress for the New Urbanism", focuses mainly on the city itself with strong emphasis on its visualizing:

> *The Congress for the New Urbanism views disinvestment in central cities, the spread of placeless sprawl, increasing separation by race and income, environmental deterioration, loss of agricultural lands and wilderness, and the erosion of society's built heritage as one interrelated community-building challenge. . . . We stand for the restoration of existing urban centers and towns . . . We advocate the restructuring of public policy and development practices to support the following principles: neighborhoods should be diverse in use and population; communities should be designed for the pedestrian . . .*
>
> *We are committed to reestablishing the relationship between the art of building and the making of community, through citizen-based participatory planning and design. We dedicate ourselves to reclaiming our homes, blocks, streets, parks, neighborhoods, districts, towns, cities, regions, and environment.* (http://CNU.org/sites/files/charter_english.pdf)

The implicit assumption is that something went wrong in our cities and that by pointing at what went wrong and at what is needed, planners and urban designers will "see the light" and cities will once again become what they used to be in the past. The question of why things went wrong, or why neighborhoods became placelessnesses, is answered by new urbanism by reference to the writing of Jacobs, Krier, and Alexander among others. In this respect they differ from CPA in that social theorists such as Harvey and Castells see cities as derived from, or as representations of, society.

12.4 Complexity Theories of Cities: First, second, or third culture of planning?

And what about complexity theories and more specifically complexity theories of cities (CTC)? What do they have to say about urbanism and planning in the 21st century? On the one hand, the reality of 21st century – of highly connected global society, major and fast changes in world society . . . and all the rest – almost invites looking at it from the perspective of complexity theory. And indeed, some of the aspects of 21st century society and cities are often described in terms taken from the language of complexity theories and CTC: a most prominent example, as noted, is Castells' (1996) *The Rise of the Network Society* while a more recent example is Healey's book *Urban Complexity and Spatial Strategy* (Healey 2007). However, both Castells and Healey are using the notion 'complexity' literally without the theoretical formalism and meaning added to it by complexity theories. In fact, in Healey's book there is not even a single reference to complexity theory.

A different case is the above noted recent book by Innes and Booher (2010) on *Collaborative Rationality and Complexity*. As in Healey's book here too, the notion of complexity refers to the reality of the 21st century of a highly complex and connected society. However, unlike Healey, Innes and Booher do make explicit link to complexity theories as a domain of research. Two more books that should be mentioned here are *A Planner's encounter with complexity* edited by De Roo and Silva (2010) *and Planning and Complexity – In Depth Analysis*, edited by De Roo, Hillier and van Wezemael (forthcoming).

Innes and Booher's book as well as most contributions in the above two edited books were made by students of planning and only a few by proponents of CTC. This is significant; firstly, since it indicates that the paradigm of complexity is becoming more and more relevant and attractive to students of the social theory oriented culture of planning. Secondly, since it indicates a potential for a fruitful discourse between the two cultures of planning and through it also between the two cultures of cities. As indicated above and elsewhere, it is my view that CTC can become "a link between space and place" (Portugali 2006), that is to say, between the two cultures of cities and their planning. More specifically, my view is that CTC have a lot to say about the 21st century city and can suggest interesting insight to the current crisis in planning. As already noted in Chap. 5, the fact is, however, that so far CTC have said very little about the 21st century city and its specific properties and even less on urban planning.

Potentially speaking, CTC have two messages to deliver to planning theory and practice in the age of postmodernity and globalization; the first is quantitative and the second qualitative. According to the first, CTC is seen as the second scientific culture of cities that similarly to the first culture, attempts to transform the study of cities and city planning into a science. According to the second, CTC indeed originated in the "hard" sciences and are thus genuinely "hard" scientific theories, but at the same time they share many properties with the "soft", hermeneutic, social theory oriented approaches. This dual nature has the potential to make CTC a bridge between the two cultures of cities and the two cultures of planning. Let me elaborate.

12.4.1 CTC: The Quantitative Message

How is CTC related to the above moving pendulum between the two cultures of planning? On the face of it the answer is apparent: complexity theory originated in the sciences, was applied to cities by scientists – physicists such as Peter Allen (1981) a student of Prigogine; and Wolfgang Weidlich (1994), colleague of Haken – and was enthusiastically adopted by "quantitative" students of urbanism. It is therefore not surprising that so far the main message delivered by CTC to planning is essentially quantitative and can be formulated as follows:

> *Indeed world society is becoming connected, society is becoming network society and so on, but the factors and forces that made our cities and system of cities more complex than ever before also provide us with the key to the solution: The last two decades have witnessed a dramatic progress in information and communication technologies. These technological changes indeed changed society but at the same time opened new possibilities. In the domain of cities and planning these new technologies created new potentials we urbanists and planners never had before: GISs (geographical information systems) that*

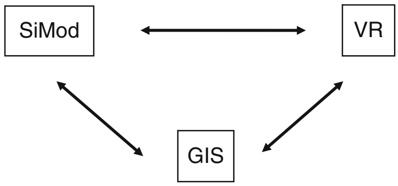

Fig. 12.1 A typical planning support system (PSS)

can easily control and process huge amounts of information, VR (virtual reality) software that allow us to build virtual cities and regions and move in them in real time, cell-phones combined with GPS that increase communication between urban agents allow also real-time monitoring of pedestrian and car movements in urban areas, and finally the new sophisticated urban simulation models (USMs) backed as they are by the theories of complexity allow us to study the dynamics of cities as complex systems.

Each of the above systems is by itself a strong planning tool and if we combine them together into an integrative comprehensive system we get a planning support system (PSS) and/or decision support system (DSS) that is more than the sum of its elementary parts.

This is, in fact, the idea behind the DSSs and PSSs that are currently advocated as the state-of-the-art of the new, second science of planning (Brail and Klosterman 2001; Brail 2006). A standard PSS is a three-part system (Fig. 12.1) composed of a set of simulation models [usually agent based (AB) and/or cellular automata (CA)], a GIS and a set of 2D, 3D and VR visualization devices (to which one can add a monitoring system based on GPS, etc.). The AB/CA simulation models are assumed to enable the planners to simulate future scenarios representing current trends, and also to envision the impact of various plans and policies; the GIS provides the data base for such scenarios, the monitoring system provides real time information and feedback, while the visualization systems provide the means to see the results at a high level of realism. As an example for such a system see the O'Jerusalem PSS (Portugali et al. 2009).

The enthusiasm currently surrounding PSS is reminiscent of the excitement that followed the appearance in the 1950s and 1960s of the *rational comprehensive planning* and its arsenal of quantitative planning tools. "This is an exciting time for simulation modeling and visualization tools in planning and public policy," writes Brail (2006) and continues: "Planning support systems (PSS) have moved from concept to application. Is this future so bright . . . ?"

12.4.2 CTC – The Qualitative Message

But there is another message complexity theory has for planning and it goes like this:

Indeed complexity theory originated in the sciences and CTC is therefore a science of cities, but complexity theory is a new kind of science referring to systems and phenomena never explicitly recognized and studied before – open, complex, far from equilibrium systems that exhibit phenomena such as chaos, fractal structure, non-causality, nonlinearity, *self-organization and the like. Such systems are qualitatively different from the cities and urban systems envisioned and studies by proponents of the first, scientific culture of cities. The latter, as noted, treated cities as simple, closed, entropic, equilibrium-tending, linear systems.*

In a recent article (Portugali 2008) I've suggested calling the approaches of the first culture of cities *classical* theories of cities and those of CTC *nonclassical* theories of cities (a distinction that echoes the terminology in physics). Classical systems are in principle simple, closed, predictable and causal. They might be highly complicated, but still simple in the sense that given all initial conditions, one can establish causal relations between their parts and predict their future state. Wrong prediction in such systems is the result of insufficient data or information about initial conditions. Complex, nonclassical systems, as we've seen above, are in principle unpredictable – given all initial conditions the future is still unpredictable. This is due to the property on nonlinearity, which in its turn is the result of the property of complexity.

Given the above differences between cities as classical systems and cities as complex systems, what are the implications to planning? What message has CTC to deliver to the planning of cities? What is the qualitative message of CTC to the domain of planning? The answer suggested below is that there are three facets to the qualitative message of CTC to planning: first, CTC suggest a cognitive approach to planning in cities – a new perception that entails the fact that planning is a basic cognitive capability of humans. This link between complexity, cognition and planning is discussed in Chap. 13 that follows; second, looking at cities from the perspective of complexity exposes the limitations of prediction upon which classical approaches to cities and planning are founded. This issue is elaborated in Chap. 14 below. Third, CTC suggest a bridge between the two cultures of planning – a bridge that becomes possible, on the one hand, due to some structural similarities between complexity theories oriented urbanism and social theory oriented urbanism, while on the other, due to some fundamental differences in the way the two bodies of theory treat cities. Chapter 15 elaborates on these issues. Finally and based on the above, Chap. 16 suggests a new structure of the planning system.

Chapter 13
Complexity, Cognition, and Planning*

13.1 Introduction

The act of planning accompanies cities from their very origin: The existence of cities, as noted in the previous chapter was interpreted as an indication for the existence of planning. Nowadays, however, planning is a profession and scientific discipline. In this conjunction between planning and cities it is common to make a distinction between planned and unplanned cities that are often called “organic cities”. American cities with their iron grid road structure as well as several of the world’s capital cities are often cited as typical planned cities, and of course, new towns. A ‘new town’ is explicitly defined as a city or a town that was carefully planned from its inception in a previously undeveloped area. On the other hand, “old towns”, old city centers such as European middle ages towns are often described as unplanned “organic” towns and cities (e.g., Hillier and Hanson 1984). But see Chap. 5 on this issue.

Planning – that is, the ability to think ahead to the future and to act ahead toward the future – is also a basic cognitive capability of humans. Psychologists and cognitive scientists tend to refer to this domain as *cognitive planning*. There is a debate among students of cognitive planning on whether or not the ability to plan is unique to humans – a property that separates humans from the rest of animals. Whatever one’s stand on this issue, it is clear that planning is specifically characteristic to humans.

On the face of it the domain of cognitive planning is distinct from the domain of urban and regional planning; the first is a personal cognitive capability while the second a specialized profession. The view in this chapter is that it is useful to explore the links between the two. Firstly, since professional planners are at the same time cognitive planners and this property might affect their behavior and action as professionals. Secondly, since some of the media currently introduced to city planning such as GIS, VR, and PSS as discussed in Chap. 12 above, are intimately related to AI and AL (artificial intelligence and artificial life) – two domains that were developed by insight from cognitive science. Thirdly, the current

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crisis of planning (below Chap. 15) might require a complexity-cognitive approach to planning. Fourthly, the fact that humans are cognitively planners affects their behavior in the city and as a consequence also the dynamics of cities with the implications that we have to take cognitive science's findings into consideration in our complexity theories of cities and their associated urban simulation models.

The discussion below starts with an overview on the domain of cognitive planning (Sect. 13.2) and on memory and planning (Sect. 13.3). It then links complexity to cognition and planning (Sect. 13.4), elaborating mainly on pattern recognition, decision making, cognitive mapping, SIRN, and retrospective memory. Next the discussion moves from solitary planning to collective urban planning and design (Sect. 13.5) and finally concludes with implications (Sect. 13.6) by discussing collective urban planning and design, by introducing the notion of *planning behavior* and by considering the implications to urban simulation models.

13.2 Cognitive Planning

Miller et al.'s (1960) book, *Plans and the Structure of Behavior*, is a good starting point to discuss *cognitive planning* – a research domain that studies planning as a basic cognitive capability of humans. Commencing from the information processing approach's analogy between brain as hardware and mind as software, Miller et al. see 'planning' as an hierarchical problem-solving technique that guides action, and 'plan' as analogous to a computer program for that purpose. Hayes-Roth & Hayes-Roth (1979) have added to the above view the notion of "*opportunistic*" planning that is typical of planners that respond to opportunities as they come and have also suggested a distinction between multidirectional and a top-down hierarchical planning; according to them planning is not a top-down but rather a multidirectional process.

Subsequent studies (Friedman & Scholnick 1987; Das et al. 1996) have suggested a more pervasive view of planning as a general process that includes problem solving, that in some cases is 'global' and hierarchical while in other cases 'local' and opportunistic (Ormerod 2005).

An important distinction is between *well-defined* planning (Davies 2005) where all the required information is available at the start of the planning process versus *ill-defined* planning that commences with only part of the required information (Ormerod 2005). Ill-defined decision and planning situations acted as one of the triggers to the interesting discussion on the role of *heuristics* in decision making and planning. Two lines of thought can be mentioned here: One by Newell et al. (1958), that is associated also with the notion of *bounded rationality* (Simon 1957) and another by Tversky and Kahneman (1974, 1981) in the context of their theory of human rationality for which, in 2002, Kahneman has received the Nobel Price in Economics. Tversky and Kahneman have suggested a set of five decision heuristics that people tend to employ in situations of high uncertainty. These decision heuristics and their relation to planning are further discussed in Chap. 19 below.

Similarly to other cognitive capabilities cognitive planning is based on memory, is related to other cognitive capabilities, and it implies a distinct form of behavior that has been termed *planning behavior* (Portugali 2009).

13.3 Memory and Planning

Memory refers to the ability of the organism to store, retain and subsequently retrieve information and act accordingly. It is common to distinguish between types of memory that differ in the sense that they are governed by different brain mechanisms and different brain circuits, and, in their cognitive functions and capabilities. One distinction is between *long-term*, *short-term*, and *working memory*. Another distinction is between *declarative* and *procedural* memories when declarative memory is further divided into *episodic* and *semantic* memory. A third distinction is between *retrospective* and *prospective* memory. Finally, there is the concept of *transactive memory* which refers to a memory held by an entire group of people. Here is a short introduction to the various forms of memory and their relations to planning.

Working memory, short-term memory, *and long-term memory* – Working memory (Miller et al. 1960) is the mechanism that enables to temporarily hold and manipulate components of current plans and planning (Ward & Morris 2005). Working memory is related to, but distinct from, the so-called short-term memory that according to Miller (1956) is constrained by the "magic number 7" to about 2.5 information bits. The relations between planning and working memory have yet to be clarified. An interesting beginning is Gilhooly's (2005) observation that most studies in this area focus on "planning in the head", thus overlooking the role of 'external memory' (Wegner 1987) in planning (e.g., paper and pencil, computer-assisted planning tools, etc.). The notion of *SIRN* (Synergetic Inter-Representation Networks) as introduced in Chap. 7 above is an attempt in this direction. Working and short-term memories are usually discussed in contrast to long-term memory and its various forms such as episodic and semantic memory that are introduced below.

Procedural and *declarative memory* – Procedural memory, also called *implicit* or *unconscious* memory, refers to the long-term memory of skills, procedures, and unconscious "know-how": riding bikes, playing music, driving a car, and crossing a street are typical examples. It can be regarded as an unconscious form of planning or rather planned behavior. The role of decision/planning heuristics might be relevant here. Declarative memory refers to long-term explicit and representational memory (Squire 2004), with further classification into *semantic memory* and *episodic memory*.

Semantic memory – refers to memory of meaning, understanding, and more generally to knowledge that is not related to specific events (Tulving 1972). From the point of view of planning, semantic memory is important with respect to causal relations and as such to planning (Fenker, Waldman, and Holyoak 2005).

Episodic memory – refers to the ability to “travel back in time” (Tulving 1983, 2002) to events, places, emotions, and experiences one encountered in the past. It is related to planning via the *time travel* ability: the same cognitive ability that enables one to travel back in time to past events, allows one to travel forward in time to planned or imagined future events. Recent neuro-cognitive studies (Spreng et al. 2009; Buckner et al. 2008; Gilbert & Wilson 2007; Buckner & Carroll 2007; Bar 2007; Addis et al. 2007; Hassabis & Maguire 2007) have speculated that such a time travel is connected to a core network (Raichle et al. 2001) which underlies cognitive abilities such as envisioning the future, navigation and planning that are “most often studied as distinct, (but) rely on a common set of processes by which past experiences are used adaptively to imagine perspectives and events beyond those that emerge from the immediate environment” (Buckner & Carroll 2007). Schachter and Addis (2007) have used the notion *constructive episodic memory* that enables us to be “remembering the past and imagining the future”. The importance of episodic memory and its time travel ability to planning is emphasized in Mumford et al.’s (2001) finding that the one common element in otherwise different definitions of cognitive planning is the involvement of simulated future actions and their outcomes.

Retrospective and prospective memory/remembering – Neisser (1982) made a distinction between *retrospective memory* that refers to a remembered past and *prospective memory* which is a memory referring to a remembered future – one “remembers to remember” and then performs accordingly (Sellen et al. 1997). Prospective memory can be interpreted as a special kind of cognitive planning, namely, the realization of delayed plans or intentions (Ellis 1996). Execution of a plan that was stored in long-term memory, after a time interval, would depend first on remembering that there was a plan at all (a prospective component), and only afterwards on remembering the specific contents of the plan (a retrospective component of remembering) (Meachem & Leiman 1975/1982). Some scholars have criticized the notion *prospective memory* on the ground that it is not a genuine memory type but rather a memory task (see discussion by Graf 2001) and thus should be termed *prospective remembering*. The latter term has been originally used by Meacham & Leiman (1975/1982) to imply the multidimensionality of the task (Dobbs & Reeves 1996) and the dynamic nature of the processes involved (Block & Zakay 2006).

Transactive memory – is a concept defined by Wegner et al. (1985) to describe the memory held by an entire group (team, family etc.). The transactive memory system includes the knowledge stored in the memory of each individual together with his/her memory about the knowledge stored and skills held by others in the group. It is a social phenomenon in which information is encoded and processed through a group’s communication processes, and it involves the operation of communication together with individuals’ memory systems. Individuals in the group act like ‘external memory’ storage for other group members and over time evolves a memory system that is wider and more competent than each individual memory system. Being a property of the group itself, transactive memory therefore cannot be traced inside or between individuals (Wegner 1987). Transactive memory and the way it develops may be seen as an underlying cognitive mechanism which is relevant to the discussion below (Sect. 13.5) on a SIRN approach to collective planning and design.

13.4 Complexity, Cognition, and Planning

The link between complexity theory, cognition, and planning follows from the fact that the brain and the various cognitive processes are commonly regarded as the *par excellence* examples of complex systems and their dynamics. Of the various complexity theories that have been applied to cognitive science, synergetics is probably the most explicitly cognitive. The title of Haken's (1996) book on this issue is indicative: *Principles of Brain Functioning: A Synergetic Approach to Brain Activity, Behavior and Cognition*. Some of the studies that are relevant to our discussion on planning are described below.

13.4.1 Pattern Recognition

Pattern recognition refers to the ability of an organism's cognitive system to recognize figures, forms, voices, and other patterns encountered in the environment. The process is implemented by the mind/brain spontaneously, that is, by means of self-organization. As elaborated in detail by Haken's (ibid) synergetics (and above, specifically in Part II), a typical pattern recognition process starts when a person (or a computer) is offered partial information of a pattern and is asked to recognize it out of several patterns stored in its memory. This offering triggers an interaction between the parts of the pattern that by means of associative memory gives rise to several configurations that enter into competition. The competition ends when the winning configuration – termed *order parameter* – enslaves the parts of the pattern and recognition is achieved.

13.4.2 Decision Making

As we'll see below in detail (Chaps. 19, 20), Haken (1996) suggested an analogy between pattern recognition and decision making in the context of planning. As in pattern recognition, a lot of (probably most) planning decisions taken by humans are ill defined in the sense that they are based on partial and insufficient information. This is also the starting point of Simon's (1957) famous notion of *bounded rationality*. Such a decision situation raises the question of "How do people complement the unknown data?" According to Haken and Portugali, as in pattern recognition so in planning decisions, the unknown data is being complemented by means of associative memory

(Haken, ibid), conceptual cognitive maps (Portugali 2005 and Chap. 6 above), SIRN and *decision heuristics*. The processes of data completion (by means of associative memory, cognitive mapping, and heuristics) are dealt with in detail in Chap. 19 below. Here, as an introduction, we discuss each of them in brief.

Cognitive Mapping. Two kinds of cognitive maps are relevant to the present discussion on planning decision making: *conceptual* and *prospective* cognitive maps (see definition in Chap. 6 above). The first refers to an image or representation of *A City*, while a prospective cognitive map, refers to one's image of a building, neighborhood, or city that doesn't yet exist or has not been visited. Such a cognitive map allows one not only to envision the planned object, but also to imagine acting in it and thus simulate and evaluate its positive or negative properties; for instance, whether the plans to expand a given city by a certain amount of inhabitants will entail an attractive, crowded, congested, rich or poor city.

SIRN Decision Making. Still in the context of the conjunction between cognitive mapping and decision making the role of SIRN should be mentioned. SIRN as we've seen above was originally developed as an approach to cognition and cognitive mapping. In Chap. 18 below we'll cast this notion into the formalism of synergetics and to the issue of decision making in the context of cities and their planning. The result would be a general SIRN decision-making model and two submodels: an *intrapersonal* submodel that refers to decision making of a single urban agent; and *interpersonal with a common reservoir* submodel that refers to decision-making dynamics of a group of planners. As we'll immediately see, the latter model can function as an approach to planning discourse analysis and to what in Sect. 13.5 below we term *collective planning*.

Decision Heuristics. The notion of decision heuristics is the cornerstone of Tversky and Kahneman's (1974, 1981) cognitive approach to decision making. According to them, when facing complex decision situations with high degree of uncertainty (i.e., ill-defined planning situations), people tend to rely on a limited number of heuristic principles. They have identified five such heuristics: *representativeness*, *availability*, *anchoring*, *similarity*, and *decision frame*. In Chap. 18 below we adapt these general heuristics to the context of city planning. More specifically, we study the similarities and differences between the pattern recognition approach to decision making and the notion of heuristics and add two more *synergetic heuristics*.

Prospective Memory as Delayed Decision Making. Finally, it is worth mentioning that Haken and Portugali (2005) have suggested applying synergetics' pattern recognition paradigm to the process of 'cue-dependent prospective memory' that as noted above can be interpreted as a special kind of cognitive planning and decision making, namely, the realization of delayed decisions and/or plans. The application involved three adaptive features: A link between retrospective and prospective memory; an analogy between the cue of the prospective plan and the small part of a whole pattern offered to a test person in the pattern recognition process; the third feature suggests that the realization of the prospective plan emerges out of a competition between existing and prospective attention parameters that compete for control over working memory.

13.5 Collective Urban Planning and Design

Planning is a basic cognitive capability. However, unlike many cognitive capabilities that are essentially solitary, personal, and subjective, planning belongs to several cognitive capabilities (e.g., "brain storming" as collective thinking) that are by their nature collective: people tend to plan together at a variety of groups' form and size, ranging from friends, families, and firms to professional planners in commercial, national, and urban planning teams. We suggest referring to such planning as *collective planning*. The full-scale study of collective planning has yet to be developed; however, several starting points already exist: the whole domain of "group dynamics" and its connection to complexity theory as in Arrow's et al. (2000) *Small groups as complex systems*; Kurt Lewin's (1943/1997) field approach to social psychology; measurement of team-shared mental models (Langan-Fox et al. 2000), collective behavior in synergetics as elaborated by Haken and applied to sociology by Weidlich's (1994) approach to the formation of public opinion; and finally, preliminary applications of the notion of SIRN to the domains of planning and urban design.

The starting point for the two SIRN applications is the discussion in Chap. 7, in particular, Figs. 7.12 (*bottom*) and 7.26 that refer to the *public, collective with a common reservoir* SIRN submodel. In developing this submodel we have made reference mainly to urban dynamics at large and to the city game (Fig. 7.7) as a simulation of this process. More recently some first steps were made towards applying this model to collective urban planning and design. However, before turning to describe these first steps a few words about planning and design are in place.

13.5.1 A SIRN View on Planning, Design, and Construction

In the domain of cities, the production of artifacts (buildings, road networks, neighborhoods, cities) commonly takes three forms: *planning*, *design*, and *construction*. While all three are processes of production, they differ in the nature of their end product: the product of planning is a *plan* such as a land-use plan or a set of policies about a given area; the product of design is some *model* of the end product, such as a graphical *sketch* of it, or 2D and 3D drawings, or a 3D physical model, or a computerized VR (virtual reality) of it; the product of construction is the end product itself, e.g., an urban neighborhood. Obviously, the three are not independent of each other: design always involves planning while planning might involve design (e.g., a land-use map/plan) but not always (e.g., when it ends with a set of policies). In a similar way, construction involves planning and design while the latter two often involve construction of a sort, but usually not of the final product.

Of the three, planning and design are commonly regarded as 'cognitive' and are thus associated with specific research domains known as *cognitive planning* as discussed in Sect. 13.4 above, and *design thinking* or, *design cognition* (Lawson 2005).

Design cognition as developed by architects, computer scientists and others, commences with the notion that the process of design is 'cognitive' due to the fact that it is associated with a whole set of general cognitive capabilities such as thinking, imaging, intentionality, planning, and the like, and specific cognitive capabilities such as visual thinking and spatial reasoning. To the latter we now want to add collective design, which can be seen as a variant of collective planning. The common view is that construction – the third step in the process of production – is not cognitive; according to SIRN as developed above (Chap. 7) it is part of cognition, too.

13.5.2 Collective Planning

Figures 7.12 (*bottom*) and 7.13 in Chap. 7 illustrate the way the third SIRN submodel has been applied to the city game and to urban dynamics at large. Another way to illustrate this process is suggested in Fig. 13.1 that in addition to describing the city game (as in Fig. 7.13) it also indicates a potential – the way the third SIRN submodel can be applied to collective planning. That is, on the one hand, Fig. 13.1 can be imagined as symbolizing a group of players playing the city game, while on the other, it can also be imagined as a group of planners sitting around a table, discussing planning policies; as in Fig. 13.2, for instance. This potential was realized by several subsequent studies that have employed SIRN as a conceptual framework and "An approach to planning discourse analysis" (Portugali and Alfasi 2008). The latter paper was based on an empirical participatory observation conducted by Alfasi (2001) as part of her Ph.D. research. In that observation she has participated in, followed, and recorded, the meetings of a planning team that was preparing a plan for the city of Beer Sheva in south Israel. While the central aim of this study was to follow and expose the dynamic of the planning discourse, it also provides an empirical illustration to collective planning, namely, to the way a group of planners are planning together.

The insight gained by this empirical study is twofold: Firstly, that a planning team can be seen as a complex, self-organizing system the dynamics of which follows the third SIRN submodel as described above. Secondly, that discourse among the planners is the main medium through which collective planning is implemented. As an extension to the above, I suggest identifying two forms of planning discourse: One that takes place between the planners who were specifically assigned to prepare the plan and another that evolves as public discourse along the lines of Habermas' (1984, 1987) *communicative action* and Healey's (1997) *collaborative planning*.

The participatory observation mentioned above exemplifies the first form, as noted. In following closely the Beer Sheva planning discourse it was possible to follow the way new planning ideas and policies emerge out of the discoursive interaction between the various planners, how they take shape, stabilize, dominate the discourse for a certain period, just to be replaced by other ideas that emerge in the discourse and so on. This process went on until at a certain stage a given planning scheme eventually emerged as the winning order parameter that finally

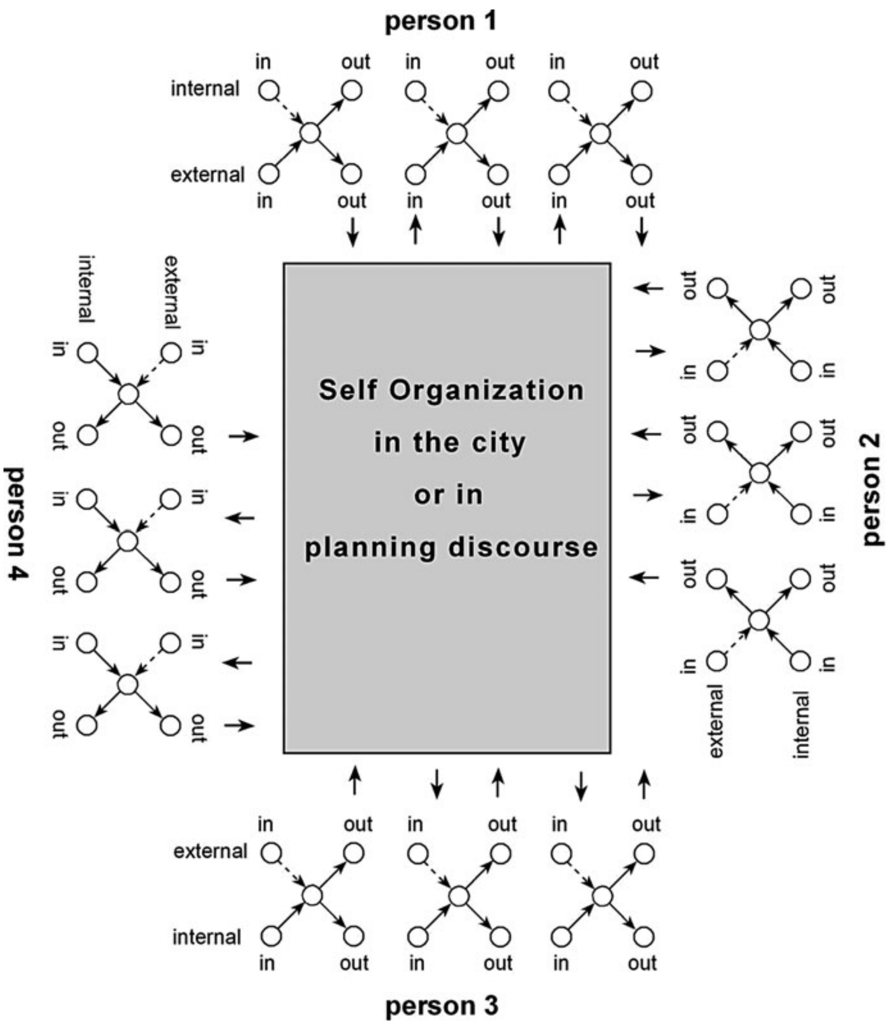

Fig. 13.1 The way the third SIRN submodel – the interpersonal, collective, with a common reservoir SIRN – can be applied to collective planning and decision making. According to this submodel, all communication and interaction between the agents involved in the process are made via a "common reservoir" which might be a planning team's discussion table, the city as a whole or parts of it

enslaved the discourse and brought it into a steady state during which no further plans were added to the discourse. Figure 13.3 illustrates the principal evolution of this process of collective planning. For a detailed discussion of the actual planning discourse as it took place in the Beer Sheva team see Portugali and Alfasi (2008). In analyzing the discourse it was possible to see how various factors such as the personality and charisma of the individual planners are affecting the planning discourse and as a consequence the final result.

Fig. 13.2 A planning team in action

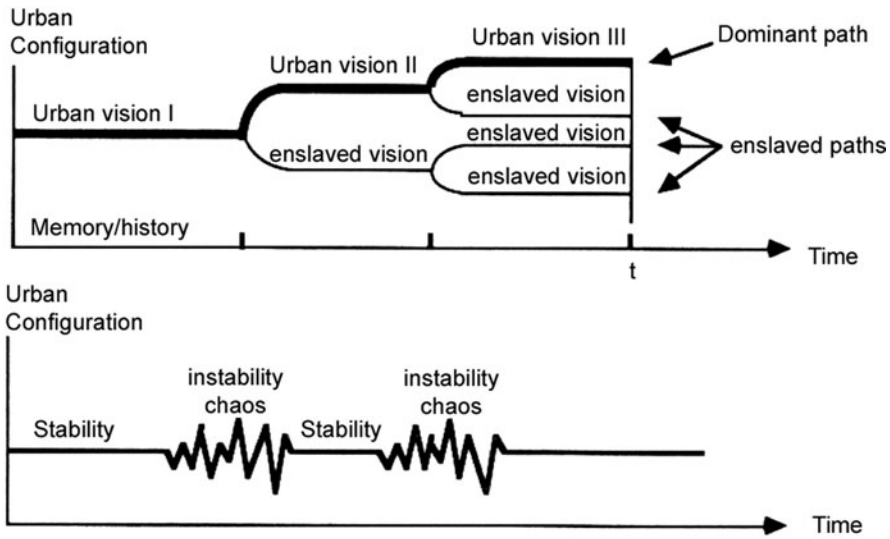

Fig. 13.3 *Top*: Bifurcation diagram illustrating collective planning discourse: Planning ideas and policies emerge out of the discourse at bifurcation points, dominate the discourse for a certain period, replaced by other ideas that emerge and bifurcate in the discourse until a certain planning scheme eventually emerged as the winning order parameter that enslaves the discourse and brings it into a steady state. *Bottom*: The result is that the collective planning process (e.g., discourse) evolves as a typical self-organizing system typified by relatively long periods of steady state during which a given plan or urban vision dominates the discourse, interrupted by short "chaotic periods" that entail the emergence of a new urban plan/vision

13.5.3 Collective Design

In a recent study the *Interpersonal with a common reservoir* SIRN submodel, with its city game, were used as a framework for a design city game (Tan and Portugali 2011). Initiated and organized by Ekim Tan (www.theresponsivecity.org/), the game was played in the context of a real urban project: the plan to add some 350 new homes to the new town of Almere Haven, Netherlands. The Almere planning department has assigned the area of Sportpark de Wierden for the extension, and decided that the plan should be made by means of public participation. The design city game described below can thus be seen as an experiment the aim of which is to explore the usefulness of city games as a public participation design tools.

The game was thus played on a 2D map of Sportpark de Wierden when the players that simulated the new residents of Almere were fifteen graduate students with diverse cultural (Indian, American, Kenyan, Dutch, Turkish…) and disciplinary (architecture, planning, sociology, anthropology…) background. In a three-hour experiment, the participants played thirteen rounds placing mock-ups based on their resident profiles. As in previous city games, here too, the participants made location decision sequentially. However, here we've added an additional rule that 'in case of conflict, existing buildings will have priority over the new-intended ones'.

Figure 13.4 shows several snapshots from the game as it developed, while Fig. 13.5 the resultant outcome. The game was interesting in several respects.

Fig. 13.4 Several snapshots from the design city game as it developed in the area of Sportpark de Wierden, Almere Haven, Netherlands (*Source*: Tan and Portugali 2011)

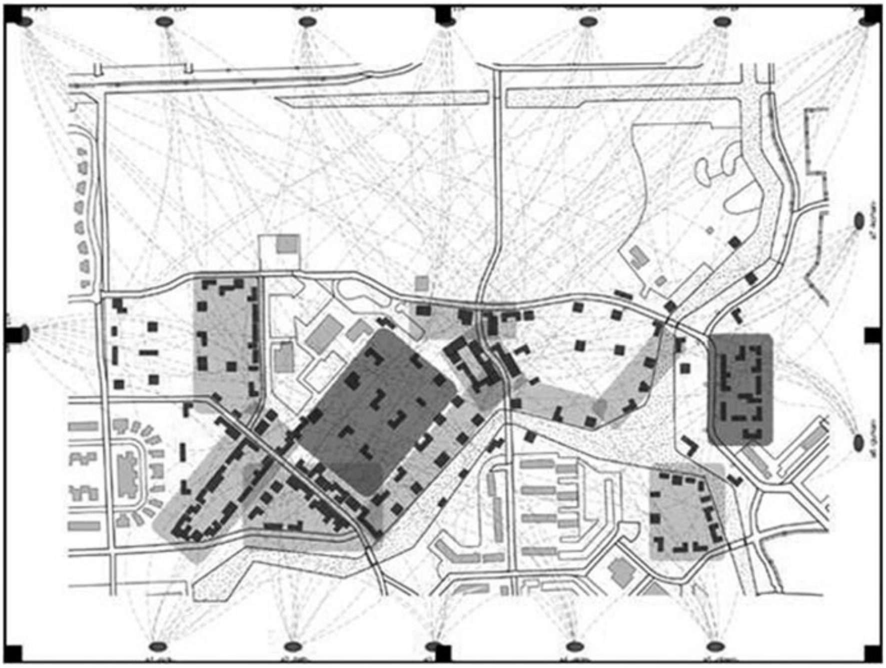

Fig. 13.5 The resultant outcome from the above design city game (*Source*: Tan and Portugali 2011)

Firstly, in the sense that while it started with the two simple rules specified above, other rules came into being as emerging properties during the game; among them rules of development, rules of network and rules of form. Secondly, as can be seen in Fig. 13.5, the resultant urban landscape is highly (self-) organized and rather rich and articulated. Thirdly and in association with the above, despite the fact that there was no single mind behind the evolving urban form, and the fact that no one in the game was concerned about the final urban form of the evolving area, the outcome is rather creative.

13.6 Concluding Implications

13.6.1 From Solitary to Collective and Professional Planning

Planning as we've seen is a basic cognitive capability of humans that is sometimes executed solitarily and sometimes collectively. Planning is also a profession and academic discipline and as such a *par excellence* collective activity. As a community of professionals and academics planners are very conscious about methodology – the good planning approach. In fact, as we've seen above (Chap. 12) a major portion of planning theory is devoted to the debate about the appropriate planning approach, which is not usually the case with solitary or collective cognitive planners – they need not always be conscious and aware of the methodology they employ in their planning, be it Kahneman and Tversky's heuristics, Simons' bounded rationality or a purely rational approach.

Every professional planner when practicing planning is thus functioning, on the one hand (usually unconsciously), as a solitary and/or collective cognitive planner, while on the other, as professional planner who is fully conscious of the appropriate approach to planning. As a consequence, every practicing professional planner is subject to a built-in tension between planning according to the book, that is, according to the prevailing methodology – the way the community of planners have defined the appropriate approach and methodology of "good planning", and planning that results from the fact that each professional planner is first and foremost a human being and as such executes solitary and collective cognitive planning as everybody else.

This tension between the cognitive and professional forms of planning came out clearly in the participatory observation of the Beer Sheva planning team. As we've seen, the two planning processes, the professional and the cognitive (the planning discourse according to the SIRN model) evolved in parallel and at least in the specific case of Beer Sheva the collective cognitive planning process "took over".

The question is 'how this knowledge about solitary and collective forms of cognitive planning and the way they interact with professional planning can inform planning theory and practice'? As a first step toward answering this question we suggest looking at the directions in which current theory of professional planning is moving. As we've seen above (Chap. 12) and will further see below, planning theory is moving, on the one hand, toward social theory oriented collaborative and strategic planning approaches, while on the other, toward complexity theory oriented planning studies that are split into two branches: one that attempts to develop planning support systems that take advantage of the rapidly developing sophisticated modelling approaches and communication technologies, and another that attempts to reshape planning systems as complex self-organizing systems (Chap. 15, below).

Planning as a cognitive capability can inform both directions: it can inform collaborative and strategic planning by adding the ways solitary and collective forms of cognitive planning participate in the communicative-collaborative process that determines urban planning strategies. The case of planning discourse analysis discussed above indicates one possible direction of this line of thinking. It can also inform the complexity theories oriented planning approaches: to the PSS is can add the cognitive dimension that is needed to make such support system accessible and legible to professional as well as to nonprofessional planners; to CTC oriented studies it can add the notion of *planning behavior* that is described in Sect. 13.6.3 below.

13.6.2 Collective Design?

The design city game described in Sect. 13.5.3 exposes yet another aspect of collective planning and design: In the planning discourse associated with collective planning (Sect.13.3.2) we had a group of planners discussing the way the overall structure of the city of Beer Sheva should look like in the future – after the plan/vision will be approved by the authorities and will start to be implemented. In the case of the design city game there was no vision of the overall future structure of the neighborhood or the way it should look like; nor was there a clear boundary between the stage of planning and design and the stage of implementation. In fact the players never concerned themselves with such questions – the concern of each player was his or her building and the best way to integrate it into the existing structure of the city. The overall structure of the city in each stage of the process was thus an emergent property – a genuine product of a process of self organization; very much like the urban simulation models elaborated in SOCity (Portugali 2000, Part II) and in Part IV below.

The interesting question is the extent to which this collective design city game can indicate a new approach to urban design – a collective urban design? More specifically, whether the design city game should be seen as a kind of urban simulation game the aim of which is to test different design rules and their impact on the emerging urban form – very similar to the use of urban simulation models in the context of planning/design support systems, for instance; or whether the game should be seen as an imitation of reality – a model of a real design process in which the future inhabitants of the neighborhood or the city are directly involved in the process; or of both? The answer suggested by Tan and Portugali (ibid) is that the above game indicates a potential that has yet to be further experimented and tested and only then realized.

13.6.3 Planning Behavior

Planning behavior is a new term suggested recently by Portugali (2009) to refer to the fact that the various cognitive capabilities imply also a distinct form of behavior. For example, the ability of animals and humans to construct cognitive maps is related, on the one hand, to *exploratory behavior* in animals (Golani et al. 1999) and humans (Munk-Vitelson 2005), while on the other, to the notion of *way-finding behavior* (Golledge 1999). In a similar way, Portugali (ibid) proposed as a working hypothesis that the various cognitive planning capabilities of humans entail a distinct form of behavior that he suggested calling *planning behavior*. It is interesting to mention that Golani et al. (above) refer to exploratory behavior as *phenotypic behavior*.

The phenomenon of planning behavior has immediate implications to complexity theories of cities and to urban simulation models, namely, that a lot of agents' behavior in cities is determined by plans that are not yet (and might never be) materialized, by what agents plan to do and so on. Some of these issues will be further discussed in the next chapter that deals with predictions, while others that concern urban dynamics and urban simulation models will have to await subsequent studies. It is important to emphasize that the above preliminary notes on planning behavior should be seen as beginnings for a whole new domain of research that has yet to be fully scrutinzed.

Chapter 14
Learning from Paradoxes about Prediction and Planning in Self-Organizing Cities

14.1 Introduction

Since early days paradoxes have been useful (and enjoyable) analytical tools; mainly due to their capability to expose things that are wrong when everything appears to be right. Zeno paradoxes are a good example to their use in antiquity, while in modern science theoretical physics stands as a domain where paradoxes are intensively used. This is not the case with cities and their planning, however. This chapter introduces paradoxes as useful means to study predictions in the context of cities and their planning. It discusses several city planning paradoxes and suggests seeing their origin in the complexity of cities and in the role played by cognitive maps and information exchange in complex, self-organizing cities.

14.1.1 Achilles and the Tortoise

> *The Greek hero Achilles, the fasted man, conducted a footrace with the slow tortoise. Graciously, fast Achilles allowed the slow tortoise a head start of a hundred meters. But then, as the race started, something strange happened: during the time Achilles run the hundred meters that brought him to the tortoise's starting point, the tortoise "run" a certain much shorter distance, say one meter. During the time Achilles run that one meter distance, the tortoise advanced farther; and so it continued: whenever Achilles reached the tortoise's previous point, he still had farther to go and so on until infinity. Swift Achilles gradually realized that he can never overtake the slow tortoise.*

This is, of course, one of the famous paradoxes of 5th century B.C. pre-Socratic Greek philosopher Zeno from Elea in southern Italy. Aristotle is his Physics (VI:9, 239b 15) summarized it as follows:

> *In a race, the quickest runner can never overtake the slowest, since the pursuer must first reach the point whence the pursued started, so that the slower must always hold a lead.*

J. Portugali, *Complexity, Cognition and the City*, Understanding Complex Systems,
DOI 10.1007/978-3-642-19451-1_14,

14.1.2 Paradoxes

As can be seen from the story about Achilles and the tortoise, a paradox "is an argument that starts with apparently acceptable assumptions and leads by apparently valid deductions to an apparent contradiction" (Aharonov and Rohrlich 2005, p 2). It is generally believed that Zeno was not the first to use paradoxes as means to convey ideas; that other philosophers of his time did so before him; however, his set of paradoxes is the first known documented example. The essense of this method is close to the method of proof called *reductio ad absurdum*, also known as 'proof by contradiction'. Both are often credited as a source of the dialectic method (Kains 1988).

A proof by means of a paradox "is useful because it can show that something is wrong even when everything appears to be right" (Aharonov and Rohrlich, ibid). For example, in Zeno's paradox the apparently acceptable assumptions, followed by the apparently valid deductions, entail a *reduction ad absurdum* that contradicts common sense. Such a discrepancy is of course challenging and indeed, Zeno's paradox provided an impetus for philosophers and mathematicians to solve it – in early times as well as today (Salmon 2001; Sainsbury 1995; Faris 1996).

Zeno's paradox is presented in contemporary mathematics courses to elucidate the concept of *convergence* of series: implicit in Zeno's case is the (false) assumption that each consecutive step is smaller than the foregoing one so that the sum of all these increments are finite and similarly also the time permitted. Within these *finite* limits Achilles indeed cannot overtake the tortoise. But when longer distances (times) are permitted, he can.

It might be added that even if the above-noted assumption were not false, still Achilles must win the competition: his body is built in such a way that he cannot make steps below a certain size so that the above assumption can be valid up to a threshold beyond which Achilles must overtake the tortoise. This argument about Zeno's paradox illustrates the importance of embodiment and scale. However, having said the above, it is important to emphasize that from the mathematical solution to the paradox follows that even if Achilles' body were a line, he would still win the competition – the solution has to do with convergence. (I'm indebted to Professor Haken for his comments about the above Zeno's paradox).

Throughout history, paradoxes have proved to be very useful and often enjoyable learning tools. In ancient times they were employed mainly in the domains of logic and philosophy. In the 20th century we see an intensive use also in other domains such as mathematics, economics, and physics. Wikipedia, for instance, lists 18 economic paradoxes. In theoretical physics, some of the central controversies of the 20th century have developed by means of paradoxes – especially those that concerned and still concern the relations between Einstein's relativity and quantum theory. Some of them, such as the EPR – Einstein, Podolsky, and Rosen (1935) thought experiment, and Schrödinger's cat (described below), became very famous indeed (and useful). It is thus not surprising that Aharonov and Rohrlich (2005) have entitled their book about the history and recent advances in theoretical physics *Quantum Paradoxes*.

Cities (like life) are full of paradoxes and so is also the realm of urban and regional planning. However, apart from a few exceptions, paradoxes have never played a significant role in the discourse about urban and planning theory. The first aim in this chapter is to demonstrate that theorizing by means of paradoxes has the potential to be a very useful learning tool in the discourse about, and study of, cities and their planning. In what follows I illustrate the usefulness of paradoxes by examining several real and imaginary urban and planning paradoxes and by discussing their theoretical foundations.

The various planning paradoxes that are discussed below arise from a discrepancy that to my mind characterizes the domain of urban and regional planning: On the one hand, planning theory, as well as the structure of planning law, practice and administration, are all based on the (usually implicit) assumption that cities are essentially predictable entities; that given sufficient data and information, their future behavior is in essence predictable. On the other hand, current urban theory suggests that cities are complex, self-organizing and nonlinear systems and that as a consequence their future behavior is in essence not predictable; even if sufficient information and data is collected and available (Portugali 2000 and above). The second and major aim of this chapter is to employ several imaginary and real prediction paradoxes as means to expose the above discrepancy and elaborate on it.

The discussion below is divided into two major parts: the first (Sect. 14.2) describes and examines four paradoxes. Its aim is to illustrate the usefulness of paradoxes in scientific discourse and to provide the data and background to the discussion that follows. The second part (Sect. 14.3), "learning from paradoxes", examines several phenomena and aspects that explain why the planning paradoxes arise. The chapter then concludes with a discussion about the implications to planning theory and practice and suggests further research directions (Sect. 14.4).

14.2 From Schrödinger's Cat to Planning Paradoxes

This section describes and studies four paradoxes in a sequence. The first is the famous Schrödinger's cat thought experiment (Sect. 14.2.1). It is "famous" for the impact it had on theoretical physics and on the philosophy of science, and for being a "classical" example of the role and usefulness of paradoxes in scientific discourse. As we shall see below, Schrödinger's cat provides also a theoretical context and source of inspiration to two planning issues that will be elaborated below in Sect. 14.3: SFFP – the phenomenon of self-fulfillment and self-falsifying predictions (Sect. 14.3.1) and the distinction between classical and self-organized urban and planning theories (Sect. 14.3.2). The *rbc paradox* that is described next (Sect. 14.2.2), takes us to the realm of cities, whereas the next two paradoxes, the imaginary prediction-planning paradox (Sect. 14.2.3) and the real prediction-planning paradox (Secs. 14.2.4) provide the main case studies to the discussion in Sect. 14.3 that follows.

14.2.1 Schrödinger's Cat

Here is the thought experiment as formulated by Schrödinger (1935, p 807) and as illustrated in Fig. 14.1:

> *A cat is penned up in a steel chamber, along with the following device (which must be secured against direct interference by the cat): in Geiger counter there is a tiny bit of radioactive substance, so small, that perhaps in the course of the hour one of the atoms decays, but also, with equal probability, perhaps none; if it happens, the counter tube discharges and through a relay releases a hammer which shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would say that the cat still lives if meanwhile no atom has decayed. The psi-function of the entire system would express this by having in it the living and dead cat (pardon the expression) mixed or smeared out in equal parts.*

In terms of interaction we can say that there are two interacting persons here: Person 1 who sets the box and Person 2 who opens it and finds the cat dead. The question is: who is the murderer? Classical physics answers that person 1 is the murderer! Quantum theory answers that person 2 is the murderer! The reason: until Person 2 opens the box (i.e. "observes"), the cat is at once dead and alive! (A third answer might be that both persons, 1 and 2, are the murderers: they murdered the cat by means of their interaction.)

Schrödinger's aim in setting this thought experiment was to expose the absurdity of the quantum answer: The idea that a cat can be at once alive and dead and that humans, by means of their act of observation, might affect the state of physical entities, contradicts human experience in the world of matter; hence the paradox. In retrospect we know that Schrödinger's cat paradox led not to the falsification of quantum theory but

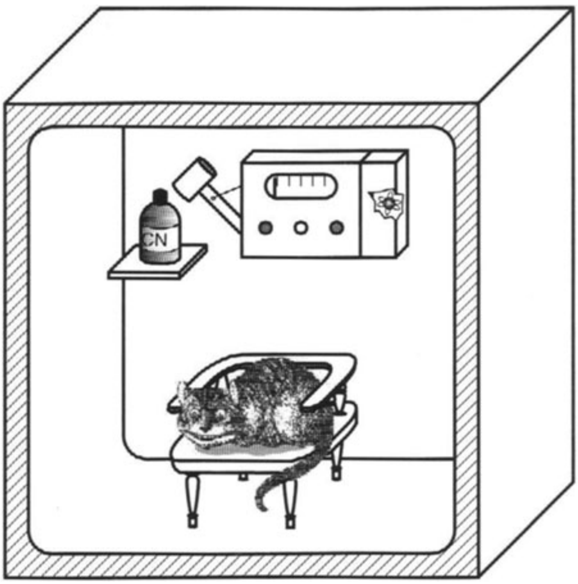

Fig. 14.1 Schrodinger's cat inside the steel chamber unaware of the Geiger counter, the radioactive atoms, the bottle of cyanide, and the hammer
Source: Aharonov and Rohrlich 2005, Fig. 9.1

rather to its elaboration by theories such as Everett's (1955, 1957) *the many worlds interpretation* (DeWitt and Graham 1973) and Bohm's notions of *causal interpretation*, *implicate order* and *ontological interpretation* (Bohm 1957, 1980; Bohm and Hiley 1993). These theories share the view that in the subatomic quantum domain, there are no external observers but rather interacting entities. In such a realm the observer by his/her act of observation participates and influences the process.[1] As we shall see in some detail below, while in the domain of matter this point of view seems astonishing, in the domain of cities and planning it is not; in fact it is specifically relevant to our understanding of the role of predictions and observation in the domains of complex systems in general and of cities and planning in particular.

14.2.2 The rbc City Paradox

Cities as noted are full of paradoxes. A well-known urban paradox that was associated with Alonso's (1964) 'trade off theory' and his notion of *rbc* (rent bid curves) went like this: The theory commences with three apparently acceptable assumptions that

- Urban phenomena (e.g., land value) decay with distance from the city center. This assumption is known as the "distance decay function".
- Land-use is determined by means of agents' competition over land.
- Demand for urban land decays with distance from the city center.

These apparently acceptable assumptions led to the following apparently valid deduction:

- The higher bidders capture the city center, the medium bidders the area beyond the center and the lower bidders the periphery.

  The above deduction, in its turn, leads to an apparently acceptable conclusion:
- The richest agents capture the city center

  Empirical evidence indeed supports this conclusion, but at the same time exposes an apparent empirical contradiction:
- The poorest agents too live at the center on the most expensive urban land.

  As in many other paradoxes, this paradox has proved useful in that it provided an impetus to refine the theory (Harvey 1971, 1973; Portugali 1981) as described in Fig. 14.2.

But the above example is an exception; for while cities are full of paradoxes, paradoxes have never played a significant role in urban theory. In what follows I

[1]For a somewhat different view see Aharonov's notion of *weak measurements* (Aharonov and Rohrlich 2005). Most theoreticians of quantum theory would not subscribe to Everett's nor to Bohm's explanations. The reason being "decoherence" (Zurek 2003), namely, that the cat's fate is not that of a microscopic quantum system but rather of a macroscopic "classical" body. I'm indebted to Professor Hermann Haken for turning my attention to this point.

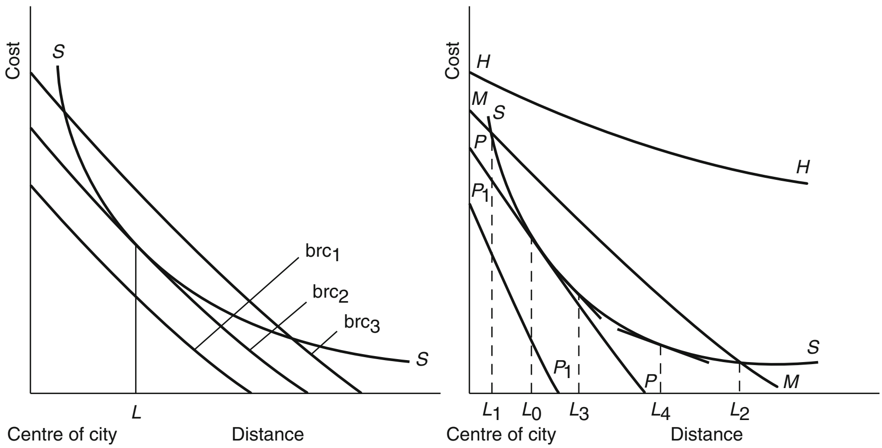

Fig. 14.2 In Alonso's mapping of the rent bid curves (*left*), equilibrium is reached on location *L* where the city land price curve (*S-S*) is tangential to the lowest of the bid rent curves … (*brc2*). The *rbc* paradox entailed the recognition that the *rent bid curves* vary according to the economic state of the urban agents with the implication that the process of location is sequential (*right*): First come the rich with their flat *rbc* (*H-H*) that give them freedom of choice to live everywhere in the city. On the other hand, the poor with their very steep *rbc* (*P-P*) are forced to locate at L_0 only; finally the middle classes in between (*M-M*) have a choice to live in all locations between L_1 and L_2 (*Source*: Portugali 1981, pp 290–292, Figs. 5.6, 5.7)

look at some imaginary and real urban paradoxes and discuss their theoretical foundations.

It is important to clarify the term 'agent' as used above and as further employed in the discussion below. In both connections it is employed as it is common to use it in simulation models of complex systems (as in Part IV below). In the latter, every entity that is part of the system and its network, and participates in its interaction, is termed 'agent'. Thus in a city, every inhabitant or a person that is active in the city is an agent and so is each of the many private companies and public institutions that operate in the city.

14.2.3 An Imaginary Prediction Paradox

Imagine that you are an appreciated transportation expert in charge of monitoring a certain road network. The time is 7:30 a.m. and observing the incoming data by means of your transportation prediction models you see a traffic jam at junction X at 9:00 a.m. This finding puts you in a dilemma: If at 8:00 a.m. you announce your prediction in the radio – that at 9:00 a.m. there is going to be a major traffic jam at a certain junction – all commuting drivers will hear it and since they trust your prediction, they will avoid the junction and there will be no traffic jam there – your prediction will be falsified. If this happens you might loose your credibility as a predictor. The dilemma here is not just your personal reputation and ego, but its consequences; if in the next morning you predict another major traffic jam, drivers will not believe you and the event will happen as predicted. The general intuitive assumption is that the better a prediction, the greater are the chances that it will be materialized as predicted. The paradox in the above example is that the better a prediction is, the greater the chance that it will *not* be materialized.

The above paradox is typical to cases of *self-defeating* or *self-falsifying* predictions. A mirror image of the latter is the so-called *self-fulfilling predictions*. An example here might be a rather arbitrary prediction that thousands of people are planning to come tomorrow night to the big demonstration at the city center. Since people trust this prediction, many of them decide to go to the city center to see and participate in, the event. The paradox here arises because the example falsifies our intuitive assumption that the chances of an arbitrary prediction to materialize are very low. What we face here, as noted, is a case of self-fulfilling prediction. In Sect. 14.3.5 below we further discuss these issues.

It must be emphasized that the description above refers to a rather simplistic situation in which all receivers of the predicted information behave in a uniform way. As implied by the notion of 'semantic information' discussed above (Chap. 9, see also Sect. 14.3.6 below), in reality receivers of information might behave in a variety of ways that depend on their character, culture, social norms, and also on heuristics and other factors that participate in determining human behavior in situations of uncertainty. In order to capture this variety one thus has to investigate various behavioral patters and their implications. In fact, in Chap. 18 below I present some preliminary steps toward building an urban simulation model the aim of which is to study such processes. We hope to be able to report on some findings from this model in the future.

14.2.4 A Real Case of Planning Paradox

City paradoxes are specifically significant in the domain of city planning. This is so because of the very structure of the planning process: It typically starts with a set of assumptions and goals based on past experience, continues with a set of deductions-predictions about the future, followed by a set of actions that are assumed to meet the predictions (Chap. 12 above; see also Portugali 2000, Chap. 11). For example, past experience shows that the rate of growth (of, say, population) in the city is x. By means of deduction one can determine the future state of x. By means of a set of appropriate actions and policies the future demand can be supplied in the appropriate target year.

The planning paradox arises when a set of apparently acceptable assumptions about the past, followed by apparently acceptable deductions-predictions about the future, further followed by apparently acceptable policies and actions, lead to apparently contradictory results. Similarly to paradoxes in general, a planning paradox is useful because it can show that something is wrong even when everything appears to be right.

A real case of planning paradox due to self-falsifying prediction followed the immigration wave from the former Soviet Union to Israel in the early 1990s. The professional planning prediction was that Israel is approaching a housing shortage. The entailed plan was that the government should therefore purchase a large number of mobile houses and locate them on the outskirts of towns and cities. The implementation of this policy ended in failure due to spontaneous initiatives by a large number of individuals ("latent planners"), who, as a consequence of the predicted shortage and the prospect of making money, transformed existing non-residential buildings into residential ones. This they did mainly in city centers, which, from the point of view of newcomers, are the most attractive places. The outcome was that the vast majority of apartments prepared by the latent planners were rented, while many of the mobile houses prepared by the government's planning bodies were left unwanted and unoccupied (Alfasi and Portugali 2004).

On the face of it the above event can be interpreted as 'normal response of market forces' – which is true. However, as will be clarified below, the point is the implicit (wrong) assumption made by the planners that their predictions and plans are external to the events predicted. From the theory of complexity (below, Sect. 14.3.3) follows the exact opposite: that predictions and plans, once produced, become participants in a complex urban dynamics. This is the main reason why the 'normal responses of market forces' and of cities are hard to predict.

14.3 Learning from Paradoxes

The two prediction-planning paradoxes discussed above in Sects. 14.2.3, 14.2.4, are a consequence of SFFP. The discussion in this section starts by elaborating on the phenomena of SFFP. This discussion entails the question as to how these phenomena arise. The answer to this question starts with a distinction (inspired by Schrödinger) between *classical* and *self-organizing theory of planning* (Sect. 14.3.2) and continues by showing that the above prediction-planning paradoxes are a result of the fact that planners tend to treat complex self-organizing cities as if they are classical systems. This answer in its turn entails several questions that concern the nature of complex systems in general, the difficulties to predict their behavior, the uniqueness of cities as complex systems and the specific sources of their complexity. Sections 14.3.3–14.3.6 attempt to discuss these issues. Section 14.3 introduces in some detail the notion of self-organization and the problematic of prediction in such systems. Section 14.3.4 discusses the uniqueness of cities as *dual complex systems* and the implications thereof to prediction and planning, while the remaining two subsections suggest finding the sources of this uniqueness of cities and the implications to planning and prediction, in the roles played by memory (Sect. 14.5) and information (Sect. 14.6).

14.3.1 Self-Fulfilling and Self-Falsifying Predictions (SFFP)

The notion of self-fulfilling prediction or prophecy is a rather old one. It appears time and again in Greece mythology with the story of Oedipus being the most well-known one; it appears in Roman mythology in the story of Romulus and Remus, in the mythological story of Krishna (in the epic *Mahabharata*) and more.

In social and scientific discussions one can mention sociologist Robert K. Merton (1949) who in his *Social Theory and Social Structure* discusses the concept of the self-fulfilling prophecy in some length:

> *The self-fulfilling prophecy is, in the beginning, a* false *definition of the situation evoking a new behaviour which makes the original false conception come true… prophecies or predictions … become an integral part of the situation and thus affect subsequent developments, This is peculiar to human affairs. It is not found in the world of nature, untouched by human hands.*

Philosopher Karl Popper (1976) goes one step further than Merton and suggests that this phenomenon that he called *the "Oedipus effect"* can be found in nature too:

> *One of the ideas I had discussed in The Poverty [of Historicism] was the influence of a prediction upon the event predicted. I had called this the "Oedipus effect", because the oracle played a most important role in the sequence of events which led to the fulfillment of its prophecy…. For a time I though that the existence of the Oedipus effect distinguished the social from the natural sciences. But in biology too – even in molecular biology – expectations often play a role in bringing about what has been expected.*

The notion of self-defeating prediction is less known and discussed. A case in point here is the so-called *Osborne effect*: In 1983, inventor Adam Osborne, founder of Osborne Computer Corporation (OCC), pre-announced several next-generation computer models which had not yet been built, highlighting the fact that they would outperform the existing model. According to the myth, sales of the Osborne 1 immediately plummeted as customers opted to wait for these improved systems; this caused an attendant drop in cash flow and thus profits, and a few months later the company became bankrupt.

14.3.2 Classical vs. Self-Organizing Planning Theories

The phenomena of SFFP arise when the predictor is not an external observer, but an internal agent in the multi-agent system under consideration; just like the other agents that are exposed to the prediction. The fate of the prediction in this case is determined by means of the interaction between the many agents of the system. In fact, Schrödinger's cat that was discussed above was exactly about this: in the subatomic quantum domain, he said, there are no external observers but rather interacting entities.

As already noted above, while in the domain of matter Schrödinger's setup is contradictory, in the socio-human domain it is rather common: predictions about the stock exchange participate in its behavior. The behavior of the market is determined by the interaction between the message predicted by agent 1 and its interpretation by agent 2: until agent 2 interprets agent 1's message (that is to say, "opens the box"), the prediction, like Schrödinger's cat, is at once dead and alive.

Theoretical physics had and still has a major influence on discourse about the nature of science and scientific method. Prominent figures in this domain, such as Thomas Kuhn, Karl Popper and others, have taken physics as their major case study. The discussion about the scientific method in its turn had a major influence on all sciences. The study of cities and planning was no exception: in its attempt to transform the study of cities into a science and planning into "rational comprehensive planning", it was strongly influenced by the discourse on scientific methods (Camhis 1979). It is therefore not surprising that the tension between the classical and quantum theories in physics has an echo in the domains of cities and planning.

This echo shows itself in the tension between what I suggest to call *classical urban and planning theory* and the recently emerging view that cities and planning are essentially complex self-organizing systems: On the one hand, one finds *classical urban and planning theories* that implicitly or explicitly treat cities as machines, urban scientists as external observers and planners as external experts. Location theory is a typical example of a classical urban theory, while rational comprehensive planning of a classical planning theory (Chaps. 2 and 12 above). On the other hand, there are urban theories that treat cities as systemic wholes, and scientists and planners as some of the many parts, agents and forces that participate in a complex and spontaneous urban game (Allen 1997; Batty 2006; Portugali 2000 and the present book of course). Complexity and self-organization theories of urban dynamics belong to the second group.

The prediction and planning paradoxes noted above are due to contradiction that arises from the fact that many urban scientists and planners tend to treat cities as classical systems overlooking the evidence that cities are complex self-organizing systems. For example, in the case noted above regarding the plans to meet the migration wave from the former USSR to Israel, the planners treated the planning field as if it was a classical system, not being aware to the intricacies of the complex ways their plans participate in the urban dynamics. What is it in complex self-organizing systems that makes them in essence unpredictable? To answer this question we have to look into the properties of such systems.

14.3.3 Prediction in Complex Self-Organizing Systems

Self-organization, as we've seen above, is a property of open and complex systems: open in the sense that they exchange matter, information and energy with their environments and complex in two senses: first, their parts are so numerous that there is no technical way to determine causal relations between them. Second, their parts form a complex network of interaction, with feed-forward and feedback loops, that makes the determination of causal relations in essence impossible. Such systems are typically characterized by nonlinearity, phase transition and fractal structure and the property of emergence.

Prediction in the context of complex systems such as cities is associated with four fundamental properties of such systems. First, the nonlinearities that typify cities imply that one cannot establish predictive cause-effect relationships between some of the variables. Second, many of the triggers for change in complex systems have the nature of mutations (Allen 1997). As such, they are unpredictable, not because of lack of data, but because of their very nature. Third, unlike closed systems, in complex systems, the observer, with his/her actions and predictions, is part of the system – a point made by Jantsch (1981) more than two decades ago and largely ignored since then (Fig. 14.3). In such a situation, predictions are essentially feed-forward loops in the system, important factors that affect the system and its future evolution with some interesting implications that include self-fulfilling and

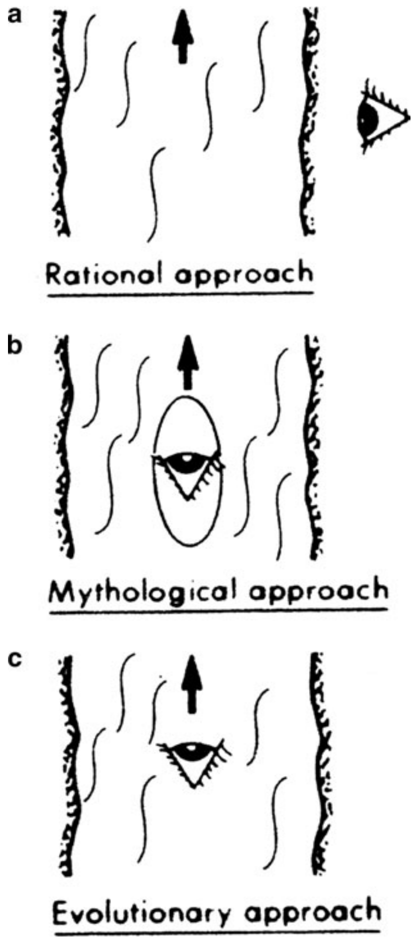

Fig. 14.3 Jantsch's (ibid Fig. 8) conceptualization of "the three modes, or levels, of perception and inquiry illustrated by the image of the stream. At the rational level we are outside the stream, at the mythological level we try to steer our canoe in the stream, but at the evolutionary level we are the stream" (ibid, caption)

self-falsifying or self-defeating predictions noted above. Fourth, cities as complex systems are different from complex systems commonly discussed by theories of complexity – they are, as noted several times above, dual complex or *dual self-organizing systems*.

14.3.4 Planning in Dual Self-Organizing Systems

As we've seen above, the main theories of complexity and self-organization were originally developed by physicists and by reference to physical phenomena such as liquid dynamics or LASER; at a later stage these theories were applied to cities – again by physicists. Thus, P. Allen (1997) has applied Prigogine's theory while Weidlich (1999) Haken's synergetics. As we've further seen, one of the major insights gained by our study *Self-Organization and the City* (Portugali 2000), was that there is a major difference between material and human systems: in material systems the parts are simple (atoms, molecules etc.) and complexity is an emergent property of the system as a whole. In human systems the situation is different: each of the parts (individuals, households, firms . . .) is in itself a complex system. Cities in this respect are *dual self-organizing systems*. The implications: First, the interacting elements in such systems are *agents* and not *parts*, that is, entities that have cognitive capabilities such as learning, thinking, decision making and the like; one of these capabilities is *planning* – agents plan and take decisions according to their past experience (learning) and their plans. That is, the interaction in dual self-organizing systems is between agents and their plans. Second, and as a consequence of the above, each agent, be it an individual person, a household, a private company or the city's planning authority, is a planner at a certain scale; and because of nonlinearities, the plan of a nonformal, small-scale planner might be more effective and influential than that of a formal, large-scale planner (see examples in Chap. 15 below and in Portugali 2006a, p 20).

14.3.5 Memory, Complexity, Prediction, and Planning

Memory is a very general notion referring to a variety of cognitive capabilities and tasks. Thus, in cognitive science it is common to distinguish between various forms of memory: long-term memory, working memory and so on (Roediger III, Marsh, and Lee 2001). Looking at the various forms of memory discussed in the literature, one can distinguish between forms of memory that refer to the past (retrospective memory, autobiographic memory, etc.) and forms of memory that refer to the future (e.g., prospective memory/remembering, aims, intentions). As elaborated in Chap. 13 above in some detail, planning is a basic cognitive capability in humans (Owen 1997) and a plan can thus be seen as a form of memory task that refers to the future.

Another form of memory that is significant to cities and planning is *cognitive map*. As discussed above (Chap. 6), a cognitive map is commonly defined as memory about large-scale extended space; there it has been suggested that "it would be useful to treat cognitive maps not in terms of a single meaning entity, but in terms of kinds of cognitive maps" (ibid). As an illustration we've discussed several forms of cognitive maps that included *autobiographic cognitive maps*, *prospective cognitive maps* and so on. To the above I suggest adding the view that a spatial plan – a city plan, for instance – is a cognitive map about the future.

In terms of complexity theory, plans can be interpreted as feedforward loops that affect agents' action in the city. For example, if you consider buying a house near a lot that is planned to be (say, 5 years from now) a site for a polluting installation, you are very likely to evaluate the house as if the polluting installation is already there; this, despite the fact that the lot is currently a beautiful open space and that not all city plans are eventually implemented. Your decision not to buy will function as a feedforward self-fulfilling loop.

Action in the city in its turn feeds back to agents' memory thus shaping their past forms of memory, including their retrospective cognitive maps. The latter then participate in shaping their prospective cognitive map and their entailed actions, and so on in circular causality. Such feedback processes are done either directly when the information about individual decision spatially diffuses in the city, or indirectly by individual actions that participate in shaping the global structure of the city that then feeds back to individual memories. As is well recorded, the existence of this complex network of feedback and feedforward loops is one of the properties that make systems complex in the first place. CogCity is an urban simulation model built in light of the above process (Chap. 18 below).

14.3.6 Prediction as Information

Predictions and plans are essentially kinds of information transmission. As we've seen above (Chap. 8), according to information theory (Shannon and Weaver 1949) the relevant entities in the process are the sender, the message, the channel and the receiver(s). As is well recorded, Shannon's main aim was to find a way to measure the quantity of information contained in a message going through a certain channel. And indeed, his main achievement was a definition of information as a pure quantity irrespective of the meaning enfolded in the message.

In Chaps. 8 and 9 above, we've elaborated on the distinction between *Shannonian information* which is "information" with meaning exorcised" and *semantic information*, which is information as used in everyday language, that is, information with meaning. Shannonian and semantic forms of information are further distinguished; first, by the property that Shannonian information is independent of the receiver, while semantic information is dependent upon the receiver – by the meaning attached to it by the receiver. Second, by the fact that Shannonian information is a property of simple and closed systems, while semantic information of open and complex systems.

Cities are *par-excellence* open, complex and as such self-organizing systems as we've seen above. We've further seen that in the context of cities (and complex open systems in general) Shannonian and semantic information are interrelated. Applied to predictions one can speak of *Shannonian prediction* and *semantic prediction*. In the first, the outcome of the prediction is independent of the receiver(s) while in the second it depends on the meaning attached to it by a receiver or receivers. A weather forecast is a good example for both: it has no effect on the climatic system, but it might affect the urban system – following the prediction people might behave in different ways that might entail phenomena of self-falsifying and self-fulfilling predictions as described above.

14.4 Concluding Notes

This chapter introduces paradoxes as useful means to study cities and their planning. It discusses several city planning paradoxes that are associated with the phenomena of SFFP and suggests seeing their origin in the complexity of cities and in the role played by cognitive maps and information exchange in complex, self-organizing cities.

The major lesson that must be learned from the discussion about the paradoxes is that planners have to take into consideration the implications of the complexity of cities and regions. Namely, that due to phenomena of SFFP that typify complex systems, prediction is problematic and the expectations that plans will be implemented as planned is not realistic. This situation entails several questions. First, can there be an alternative to prediction as a basis for planning? Second, is every planning act in the city subject to self-organization? Third, what then is the role of planning in the context of a complex system such as a city?

The answer to the first question is positive: As we'll see below (Chap. 16) planning need not rely on predictions but rather on planning rules that concern the relations between the various elements that compose a city. The answer to the second question is negative: Some planning acts are and must be fully predictable and controlled while others need not. This view follows the distinction suggested in Sect. 13.3.2 above between *classical* vs. *self-organized planning*. Classical planning refers to a relatively simple "closed system" planning process; closed in the sense that it is, or rather should be, fully controlled. *Self-organized planning* refers to a relatively complex "open system" planning process, which like other open and complex systems exhibits phenomena of nonlinearity, chaos, bifurcation and self-organization (Portugali 2005, p 21). In fact, both forms of planning exhibit themselves in many planning acts. For example, the planning of a bridge must proceed as a classical, closed-system planning act in the sense that there is no point starting such a project unless we have full control on the outcome. Self-organized planning starts to play after the bridge is completed – once it is built it triggers a complex urban dynamics that makes its impact on the city as a whole unpredictable and uncontrollable. This is true with respect to the planning of a relatively simple object such as a bridge, and even more so with respect to master plans, development plans and other forms of large-scale city planning.

The answer to the third question follows from what has been said above: in the context of complexity, plans do not determine or control the development of the system concerned (a city, a region etc.), but rather become participants in a multi-agents planning game. This is so with respect to plans made by formal planning agencies (e.g., the city's planning authority, a professional private planning office, etc.) and this is so with respect to a nonformal planning act made by an individual household, for instance; due to nonlinearity the nonformal plan might have a much stronger impact than the formal one (for an example see Chap. 15).

Paradoxes are useful mainly because of their capacity to expose things that are wrong even when everything appears to be right. Paradoxes are also a lot of fun. By means of paradoxes we have exposed and discussed several specific issues that concern the more general question of the relations between planning and self-organization. A full-scale discussion of this general issue extends beyond the frame of the present chapter and requires a separate discussion that we hope to develop in the future.

Chapter 15
CTC, Social Theory Oriented Urban Theory, and Planning

In previous chapters we've seen that there are several interesting resemblances between complexity theory and social theory and as a consequence between CTC and social theory oriented urban theory. We have further seen, however, that beyond the latter similarities, there is a fundamental difference between CTC and social theory oriented urban studies: The starting point of SMH and PPD urban theories is society at large when the city is perceived as a representation of the larger and more fundamental system – society. CTC as interpreted in this book, start from the nature of the city itself as a complex self-organizing system.

The question that this chapter aims to address is this: What are the implications of the above similarities and difference to urban planning? The answer is twofold: on the one hand, the discussion in this chapter shows that the above similarities apply also to social theory oriented planning theory. More specifically, that communicative planning can and should be reformulated as a process of self-organization. This is elaborated in Sect. 15.1. On the other hand, however, the above-noted difference exposes a lacuna in planning theory, namely, that it has never theorized about the structure of the planning system. Sect. 15.2 elaborates on this issue and concludes with a suggestion to reformulate planning theory accordingly.

15.1 Linking CTC Oriented and Social Theory Oriented Planning

15.1.1 The Self-Organization of Communicative Planning

The fact that CTC originated in the sciences and at the same time also have genuine similarities with the second culture of cities, provided the basis for my claim that complexity theory can provide a link between space and place, that is, between the two cultures of cities (above Chap. 1, and Portugali 2006). Can the same be said about the two cultures of city planning? Put in other words: Communicative and strategic planning approaches that currently dominate planning discourse are seen as the planning counterpart of the second culture of cities and as a response to the

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postmodern urban condition of globalization, the decline of the welfare state and the rise of strong civil society. Can there be links between CTC and social theory oriented planning similar to the links discussed above?

The answer to my mind is positive: In his book *A Sociological Theory of Communication: The Self-Organization of the Knowledge-Based Society*, Loet Leydesdorff (2001) makes an explicit link between Giddens' theory of structuration (Giddens 1984), Luhman's perception of society as a self-organizing system and Habermas' communicative action (Habermas 1984, 1987, 1990). In line with this view I suggest similar relations between self-organization and communicative planning, namely that complexity and self-organization theories provide a theory to the way communicative planning discourse is evolving.

Some indications that this is indeed the case emerge from the discussion in Chap. 13 above (and from Portugali and Alfasi 2008) on planning discourse analysis in which it is shown that planning discourse evolves by means of self-organization as a synergetic inter-representation network (SIRN). This theoretical-empirical study, as we've seen, followed closely, by means of participatory observation, the discourse of a small planning team that was assigned to plan the city of Beer Sheva, Israel. What is striking about this case study is that the planning team conducted its activities in line with the rational planning approach and yet, despite their intentions the real process of planning evolved as a self-organized SIRN process. What this study indicates is that discourse is central to planning, including to the rational comprehensive approach, that planning discourse evolves by means of self-organization and that there exist an interesting potential (that has yet to be fully elaborated and realized) of linking complexity/self-organization theories with the communicative planning approach.

15.1.2 The Ethical Dimension of CTC

But the potential link between complexity theories oriented planning and social theory oriented planning goes beyond self-organized communicative planning. Communicative planning commences with an ethical message suggesting that this form of planning implies a more democratic and socially just planning process and practice. This is so since it gives a central role to the various NGOs that compose the third sector of civil society. The idea is that these organizations are genuine representatives of society so that their active participation in the planning discourse and process gives a stronger say to sections of society hitherto not represented. Communicative planning is not specific about the planning framework within which the communicative discourse should take place. From recent studies it seems that strategic planning is regarded as the favorable approach for this purpose. As we've seen above (Chap. 12), central to the strategic planning approach is the determination of the future *vision of a city* as the locomotive of the planning process. According to communicative planning the active participation of the various civil society organizations in the discourse that determines the urban vision will lead to a more democratic and socially just planning.

Complexity theory originated in the sciences with no explicit ethical message and, as a consequence, CTC commonly come with a self-image of a scientific and thus objective and ethically neutral approach. My claim is that the extension of the theory to the human domain and to cities does enfold an implicit ethical message that I'll try to explicate. The latter follows from our observation that each urban agent is a planner at a certain scale and that due to nonlinearities the planning actions and ideas of single individuals can be as influential as plans and actions of the city's planning team. In other words, from the point of view of CTC there is no qualitative difference between large-scale formal planning institutions such as governmental or municipal planning bodies, medium-size planning organizations such as NGOs and small-scale, unofficial, planners such as firms, households and individuals. A nice illustration of this property is the story about the butterfly effect of the balconies of Tel Aviv.

15.1.3 The Butterfly Effect of Tel Aviv Balconies and its Implications

From its early days in the early 1920s the city of Tel Aviv has been a city of many balconies. People used to spend long hours sitting on their balconies, especially on summer evenings and nights. One day, probably in the late 1950s, an unknown resident of Tel Aviv decided to enlarge his/her apartment by closing the balcony and making it a "half-room". He/she made a small plan, hired a builder and implemented the plan. One of the neighbors liked the idea and did the same. A process of innovation diffusion started – very much in line with Hägerstrand's theory (Hägerstrand 1967, above Chap. 2) – and before long the vast majority of balconies in the country as a whole was closed (Fig. 15.1, *right*). At this stage, the municipalities decided to intervene and started to tax all balconies, open and closed, as if they are a regular room. In response, developers started to build buildings with closed balconies (Fig. 15.1, *center*). For several years no balconies were built in Tel Aviv and other Israeli cities. But then, with the arrival of postmodern architecture, balconies became fashionable and architects started to apply for permits to build balconies – not to seat on them as in the past, they said, but as a decorative element. Equipped with their past planning experience and the wish not to lag behind the advancing (post)modern style, the city planners gave architects and developers permits to build open balconies but in a way that would not allow them to be closed as in the past. The result is the "jumping balconies" so typical nowadays in Israel's urban landscape (Fig. 15.1, *left*).

A comparative empirical study on "urban pattern recognition," which took place in the early 1990s at Tel Aviv University and involved cities from Europe, America, and East Asia, found that the most prototypical architectural patterns in the cityscape

Fig. 15.1 Tel Aviv Balconies. *Right:* Typical Tel Avivian balconies of the 1950s and 1960s. Note that the balconies on the first floor of the building are "open", while the others are "closed". *Center:* Following the municipalities' new rules, developers started to build buildings with closed balconies. *Left*: A building with "jumping balconies" *Left* and *Center* from Alfasi And Portugali 2009, Fig. 5

of Israel are one: the closed balcony, and two: the jumping balcony (Reuven-Zafrir, not published).

The story of Tel Aviv balconies illustrates three aspects of the relations between CTC and planning. The first aspect concerns the property of nonlinearity by which the planned action of a single person might have a much stronger and significant impact on the urban landscape than the plans of architects and official planners. The second aspect concerns the planning implications of the specific nature of cities as dual complex self-organized systems. Applied to planning, cities as dual complex systems imply that each urban agent is a planner at certain scale and that planning is a basic cognitive capability of humans (above, Chap. 13). From these two properties follows a new view on the dynamics of cities: The common view is to see the city as a complex systems that comes into being out of the interaction between its many agents, and planning as an *external* force acting on the system – say, by means of new planning policies. From what has been said above follows a new view according to which each urban agent is a planner – be it a single individual, a firm or the city's planning team – and the city comes into being out of the interaction between the many agents *and their plans*. Similarly to small-scale urban agents/planners, the official planners are participants in the overall urban game.

15.1.4 Forms of Planning

One outcome from the above is a twofold distinction between forms of planning: on the one hand, a distinction between top-down, *global planning* vs. bottom-up, *local* *planning*. The first refers to a planning process implemented by professionals – city planners, architects, engineers, etc. – while the second to planning as a basic human capability (Portugali, 2005a). On the other hand, a distinction between *mechanistic* or *engineered* or *entropic planning* vs. *self-organized planning*. The first refers to a relatively simple "closed system" planning process, closed in the sense that it is, or rather should be, fully controlled. The second refers to a relatively complex "open system" planning process, which like other open and complex systems exhibits phenomena of nonlinearity, chaos, bifurcation and self-organization. The planning of a bridge or a building is an example of the first form of planning, while a city plan is an example of the second.

The above forms of planning are related to each other in the following way: on the one hand, there are certain planning activities that unless they are fully (or almost fully) controlled they would not be attempted at all. In other words, unless one can create a closed system for them one would not attempt to implement them. For example, one would not build a bridge or a building unless one can "close the system", at least temporarily, and thus have full control on the outcome, namely, that the bridge will not collapse. On the other hand, in a self-organized planning such a requirement doesn't exist, for instance, when making a city plan. In the latter case, once the city plan is completed and implemented, the story just begins – it triggers a complex and unpredictable dynamics that no one fully controls. This is true with respect to master plans, development plans and other forms of large-scale city planning, but it is also true for the global effect and role of small-scale plans implemented in the city: the effect of a new building or a bridge on the urban system as a whole is neither predictable nor controllable. Similarly to large-scale plans, they become participants in the urban self-organized planning game.

15.1.5 Public Participation in Planning

The co-existence of global and local forms of planning sheds new light on the notion of 'public participation in planning'– an issue that like a shadow accompanies the discourse in planning theory from its very beginning. The basic idea, as formulated by Davidoff's (1965) seminal paper "Advocacy and pluralism in planning", is that in order to be *genuinely* democratic planning has to find a method to involve the public in the actual process of planning. The method is the so-called *advocacy planning* – an idea that was received with great sympathy by the community of planners, was given endless amount of pay lip in academic publications, conferences and planning projects, but was never really implemented in reality (Arnstein 1969; Healey 1997; Forester 1999; Douglass and Friedman 1998, and further bibliography there).

The discourse about public participation in planning as it currently takes place is based on an implicit assumption that there exists only one form of planning – global planning, and, as a consequence, on a sharp dichotomy between the planners and the planned (see below). As just noted, public participation is the outcome of a common view among planners that in order for planning to be really democratic and just, planners have to give more say to people, above and beyond the say given to them via the prevailing political process in democratic societies.

The fact that global and local planning co-exist and interact in the dynamics of cities, and that in many cases local planning can be more dominant and effective in the overall urban process than global planning, implies that it must be perceived not as a reactive force, but as an important source for planning ideas and initiatives. From CTC thus follows that the role of public participation and planning democracy are not just to be more generous to the people affected by the planning, but also to allow the huge amount of planning energy to go bottom-up.

15.2 Toward a CTC-Derived Planning Theory

15.2.1 The Current Problematic of Planning Theory

Let us reiterate the question: What have complexity theory and CTC to say about urbanism and planning in the 21st century? First, as we've seen they suggest a new set of tools: urban simulation models, decision support systems and planning support systems. Second, they suggest that mathematical formalism is not automatically alien to critical science and social theory. Third, they suggest a new insight on the problematic of planning in the 21st century – on what Schonwandt (ibid) has recently termed "planning crisis". The new insight is this: according to the prevailing view the current problematic of planning theory is the result of the dramatic changes that mark the last three decades, namely, globalization, glocaliztion, the decline of the welfare nation state, the rise of a stronger civil society, in short, of the new postmodern condition. The latter have made the city and its planning complex to the extent that the good old planning approaches do not function properly and new ones (communicative and/or strategic planning, etc.) should replace them.

From CTC follows that cities and their planning were always complex – from the very emergence of civilization and urban society some 5500 years ago. What the new era of globalization did was to expose and bring to the fore this complexity; it created a situation that the complexity of cities can no longer be ignored. The story of Tel Aviv balconies took place in the 1950s and 1960s and planning paradoxes were always present in the cities. In fact, the shortcomings of the prevailing planning theory and its approaches were apparent already in the late 1960s and early 1970s – for example, in the writings of Jane Jacobs and Christopher Alexander – and as noted in Chap. 3, these shortcomings provided one of the impetuses to the emergence of critical urban theory and planning.

What then is the source of the current problematic of planning? From complexity theory and CTC follow that for several decades planning theory, discourse and practice have treated cities and planning as simple systems and yet they are not – they have always been and still are complex systems. In order to overcome the crisis planning theory has to treat cities as such. When this is done three theoretical tasks and domains of research come to the fore: to understand the dynamics of cities as complex self-organizing systems, to formulate a *planning process* appropriate for cities as such and, to design and build a *planning system* that is tuned with the city as a complex self-organizing system. As we'll immediately see, planning theory has dealt with the first and the second tasks but overlooked the third.

15.2.2 The Structure of the Planning System – The Missing Components of Planning Theory

Planning theory has traditionally dealt with the first task in a research domain termed *theory in planning* (Faludi 1973a, b). As we've seen above, in the 1950s and 1960s such a theory was "borrowed" mainly from the first culture and science of cities, while since the 1970s the dominancy of the first culture of cities declined and the second culture of cities with its SMH approaches became the dominant theory in planning. As we've just seen, in the recent decade or so the SMH and PPD approaches gave rise to collaborative planning that is closely linked to strategic planning and in parallel we start to see also the influence of CTC. As for the second task, this has traditionally been dealt with in a research domain termed *theory of planning* (Faludi, ibid) that focuses on the desirable planning process. As we've seen above, the rational comprehensive approach dominated the field (in both theory and practice) in the 1950s and 1960s, while recently notions of collaborative and strategic planning are becoming dominant.

The distinction between *theory in planning* vs. *theory of planning* is due to Faludi, as noted – specifically in his two books that appeared in 1973, one written by Faludi and entitled *Planning Theory*, and the second edited by him and entitled *A Reader in Planning Theory* (Faludi 1973a, b). The significance of his project was not so much in inventing this distinction as with appropriately observing the field of planning as it has developed in the 20th century. *As for the third task – the structure of the planning system – the fact is that planning theory simply doesn't deal with this issue.*

Faludi has suggested the above distinction more than 35 years ago. And despite the fact that following its appearance it has been criticized on the ground that the process of planning cannot be separated from the content of planning (Harvey 1985b; Portugali 1980), this distinction still prevails in the sense that the notion planning theory has become a common name to the theorization on the process of planning, while other issues such as the structure of the planning system or the question of the right planning rules and codes are treated as technical questions or as local pragmatic questions or as ethical issues or as aesthetic issues but not as general theoretical or scientific issues.

Thus, for example, in *Readings in Planning Theory* that was edited by Campbell and Fainstein (1996/2003) there is not even a single reference to the issue of the structure of the planning system; not in the first edition from 1996 and not in the revised and extended edition from 2003. Their book whose title echoes Faludi's book from 1973, comes to update and re-define planning theory in light of the changes that took place since Faludi's (1973) *A Reader in Planning Theory*. Campbell and Fainstein open their book with a long and detailed introductory chapter that deals with the difficulties of defining what planning theory is. The issue is elusive they write, interdisciplinary, many claim that it has no right of existence, specifically today at the age and condition of postmodernity where there is no more room for grand theories. As a consequence they suggest six (five in the 1996 edition) domains of planning discourse and theorization that to their view make the field of planning theory: *historical roots*, *justification*, *ethics*, *effectiveness*, *style* and *the public interest*. The structure of the planning system is not in the list as can be seen. According to Campbell and Fainstein (ibid) the aim of their planning theory is to inform and support the practice of planning and indeed it does so in a variety of issues; the issue of the appropriate planning structure is not one of them, however.

The question of the planning structure is not included in the agenda of planning theory but it does take place in three connections of the discourse of planning: one, as a technical or pragmatic-local issue that is related to specific countries, while the second is in the form of a comparison between planning systems of different cultures and/or countries (Cullingworth 1993, 1994; Booth 1995; Newman and Thornley 1996; Healey 2007; Booth et al. 2008). The third domain that is associated with the issue of the planning structure concerns *urban governance* as discussed above (Chap. 12). The basic thesis here is that the structure of governance has been transformed from a play between two actors – the first (public) sector vs. the second (private) sector – to a play between three sectors: the first, the second and the *third sector* – composed as it is of the various NGOs that form *civil society*. The current response of mainstream planning discourse to this new reality is once again dominated by the "Faludian attractor", though implicitly; namely, the tendency is to look for a planning process that will be more appropriate to this new urban governance reality. And indeed, this is found in the notions of communicative planning and strategic planning as discussed above. Once again the question of the structure of the planning system is not on the agenda here.

This situation in the domain of urban planning of overlooking the structure of the system – the urban planning system – diametrically differs from the theoretical discourse in other disciplines such as economics, sociology or politics. In the latter, the issue of the structure of the (economic, social or political) system provides the starting point for the theoretical discussion in most domains of the social sciences; the domain of cities and urban/spatial planning is an exception in this respect. There are a few exceptions such as Alexander (2002–2004) or Lefebvre (1970, 1974) but these are exceptions that prove the rule. The question is why? Why planning theory refrains from discussing the structure of the planning system? In what follows I suggest three working hypotheses on this issue, namely, that this is a result of the perception of the city in urban theory as a derivation, and/or as a market failure, and of treating planning as a governmental arm.

15.2.3 The Perception of the City as a Derivation/Representation and its Planning Implications

> After the Walrasian equations had confirmed ... that even an economy given over to competition will hover in equilibrium, *nothing fundamentally new seemed to have been added when this proof was complicated by the introduction of space and time*. (Lösch 1954, p 92, italics added).

This sentence is interesting for several reasons (Portugali 1984a): firstly, since it was declared by a person whose life project was the impact of space on the economy; secondly, since this sentence represents the prevailing view among proponents of the first culture of cities; third, since proponents of the second culture of cities who criticize strongly the first culture, share with them this view of the city, as secondary to the economy. The city, claims Castells (1977), is a representation of society, while according to Harvey, the city of today – the global postmodern city – is a product of the capitalist mode of production that dominated society in the 20th century and continues to dominate it in the 21st century – including the structure of its planning authorities and agencies.

This view of the city as a derivation or representation and as such as an entity that has no independent existence of its own typifies also the discourse in urban planning. For liberal-capitalist planners, planning is a major means and instrument at the hands of the governments to deal with market failures and externalities – specifically with the spatial properties of these general phenomena (see below); while according to Structuralists and Marxists planning is a component of the superstructure of society that is central in reproducing the liberal-capitalist society including the injustice inherent in it – the general as well as the urban. On the other hand, from planning theory discourse follows the sense that the process and act of planning is independent of the space of planning. As a consequence, it is possible to deal with the process of planning independently of the structure of the urban society and the urban space. Planning, according to this perception, is external to the city; it is an act *on* the city. Such a view goes hand in hand with Faludi's distinction between theory of planning and theory in planning and it is the view that still dominates current planning thought. The controversy today is between proponents of the rational comprehensive vs. communicative or strategic planning – for both the question is what is the best way to act on the city.

From the perspective of such views on the city and its planning there is no need and room to deal with the structure of the planning system. The latter is at best a representation or derivation from larger and more profound systems – economic, political and/or social.

15.2.4 The City as a Market Failure and Externality

According to the liberal ideology that dominates the western society, specifically in this age of globalization, the economy should be guided by the invisible hand of the market, that is, by a bottom-up process in which except for exceptional situations the public sector should not be involved at all. Two such exceptional cases are public goods and externalities.

Modern town planning can be seen as a direct corollary of market failure that entailed the industrial revolution. The story in short can be told as follows: the industrial revolution entailed a process of urbanization never experienced before in human history. This process of urbanization, in its turn, entailed problems – externalities of the free operation of the market – that society never encountered before and that the free market failed to solve. And since the market – the second sector – failed, the task of dealing with the new problems was transferred to the first sector, that is to say, to the public sector. How? By means of city planning. The result: planning is essentially an instrumental arm of the various governmental bodies. In such a reality the question of the appropriate structure of the planning system is not related at all to the city or to urban theory; rather it is a component in the prevailing governance of the country. Furthermore, there is no need and logic in such a reality for planning rules and laws that are derived from the nature of cities; this is so for the simple reason that the planning rules in such a situation must be derived from the nature of the dominating governance.

15.2.5 Planning as an Instrumental Arm of the National Government

Planning is commonly perceived – by the community of planners and by the law – as part of the executing bodies of national and local governments. Obviously, in other domains too governments have executing bodies as arms – in the economic domain for instance. However, there is a fundamental difference between economic theory and urban theory and between economic planning and urban planning. The economy is commonly perceived as an independent entity – independent from the state, the city and their governments. Governments *intervene* in the economy; try to influence it in a variety of direct and indirect ways. But the basis for all that is, the basic view of the economic laws and of the economic theory and of those engaged in economic planning, is that the economy is a relatively independent entity. Therefore in every liberal country and society we find a whole system of universal economic laws the aim of which is to define and create the framework for the appropriate operation of the economic system. The economic structure of every state is derived, on the one hand, from the economic theory, while on the other from the specific economic-political-social culture of ever country. This is not the case with urbanism, the city and their planning. There is no recognition here that similarly to the economy the city too has some degree of autonomy. As a consequence, we do not find in theories about cities and their planning, discourse about the structure of the planning system, or discourse about planning rules that are derived from the very nature of cities.

15.2.6 The Planners and the Planned

A reality where planning is an instrument and arm of the national and/or urban government and planners are essentially governmental officers, inevitably leads to a gap between the planner and the planned: the planner is a professional that is working for the government, whereas the planned is the public. The community of planners was the first to identify this gap and to react to it. Studies such as Davidoff's (1965) *advocacy planning* as discussed above and Pahl's (1970) *Whose City?*, came from dissatisfaction from this situation – from the gap between the planners and the planned, from the authoritative structure of urban and regional planning and from the role of planners as part of the establishment.

This feeling of discontent shows in the ongoing discourse about *public participation in planning*, the basic motive of which, as we've seen above, is that the prevailing planning process in the western societies discriminates the poor and underprivileged sectors of society and the process of planning must include a body that corrects this discrimination. *Advocacy planning* is probably the most well-known early suggestion for correction, while communicative-strategic planning is the most recent attempt. The idea is, as noted above, that by making the third sector, with its many NGOs, a full partners in the planning discourse as it takes place in the various formal planning institutions (such as urban, regional and other planning committees), the voice of the public, the poor and the underprivileged will be heard. Communicative-strategic planning in this respect is a new version of the old advocacy planning. And indeed, in many countries representatives of the various NGOs are already becoming formal and active partners in planning committees. A case in point is Israel in which the NGOs Israel Union for Environmental Defence and the Society for the Protection of Nature in Israel are formal members in the regional and national planning committees.

Does this new situation give more say to the unprivileged and eliminate the gap between the planners and the planned? Judging from the Israeli experience the answer is negative: Firstly, being voluntary nondemocratically elected bodies that get their financial support from global and/or political bodies outside Israel, there is no guarantee that NGOs such as the two mentioned above are genuine representatives of the unprivileged sectors of Israeli society (Alfasi 2003). Secondly, making NGOs formal partners in the various planning committees simply implies adding two more bodies to the camp of the planners while leaving the gap between the planners and the unprivileged planned as before.

The problem to my mind is that the gap between the planners and the planned is built into the structure of the planning system that prevails in Israel as well as in most western societies; in fact, the existence of this gap is one of the factors that create some of the underprivileged sectors in the first place. As a consequence, as long as the structure of the planning system will not be changed, the good intentions of communicative-strategic planning will lead to the very same outcome as before, namely, to a gap between the planners and the planned and to a situation in which the voice of the underprivileged is not heard in the planning process.

15.2.7 Toward an Urban Derived Urban Planning

The title of this section comes to indicate what has been said above, namely, that so far mainstream urban planning theory has not been derived from the nature and properties of cities but rather from other larger entities such as society at large. However, as hinted above, while this was the rule, there were a few exceptions. One example is the Chicago school and its studies about the city (Chap. 2 above). For example, Wirth's (1938) "Urbanism as a way of life" suggests that cities and urbanism shape social relations and society; in the domains of planning and architecture, the projects of Jacobs and Alexander as discussed above stand as exceptions. Finally and more recently Lefebvre's (1970) *The Urban Revolution* suggested a provocative view according to which urbanism is becoming the mode of production – the driving force – of society.

What is common to the above approaches is that they theorize about the city on the basis of its own specific properties and not as a derivation. This is also the case with CTC, as we've seen above. Unlike mainstream urban theory, CTC suggest seeing the city as a complex self-organizing system. What CTC further suggests, however, is that enfolded in the complexity of the city and in the self-organization processes that typify it, are several important qualities that modern town planning has almost destroyed – qualities that need to be preserved. The planning system in its current structure is not built to do so – not in its rational comprehensive form, nor in its communicative-strategic form.

The world-view that dominated and still dominates the domain of planning is that without central control and planning the city will deteriorate into a chaotic situation of disorder and externalities. Complexity and self-organization theories suggest the exact opposite: that in the absence of central planning the city still has the capacity to self-organize and that in certain cases it self-organizes itself despite of planning and irrespective of planning (e.g., the case of the Tel Aviv balconies as described above). Complexity theories further show that every urban agent is a planner at a certain scale and that the urban process is not a mysterious outcome of the invisible hand of the market, but rather a result of a process of self-organization that starts with the interaction between the urban agents and their plans, at a variety sizes and scales. Finally, from complexity theories follows that similarly to the economic, the social or the political domains, the urban domain too is relatively independent. Similarly to the structure of the other systems – the economic, social or political – the structure of planning system is related to the other structure but

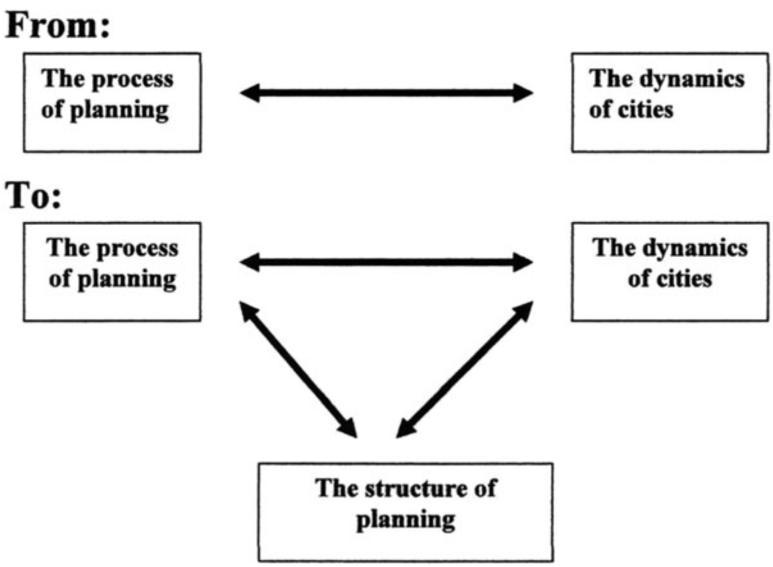

Fig. 15.2 A suggestion to re-structure planning theory

similarly to them, it has a degree of autonomy that justifies an urban derived urban theory with a planning theory that complements and supports it.

From CTC thus follows a need and potential for an urban planning theory that is derived from the very nature of cities, from the fundamental properties of cities as complex self-organizing systems. This potential can be realized if we reformulate and/or extend the theoretical domain of planning as presented in Fig. 15.2; that is to say, from a dual Faludian structure of *theory in planning vs. theory of planning* (Faludi 1973a, b), to a triple structure that includes a third component that deals with the desirable structure of the planning system. Chapter 16 that follows closes Part III with a suggestion of what the third component of planning theory, namely, a CTC-derived planning system, might look like.

Chapter 16
A Self-Planned City

16.1 Introduction

The process of planning as developed during the 20th century was (and still is) characterized by two basic properties: Firstly, it was developed as a top-down hierarchical process in which the national planning authorities produce large-scale national plans, within which regional planning bodies plan their regional plans, within which urban planning authorities produce their urban plans and so on down the hierarchy to neighborhoods and below. The major socio-spatial-political entity in such a system is the nation-state and indeed planning is seen as its executing arm. In such a system it is just natural that planning ideas and innovation should come top-down by the planners – a situation that might often imply a nondemocratic planning reality – as the story of advocacy planning testifies.

Secondly, planning theory and practice were developed with heavy reliance on the ability to predict the future states of the planned area, that is to say, the city. The belief was that planning is essentially a scientific enterprise similar in several ways to engineering – a kind of "social engineering". And as in science and engineering, so in planning, given sufficient information and data, science with its scientific methods can predict the future state of cities. Plans according to this approach are made to meet the future demands and needs of the city and its inhabitants as predicted by means of the various scientific methods.

In previous chapters it has been suggested that CTC has the potential to give rise to a planning system that is derived not from the properties and needs of the nation-state, but from the very structure of the city itself. The central theme of this book is that the city is a complex self-organizing system. And as we've seen in the preceding chapters, from the city as complex self-organizing system follow two major implications to the theory and practice of planning: one, that cities are unpredictable with the implication that the heavy reliance of planning on prediction is problematic. From this conclusion follows a need to reformulate a planning process that is not dependent on predictions. Two, that due to the nonlinearities that typify cities as complex systems, many planning ideas and innovations can and do emerge bottom-up. From here follows a need to redefine a planning system that will allow planning ideas and innovations to flow bottom-up.

J. Portugali, *Complexity, Cognition and the City*, Understanding Complex Systems,
DOI 10.1007/978-3-642-19451-1_16,

Can there be a planning system the principle and structure of which are derived from the nature of the city as a complex system; that is to say, a planning system that is not dependent on predictions and one that allows planning ideas and innovations to flow bottom-up? In *Self-Organization and the City* (Portugali 2000, Chap. 11, written with N. Alfasi) we've answered this question in the affirmative and have made a first attempt to sketch such a planning system in very broad lines; we've termed it SOCity (self-organized city) or a *self-planned city*. A second and more detailed attempt was made in the years 2004–2006 in the context of a project to the Israeli ministry of housing entitled *A New Structure to the Israeli Planning System* (Portugali et al. 2006; Alfasi and Portugali 2009). Finally it is important to mention in this connection Alfasi and Portugali's (2007) study in the journal *Planning Theory* that elaborates on "planning rules for a self-planned city".

The discussion in this chapter summarizes the above studies while adding to them two new elements: first, it shows how the notion of communicative-strategic planning can be integrated in the proposed planning system. Second, it further elaborates and emphasizes the role of *planning hermeneutics* in the overall process of our self-planned city. The discussion below evolves as follows: it starts by stating the basic principle of the proposed system, which is a separation of the planning authorities similar to the separation of authorities in a "regular" democratic society (Sect. 16.2). It then specifies each planning authority and its basic properties: the legislative planning authority (Sect. 16.3), the judiciary planning authority (Sect. 16.4), and the executive planning authority (Sect. 16.5). The discussion closes with a few concluding notes (Sect. 16.6).

16.2 The Three Planning Authorities

In most current urban planning authorities the city's planners wear two, or even three hats. One day they are planners that prepare plans or initiate planning policies; for example to build high-rises in a certain area of the city. The next day they are the members of the city's planning committee that has to approve or reject the plan or policy they have made yesterday. The planners, in most urban planning administrations, prepare the master- or development- or land-use plans, they then approve their own plans that later become the planning law, and once this is done they are responsible for the so-called planning control, i.e. implementation. All these take place under the same administrative roof – the city's planning department, for example. There is no separation of power and authorities in the usual modernist town planning.

The principles of our self-planned/self-organized city (SPCity) are different; in fact, they are rather simple and well known. Firstly, they take the principles of the separation of authorities that form the basis of the modern liberal democratic polity as its model and apply them to the domain of city planning. Planning in SPCity is thus a three-layer system: the legislative, the judiciary and the executive. This is presented diagrammatically in Fig. 16.1. Secondly and with respect to the judiciary

Fig. 16.1 The three-layer system of SPCity: the legislative, the judiciary, and the executive

planning authority, they take the principles of the bottom-up structure of our urban simulated models as developed in SOCity (Portugali, 2000) and in Chaps. 17 and 18 below, and apply them to our self-planned city. Planning rules in our SPCity thus concentrate on the local relations between the various urban elements of which a city is composed (buildings, roads, open spaces and the like).

16.2.1 The Legislative Planning Authority

The aim of this authority is to determine and/or redefine planning laws – similarly to the legislative authority of a democratic nation-state. In the modernist city-planning system this is usually a political body composed of elected representatives that form the city council, for instance; and so it might be in our SPCity. However, in light of the recent global social changes noted above – globalization, the rising power of civil society, the declining power of the nation state, etc. – and the implied consequences to urban governance and communicative planning as discussed above, the suggestion here is that the legislative planning authority of SPCity will be extended to include also the various bodies of civil society. As suggested by proponents of communicative planning (Healey 2007) and as already practiced in many cities, there are several ways the third sector of civil society with its many NGOs can be involved in the legislative urban planning authorities. One way is that they will be formal members of the legislative planning authority (in the city council, for instance); another, that they will influence the decisions of the legislative planning authority from the outside through a public discourse and debate in the original form of Habermas' (1984, 1987) communicative action. The latter, as we've seen above (Chap. 15) evolves as a self-organizing process. And, of course, a third way is a combination thereof.

16.2.2 The Planning Executive Systems

As noted above, every agent in SPCity is a planner at a certain scale. As a consequence, in SPCity every agent can be regarded as part of the executive planning system. However, while the basic role of all acting planners is to execute approved plans, the role of the public executive system is somewhat different – in SPCity the role of the City's planning authority is more modest than in ordinary modernist cities. Namely, in SPCity the planning authority with its planners are first and foremost 'civil servants', and not 'visionaries' or 'leaders of the people' as implied by the nationalistic tradition, which dominates today's city planning and also by the new strategic urban planning. As civil servants they have two roles. The first role is to supply information to the many planning agencies that operate in parallel in the city. Unlike today's planning agencies that tend to 'keep their cards (i.e., planning information) close to their chest', in SPCity planning information is a public domain available to every agent who needs it. This is achieved by various means including a user-friendly GIS (geographic information system) installed in the Internet and in other public-domain communication-information systems. Such public domain information is essential for the operation of a parallel distributed planning.

The second role concerns the preparation of plans. Like the other planners that operate in SPCity, its city planners too initiate plans and policies and submit them to the planning courts (as described below) for approval and implementation. However, compared to today's practice, in SPCity their domains of planning are restricted (by the planning law). They are expected to plan only those domains that are essential to the operation of the city, but that the other planning agents cannot or do not plan. The city's transportation system, its schools' network, or urban system of open spaces, are cases in point. An example for a possible principle for such a separation is the division between private and *public goods*, which in the context of cities take the form of private versus 'local' or spatial public goods, services, and externalities. This division, which is partly technical and partly ideological or socio-cultural, provides, in fact, one rationale for planning in a liberal, free-market society (Portugali 1980).

16.2.3 The Judiciary Planning Authority

This is the heart of the system and its most innovative component. It is innovative, firstly, since the planning laws of our self-planned city are derived not from short- and long-term plans made for the city, but rather from general planning rules made for the city. Secondly, since the decisions to approve or reject new projects in the city are taken not by planning committees, but rather by "*planning judges*" in "*planning courts*".

16.2.3.1 Planning Laws Instead of Plans

First look at the planning law. In our ordinary cities the core instrument of the planning law is a set of plans and policies, initiated, planned, and pushed down the planning hierarchy, by the various planning authorities. Conventionally, these are essentially land-use plans that determine residential and commercial areas, industrial zones, open spaces, and the like. Once approved, these plans become the planning law. In SPCity there are no such land-use plans. The planning law in SPCity is not based on plans, but rather on a set of regulatory planning principles or rules, that refer to qualitative local and global relations in the city: between different activities, buildings and objects, between people, firms and the other agents that operate in parallel in the city, including also the city's planner. These planning principles (laws) refer to the relations between the existing structure and nature of the city and the elements that the many agents/planners plan to add to it, and they apply to all parts and aspects of the city. An example to a planning law would be that one is not allowed to build a high-rise next to a low-rise building (not even the City's planning department), because it offends the basic right of the people in the low rise for air and light. Or, one cannot locate a noisy factory in a residential area, while the location of an environmentally nonpolluting high-tech factory in that residential area will be allowed.

16.2.3.2 The Planning "Courts"

The suggestion is to introduce into the city planning process a new institution – the *"planning court"* and a new profession – the *"planning judge"*. The people who act in this domain – the planning-judges – are professionals who have specialized in both law ands planning. They are spatially organized in 'planning-courts' of various scales so that there is a court for each neighborhood, for the city, the metropolitan area, and so on. Their function is to evaluate, approve or reject, the plans prepared by the many agents that operate in parallel in SPCity. The latter, as noted, might be individuals, families, firms of all sizes, and the planners of the executive planning authorities of the city (see below). As discussed above, we consider each agent operating in the city as a planner at a certain scale. Each such planner-agent who wants to take action that might change the city (a new building, for example) must get approval at the "planning court". Once approved, the agent can implement its plan. Note that the existence of planning courts as above makes the regular planning committees superfluous.

It must be emphasized that we're not fully satisfied with the terms "planning judges" and "planning court" and we use them for the lack of better terms – which is the reason we write them in scare quote. On the one hand, our source of inspiration to the judiciary planning authority of SPCity was the regular judiciary system with its regular judges and courts. On the other hand, judges and their courts deal with controversies, whereas our judges and courts are associated with the regular operation of the planning system (in which controversies form special cases).

16.2.3.3 Advocacy Planning

The idea to link the domain of planning with that of law in not new, of course. Davidoff's (1965) notion of *advocacy planning* is probably the most well-known attempt in this direction (above Chaps. 12, 15). The latter as we've seen above suggested a new profession and a new player in the planning process: a planner-advocate that represents a given community or interest group in the planning process. As noted above, the notion of advocacy planning has attracted a lot of sympathy and attention by the community of planners and beyond, but has never been implemented in practice. The reason to my mind is that in the standard structure of planning systems there is no natural room for the advocate-planner.

On the other hand, in the planning structure of our SPCity the situation is different: Within our legislature authority we suggest a body called 'advocacy planning' which is similar in principle to the *public Defense office* in regular judiciary systems. In the latter, as is well known, the judge assigns an advocate from the public defense office to people who cannot afford one. In SPCity the advocacy planning gets into action when the planning judge comes to the conclusion that a certain agent in the planning court doesn't get appropriate representation in the process; for example when the agent that appears before the court doesn't have the money to hire a professional representative and as a consequence the "urban justice" might be damaged. In this case the professional advocate-planner acting on behalf of his/her urban agent will represent the case before the court. As can be seen, in this context of the planning court, the role of the advocate-planner is just natural.

16.3 The Planning Law

As in ordinary judiciary systems, so in our imaginary planning judiciary subsystem, planning-judges take decision on the basis of the prevailing planning law. Similarly to regular law that refers to and regulates, the relations between the various components of society, the planning law of SPCity refers to and aims, to regulate the relations between the various elements that make the city. This way of looking at the city and its planning law differs fundamentally from the conventional planning law, which as noted above, is plan-based; our, per contra, is rules-based, referring to qualitative relations between elements.

16.3.1 Sources of Inspiration

In designing the planning law of SPCity we didn't start from scratch and had several important starting points. First, projects such as Jacobs' (1961) *The Death and Life of Great American Cities* and Lynch's (1960) *The Image of the City* and even more so his *A Theory of a Good City Form* (Lynch 1981) explicitly discuss qualitative relations between urban elements. Second, one can mention also the approach of *New Urbanism* (above Chap. 15) that in its own way suggests a specific view on the relations between urban elements. The significance of New Urbanism is to my mind not in the specific urban structures and forms it suggests but in its potential to initiate a public discourse and debate about the qualities of urban form and the qualitative relation between urban elements. Third, it is important to pay attention to current environmental laws that unlike the regular plan-based planning law, they very often refer (though implicitly) to the relations between urban elements; for example, that a polluting factory, or a highway, will not be allowed near a residential area and so on. This is so not as a consequence of some theoretical choice, but due to the very nature of environmental issues.

However, the most comprehensive statement about the qualitative relations between urban elements is to my mind Christopher Alexander's project as formulated in his writings, firstly *A Pattern Language: Towns, Buildings, Construction* (Alexander et al. 1977), which is a full-scale theory regarding such relations: each of the several hundred patterns of the *language* includes rules of connections with other patterns at other scales. These patterns are specifically designed for two purposes: as a means for architectural and/or urban design and as a means to allow an interactive discourse between the planner (architect or urban designer) and the planned (the client); – secondly, in his notion of *properties* as elaborated in his subsequent writings on *The Timeless Way of Building – The Production of Houses* and *New Theory of Urban Design* (Alexander 1979; Alexander et al. 1985, 1989) and finally in the four volumes of *The Nature of Order* (Alexander 2002).

Our aim here is not to produce another pattern language, but rather a *procedure* by which such a language can emerge by means of self-organization and most importantly also adapt itself to changing views and situations. The process of *hermeneutic planning* as discussed below suggests such a procedure.

16.3.2 The Matrix of Urban Elements

The main purpose of our planning rules is to allow the planning judge of SPCity as described above to make decisions; that is to say, to approve, or reject plans submitted to her/him. For this purpose it is useful to look at the city in terms of the relations between its basic urban elements – existing and proposed by the urban agents. The notion of urban elements brings to mind Lynch's (1961) five elements that are important in making the image of the city and the city legible: *landmarks*, *nodes*, *paths*, *districts*, and *edges*. As noted in Chap. 6 above, Golledge (1999) suggested a triple geometric and thus more generalized elements system of *points*, *lines*, and *areas*. Both Lynch and Golledge were thinking of elements that are significant in shaping a person's image of the city. Our aim is to look at the qualitative relations between urban elements and for this purpose Golledge's scheme seems to be more appropriate.

We thus suggested to develop SPCity planning law in terms of the relations between three forms of urban elements: *singular elements*, of which the main exemplar is a building; *linear elements*, which are usually components of spatial networks such as roads, railroad tracks, electric lines, and other infrastructure networks, and, *district (or 2D) elements*, which are either large elements such as parks, nature reserves, airports, etc., or entities composed of numerous singular elements, such as neighborhoods, industrial areas, central business districts, towns, cities, and metropolises.

This typology provides the basic framework within which the relations between the various urban elements can be studied and determined. As illustrated in Fig. 16.2, from the triple typology follow six sets of relationships: between two singular elements (say, a new-planned building proposed next to an existing building); between singular and linear elements (a new building proposed next to a major highway); singular and district elements (a polluting building next to a public open space), linear and linear elements (cycling lane parallel to a major road), linear and district elements (a heavy traffic road crossing a public open space), and two district elements (a homogenous residential neighborhood adjacent to a park).

It must be emphasized, however, that this conceptualization of the relations between the three basic urban elements is a first approximation, the aim of which is to illustrate a potential. One way to realize this potential is to make a link to a new domain of research – *qualitative spatial reasoning* – developed in the last three decades on the interface between AI, cognitive science, and GIS (Egenhofer 2010 and further bibliography there). The central trait of this new field is the attempt to mimic people's, often intuitive, inferences regarding spatial configurations in order to draw spatial conclusions. The aim is to stress qualitative spatial properties, as

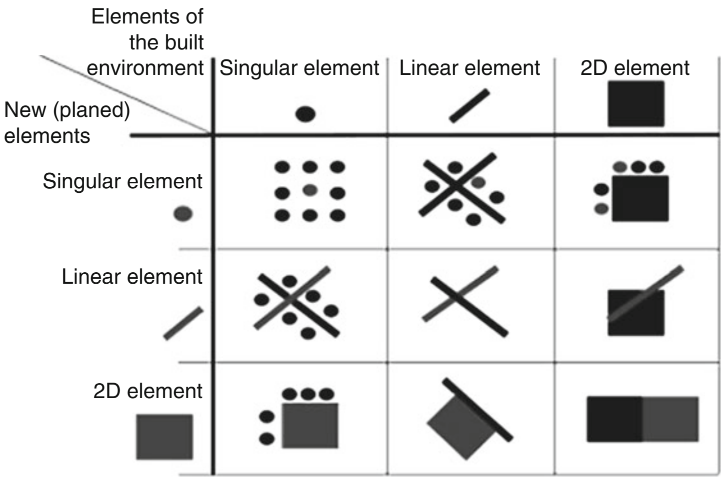

Fig. 16.2 Six sets of relationships resulting from the triple typology to *singular*, *linear*, and *district (2D)* urban elements

they are closer to human intuition than those that use only detailed quantitative values. The central goal of this new field is to pave the way to a user-friendly GIS; the suggestion here is to use it as the basis for the development of qualitative relations between urban elements in the context of SPCity. The two examples in Fig. 16.3 give the flavor of this new approach.

Next we've postulated a basic founding principle, namely, that *existing elements should have precedence over new elements*. The aim of this principle is twofold: on the one hand, to protect the city's houses, neighborhoods, parks, and other spatial elements, from harm that might be caused by building new, disturbing, elements; on the other hand, to ensure that the city would always remain complete and functioning. Its recent newly built elements would operate with its previous elements, and they could be free to change their performance without restraint. In addition, this principle provides certainty, which is an essential component for the functioning of the built environment. At the same time, however, this principle does not contradict the continuous development and change of cities, as the next section about planning hermeneutics testifies. For a more detailed discussion of the relationships between the above urban elements and the methodology to evaluate the impact of introducing a new element to the city (by means of coefficients of information alienation), see Portugali et al. (2006) and Alfasi and Portugali (2007, 2009).

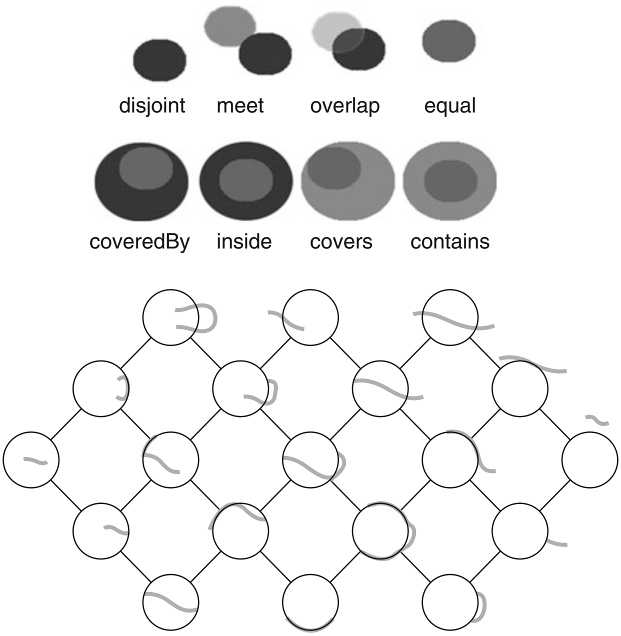

Fig. 16.3 *Top*: Eight topological relations between two regions. *Bottom*: 19 line-region relations, arranged according to their conceptual neighborhoods
Source: Egenhofer 2010, Figs. 1 and 11, respectively

Note that the relationships between the various urban elements as above, lent themselves to a reformulation in the context of GIS. Note further the potential that exists here for employing urban simulation model(s) that will evaluate the impact of adding a new element to the city on the city as a whole. The CPP (Cut, Plan, Paste) planning support system designed by Portugali et al. (2009) is a case in point.

16.4 Planning Hermeneutics

The key mechanism in SPCity that enables dynamics and change and in this way makes our SPCity an adaptive complex system, is the process of *planning hermeneutics*. To see how it operates let us follow, with the aid of Fig. 16.4, two planners as they are acting in the city. The first is a ‘private planner’, say an architect representing an inhabitant that wishes to change the façade of his/her house, while the second is a ‘public planner’, for example an urban planner that represents the city’s planning department. As can be seen in Fig. 16.4, both planners belong to what we’ve defined above as the private and public executive subsystems. As can further be seen in Fig. 16.4, the two planners, the private one operating on behalf of a single person or household, and the public one that is acting on behalf of the city, are going through the very same process. Each of them has to submit the proposal to the planning court and to convince the planning judge that it can/should be approved.

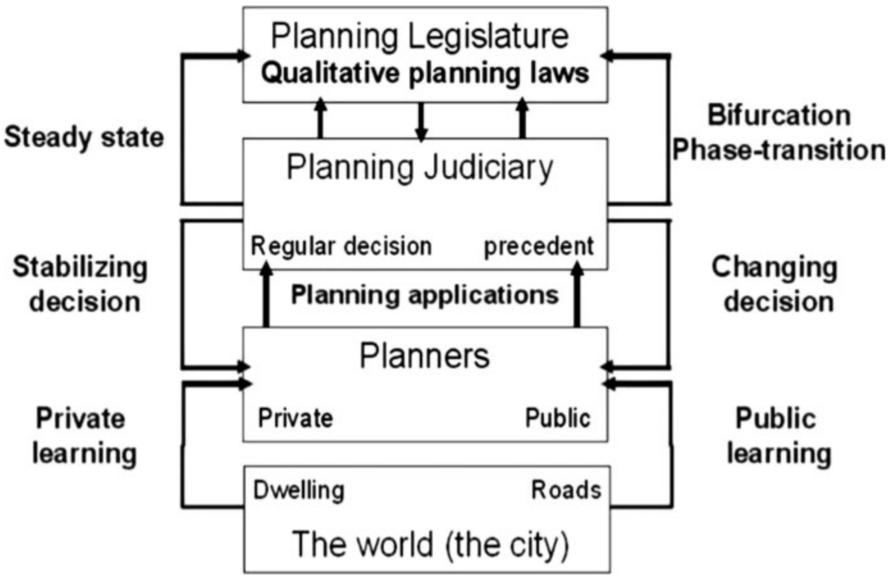

Fig. 16.4 Planning hermeneutics

Once the proposal has been submitted, the planning judge has to decide whether to accept or reject the proposal. This decision process might lead to three possible scenarios: one is that the planning judge decides that the proposal is in line with the current planning rules and thus approves the proposal as a *regular approval*. The second scenario is that the planning judge rejects the proposal on the ground that it contradicts the planning law. Such an approval or rejection entails a feedback loop to the community of planners as well as to the legislative planning authority. Its essence is a message that reproduces and thus strengthens the current planning rules. Such an approval or rejection can thus be termed *reproductive approval* or *reproductive rejection* that keep the system in its current steady state.

The third possible scenario comes into being in cases where the judge's decision is an innovative interpretation of the planning law, or even an extension and/or change of it. In this case we are dealing with a changing or *bifurcation approval*. As in an ordinary judicial system, here too, the decisions taken at the planning courts by a "planning judge" establishes a *planning precedent* and as such plays a role in future planning decisions, taken by other "judges" in different planning situations – a property which puts a high responsibility on the "judge" (as in ordinary court). The result is a cumulative process of hermeneutics by which, first, plans and ideas get into the planning rules system of the city as a whole in a bottom-up manner. A planning initiative at a personal-individual-local level might have, in this way, an impact on the dynamics of the whole city, no less than a plan initiated by the government. Second, the planning law and the structure of the city are in an ongoing feedback process of reevaluation, updating, and reinterpretation. We term this process *planning hermeneutics*.

Hermeneutics as is well recorded is the art, methodology, and theory of interpretation. It has its roots in philosophy and religious studies and from there it was extended to the domains of the humanities and social sciences. It is also central to law and legal theory and forms one of the bases for the dynamics of the law and its ability to adapt itself to the changing reality. Our usage of the notion planning hermeneutics is in line with this tradition.

To fully appreciate the significance and role of planning hermeneutics in SPCity we have to see it in conjunction with two basic principles of SPCity: *equality of all agents-planners* and the *universal status of the decisions* taken by the planning judge. The first principle states that there is no difference between a private planner and a public planner when coming to the planning court. Every agent that seeks to make a change in the face of SPCity will have to bring his plan to the planning court and get its approval.

The second principle states that planning rules and the decisions of the planning judges have universal applicability. That is to say, first, that planning rules apply to all urban agents be they individual persons, firms, NGOs or public planning bodies. Second, that once taken, every planning decision made by the planning judge similarly applies to all urban agents.

In such a situation the process of planning hermeneutics ensures an ongoing process of evolution of the planning rules of SPCity when some of the new innovative rules originate bottom-up by individual urban agents, or private firms, or NGOs, whereas others come top-down by the various governmental planning authorities. Note that in such a system the notion of public participation in planning takes an altogether new form: instead of being an extra privilege given by the planners and the authorities to "the public", in SPCity it is an integral property of the planning system. It is therefore no surprise that the notion of advocacy planning, as noted above, is an integral component of SPCity.

16.5 Concluding Notes

The above is, of course, a sketch that in order to be implemented must be further elaborated and related to the detailed practice of planning as it takes place in different countries and cities. And indeed, some preliminary steps toward implementation were already made. One such step is Alfasi and Portugali (2007) paper on "Planning rules for a self-planned city" that elaborates on the issue of planning rules, while a second step was made by two studies that have suggested *A New Structure to the Israeli Planning System* (Portugali et al. 2006; Alfasi and Portugali 2009). In these two studies it was shown how the above abstract scheme could be related to the reality of urban planning as it takes place in Israel.

Further research directions toward elaboration and implementation might include, firstly, making a link to the domain of *qualitative spatial reasoning* as already suggested above and illustrated in Fig. 16.3; secondly, making explicit the link between the planning and design rules as discussed above and environmental issues and finally, developing a planning or decision support system specifically designed for a self-planned city.

A link to environmental issues. As is very well recorded, the environmental question is becoming a central issue in public debate and discourse in general and a central issue in the domain of urban planning and design. Notions such as 'sustainable' or 'ecological cities' are capturing the center of the planning stage. In this connection it is interesting to note that the vast majority of the new environmental laws and regulations are essentially rules that deal with the relation between newly planned or designed elements and their immediate surrounding – exactly like the planning rules on which our SPCity is founded. A case in point is the *environmental impact assessment* (Marriott 1997) that is already a common and obligatory practice in many countries around the world. According to the International Association of Impact Assessment (IAIA 1999) environmental impact assessment is defined as "the process of identifying, predicting, evaluating, and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made." Note that this is exactly what the 'planning judges' of the 'planning courts' of SPCity are expected to do: to approve or reject a new urban element on the basis of its relation to its urban environment.

A decision support system for SPCity. An interesting property of our SPCity is that it lent itself to computerization in two interrelated respects. Firstly, its planning law is based on local relations between urban elements – similarly to the various cellular automata and agent base urban simulation models that provide the main methodology to study and simulate the dynamic of cities ((Portugali 2000, Part II and Part IV below). In cellular automata models, for instance, every model iteration the properties of each cell are determined anew as some function of the properties of its immediate neighbors. Secondly, as we've seen above (Chap. 12, Fig. 12.1), such models form one of the three basic components of which decision and planning support systems are composed. A case in point is the decision support system *O'Jerusalem* that was specifically designed as a tool at the hand of the Israeli high court in dealing with controversies concerned the fence/wall built by Israel along the Green Line that divides between Israel and the West Bank (Portugali et al. 2009).

Part IV
Complexity, Cognition and Urban Simulation Models

Chapter 17
Revisiting Cognitive Dissonance and Memes-Derived Urban Simulation Models

17.1 Introduction

In previous chapters we've suggested SIRN as a cognitive approach to urban dynamics. In the present chapter (and in the one that follows) the aim is to explore the implications of SIRN to urban simulation models (USM). This is done, firstly, by an examination of four interrelated properties that typify SIRN and distinguish it from most CTC approaches of urban dynamics: (1) it is a comprehensive CTC; (2) it is a cognitive CTC in an innovative way; (3) it suggests perceiving urban agents as a complex systems; (4) it implies a separation between agents' intention and behavior. Secondly, by revisiting two USM originally developed in SOCity, that is, *Self-Organization and the City* (Portugali 2000, Chaps. 7, 8): The first makes use of Festinger's notion of *cognitive dissonance*, while the second employs Dawkins' notion of *memes*. In SOCity the emphasis was on the insight these two models add to our understanding of cities as complex systems. In the present "visit" the aim is to explicate two properties that were implicit in the models, namely, the fact that they are SIRN USM and as such cognitive. The discussion in the chapter evolves in three steps: Sect. 17.2 elaborates on the basic principles of SIRN USM; Sect. 17.3 on cognitive dissonance-derived USM, while Sect. 17.4 on memes-derived USM.

17.2 Principles of SIRN USM

17.2.1 A Comprehensive CTC

SIRN is a comprehensive, circular causality CTC in which the local interaction between the urban agents gives rise to the global structure of the city, which then feeds back and prescribes the behavior, interaction, and action of the agents, and so on. As we've seen in previous chapters, this is not the case with the majority of USM currently in use: Guided by Simon's Ant Hypothesis of *simple* → *complex* relations, standard urban simulation models have become excellent tools to simulate the first part of this loop – the bottom-up process by which local interactions

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give rise to a global structure – but they fail to describe the second part of the loop – the top-down process by which the global structure of the city affects its agents' cognition and information and as a consequence their behavior in the city.

Cognitive science, and in it the domains of spatial, environmental and geographical cognition, is a science that scrutinizes the second part of the above process: the way the interaction with the environment shapes the agent's mind/brain and internal representation and the entailed behavior. In the case of space and cities, theories of cognitive maps, for example, theorize about the way agents' cognition emerges out of their interaction with their environment and how this cognition affects behavior. However, confined within its disciplinary boundaries as the science of cognition and not of artifacts and their production, cognitive science never went one step further to ask how spatial behavior affects the production of artifacts and the structure of cities.

17.2.2 A Cognitive CTC

SIRN is a cognitive CTC in that it derives agents' behavior from first principles of human behavior as explored and revealed by cognitive science. Thus for example as we've seen above, it is an approach that follows the way cognitive maps of agents are created out of agents' encounter with the urban environment, the way (ones created) cognitive maps affect agents' behavior that then gives rise to the global structure of the city that feeds back to agents cognitive maps and so on in circular causality.

However, as a cognitive approach SIRN goes one step further beyond "conventional" cognitive science and in this respect it is an innovative approach to cognition: unlike cognitive science that refrains from including the production of artifacts as part of cognition, SIRN insists on doing so. Accordingly, it treats the city as a large-scale collective artifact that, similarly to artifacts in general, came into being in a process of production; in the case of cities it is a process of collective (social, cultural, . . .) production. SIRN thus integrates the process of cognition with the process of the production of artifacts – small like lamps and large like cities.

17.2.3 Simple vs. Complex Agents

In previous chapters we made a distinction between *cognitively simple* and *cognitively complex* agents or in short, between simple and complex agents. We've suggested that from the SIRN perspective urban agents (individuals, families, firms etc.) are all complex self-organizing systems – hence the notion of dual complexity discussed above.

This cognitive complexity of urban agents shows itself in a variety of ways: Firstly, several cognitive tasks such as pattern recognition and cognitive mapping evolve as complex SIRN. Secondly, urban agents are capable of changing their original properties as a consequence of learning and/or as a consequence of socio-spatial pressure such as the pressure of cognitive dissonance as discussed below. In terms of complexity, they have the capability of undergoing cognitive phase transition. Thirdly, urban agents are multi-dimensional rather than one-dimensional – each has several "personal" properties (rich, poor, cultural affiliation, professional affiliation and so on) that might potentially affect its location behavior when the choice is made by the environment – very much like the process of evolution. Fourthly, urban agents never come to the city *tabula rasa*; they always have and use cognitive maps even of cities they have never been or seen before. Fifthly, urban agents can take decisions in situations of uncertainty by heuristics, for instance. Finally, urban agent can plan and many of their actions are influenced by their plans and by the plans of others. The notion of SIRN, in particular its *public with a common reservoir* submodel, introduced above, is an attempt to take these properties into consideration.

17.2.4 Intentions vs. Behavior

Mainstream CTC approaches to urban simulation models are currently dominated by the implicit assumption that agents' intention and behavior are causally related: intention is taken for granted as the cause of behavior, or alternatively, behavior is understood as some product of the optimization of intentions. According to SIRN, intention and behavior are two relatively independent entities, which might affect, complement, negate, or compete with, each other as elaborated in Chap. 14 above and below in Sect. 17.3. By departing in this respect from the approach of mainstream CTC, we in fact follow classical social theory as well as the inner logic of complexity theory. We also follow disciplines such as psychology or cognitive sciences.

17.2.5 Classical Social Theory

The interrelation between the individual's intentions and value system, his/her actual behavior, and society, forms a central theme in social theory and philosophy. The notion of ideology, for example, is directly related to the tension created between a person's value system and the person's actual behavior and action (Larrain 1982). Such a tension often leads to what Hegel and later Marx have called "ideological false-consciousness" which obscures people's vision from their real conditions of existence. A central controversy in social theory is between Marxists who claim that a person's value system (including intentions) is dialectically determined by his/her conditions of existence (i.e. actual behavior), and liberal humanists who consider human action as an outcome of human intentionality. Giddens' (1986) theory of *structuration* aims to synthesize the two views: on the one hand, the individual is a free agent whose intentions determine his/her actions; on the other hand, the individual is acting in a relatively autonomous social structure with its own rules and thus the individual's actions and behaviors might have "unintended consequences".

In the last decades, mainstream urban studies were strongly influenced by social theory and by Giddens' structuration, and are thus very critical of behaviorism and its application to regional science (Thrift 1983). Arguing from the perspective of social theory, they accuse behaviorists of blurring the dialectical relations between the human agency and his/her socio-spatial structure. That is, the refusal of behaviorism to consider the subjectivity of the individual with his/her wants and intentions, and to study the ways socio-spatial structures such as cities, determines individuals' intentions and ideas (for a discussion and bibliography see Jackson and Smith 1984, Chap. 3; Gregory and Urry 1985). SIRN thus provides a basis to reintegrate social theory oriented urban studies with the quantitative science of cities – an issue we've already discussed above.

17.2.6 Complexity Theories

The very ideas of complexity and self-organization with their property of nonlinear relations implies, almost by definition, a gap between intentional causes and behavioral effects, as well as various forms of unintended consequences. The very notion of *emergence*, which is central to complexity theory, implies that the emerging properties of the global system differ from those of its local parts. When the global system is a city specifically divided into ethnic groups or collectively behaving pedestrians in the city, we, in fact, have a separation between the intentions of the individual agents and their actual behavior. This is specifically prominent and explicit in Haken's synergetics approach to self-organization in which the order parameter enslaves the individuals' behaviors. As illustrated above (Chap. 6 and Figs. 6.15, 6.16) within the domain of human behavior this was beautifully illustrated in a series of experimental and theoretical studies designed by Kelso who has used Haken's synergetics approach to self-organization as his framework (Kelso 1984, 1990; Haken, Kelso, and Bunz 1985; Haken 1990). In Kelso's experiments intention and behavior are found to be methodologically and scientifically separated though dialectically related (see also Stadler and Kruse 1990).

17.2.7 SIRN

While in the above cases the separation of intentions and behavior is a somewhat implicit property, in SIRN it is an explicit principle resulting from the interplay between intentions as internal representations and behavior, action and production as external representations. This is so with respect to our interpretation of the urban process and the dynamics of cities and this is so with respect to SIRN USM. Two such models were developed in the past in the context of SOCity. In the latter, however, the SIRN nature of them was rather implicit; in what follows it becomes explicit. The first makes use of Festinger's notion *cognitive dissonance* and applies it to the context of cities, while the second applies Dawkin's notion of *memes* to the realm of cities. These two models serve also as an illustration to the way general cognitive processes that are not related specifically to space or cities, can be used in, and benefit, urban simulation models. In Chap. 18 I present a cognitive maps'-derived USM. Cognitive maps, as we've seen in the previous chapters, were from the start directly related to space and cities.

17.3 Cognitive Dissonance-Derived USM

17.3.1 Cognitive Dissonance

Unlike social theory and Giddens' structuration theory whose main concern is society, Festinger's (1957) theory of cognitive dissonance focuses directly and exclusively on the cognitive processes of the individual. The idea is straightforward: a cognitive gap or dissonance between an individual's intentions and his/her actual behavior and action, is cognitively unbearable – it creates a cognitive tension which eventually will have to be resolved either by a change of behavior and action, or by a change of intentions and value system. Festinger's theory was examined in various laboratory experiments as well as in real life observations and is now generally accepted. The theory got further support by Gazzaniga's studies on the modular structure of the brain. In his *The Social Brain* (Gazzaniga 1985, p 80) he writes the following:

> *"... the new brain science [adds to Festinger's theory] the knowledge that [cognitive dissonance is related to the fact that the brain] is organized in ... relatively independent modules that are capable of initiating disparate behavior in the first place".*

Cognitive dissonance as formulated by Festinger and elaborated by Gazzaniga provides the starting point to the notion of spatial cognitive dissonance that stands at the center of our discussion below.

17.3.2 Spatial Cognitive Dissonance

As illustrated in Fig. 17.1, Festinger's theory can easily be described by means of a bifurcation diagram. That is to say, from the perspective of the individual, a situation of cognitive dissonance drives the individual into a cognitive bifurcation point: to change behavior, or to change intentions and value systems.

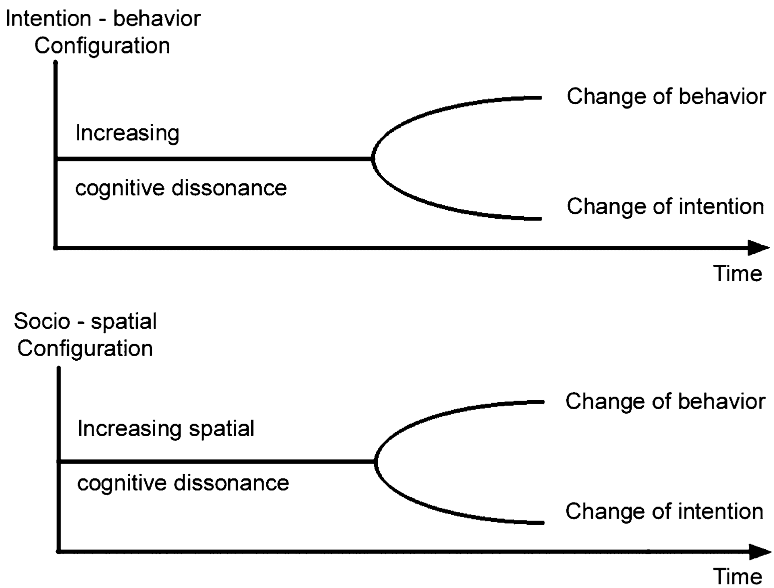

Fig. 17.1 Cognitive dissonance formulated in terms of a bifurcation diagram. *Upper*: general. *Lower*: spatial cognitive dissonance

A typical case within a city would be that of an individual living in a neighborhood where he or she does not want to live. This frustrating situation can be resolved either by a change of wants, or else by migration. An empirical examination of the intention-behavior gap, within a city context, seems to support this view (Portugali 2000, Chap. 7). It suggests that with time, people's reaction to the intention-behavior gap becomes polarized: people living for long periods of time (18+ years) in a neighborhood of another cultural group (Jews among Arabs and vice versa), become either integrative (i.e. change of intentions), or extremely segregative in their value judgment of their actual situation. This is illustrated in Fig. 17.2.

17.3.3 Cognitive Dissonance, Chaos, and Emerging Urban Boundaries

The dissonance between intention and actual behavior was also implicitly obtained as a by-product from several CA urban simulation games studies in SOCity (Portugali 2000, Chap. 5) and discussed in Chap. 4 above in relation to what we've termed "chaotic cities". The urban simulation model upon which these simulation games were based was a cellular automata (CA) model termed *City*. In the latter we have examined socio-cultural spatial segregation as resulting from two groups of individual agents (Greens and Blues) divided into various configurations according to their intentions: Blue or Green *Segregatives* who want to spatially

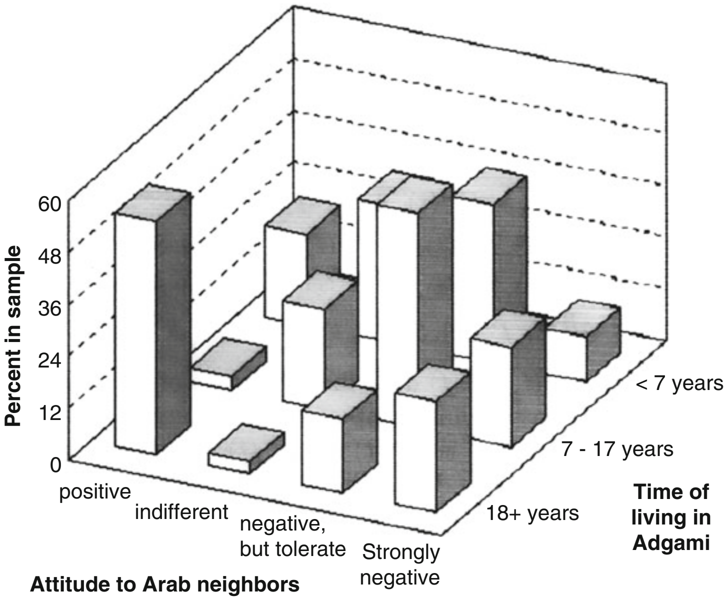

Fig. 17.2 The changing reaction in time of Jewish inhabitants living in Ajami (the Arab community of Tel Aviv–Yaffo) to their Arab neighbors. Four attitude groups were found: positive attitude about living among Arab neighbors; people indifferent as to their neighbors; negative attitude – prefer to live among Jewish neighbors; strongly negative – strong objection to live among Arabs

reside among their own kind, and Blue or Green *Neutrals* who are indifferent as to their location in the city.

In the various games played it was found, first, that in all the simulations there were always individual agents who actually behaved (i.e. were located in space) counter their intentions (e.g., a segregative Green located among Blue neighbors). Such agents live in what we termed above as 'spatial cognitive dissonance'. Second, in the majority of the simulation games these individual agents were spatially segregated in the city. The emerging city landscape was thus a highly segregative urban landscape of relatively stable Green vs. Blue areas, characterized by low level of spatial cognitive dissonance, and in-between areas of intense spatial cognitive dissonance. Third, the latter areas formed, in fact, the boundaries between the various Green and Blue urban areas. This latter finding sheds a new light on the nature of urban boundaries.

Boundaries are commonly perceived as lines separating territories. There is a rich literature on the various forms of boundaries (political, municipal, economic, natural; see Biger et al. 1995). However, implicit in the vast majority of these studies is a static view on boundaries – as the static lines that separate otherwise homogeneous areas. One of the interesting outcomes of our *City* model (that has only partly been discussed thus far) is the finding that the boundaries that emerge in our USM are in fact the most dynamic areas of the city. More specifically, they are chaotic areas characterized by high levels of spatial cognitive dissonance.

The link between chaos, boundaries and urban dynamics was already made above in Chap. 4 in connection with the model *City*. In *City* the boundaries are emergent entities that in a process of self-organization leads the city into a steady state. The central aim of *City* was to study residential segregation in cities and indeed we were able to demonstrate that the self-organized steady state took the form of a city that is spatially segregated to different cultural areas that in the model *City* represented different cultural groups. However, the really interesting finding came when we zoomed-into the boundary areas that separate relatively stable homogeneous (cultural) Green and Blue areas: we realized that unlike the rest of the urban landscape the boundaries remain chaotic. This was illustrated by means of the stability-instability surface (SIS) measure we've developed in connection with *City* (Figs. 4.22, 4.23 above). The latter represent an interesting process of 'order out of chaos': At the beginning of the process the city as a whole is chaotic and then when it is demographically growing and crossing a certain threshold, it self-organizes into a stably ordered landscape, with unstable-chaotic boundaries. Our interpretation in Chap. 4 above was that this chaotic boundary is necessary in order to keep the rest of the city stable. In the context of the present discussion we can add that Figs. 4.22 and 4.23 represent also a process by which at the beginning the city as a whole, that is, the vast majority of its inhabitants, is in a state of high spatial cognitive dissonance; but then, as the process of spatial segregation develops, spatial cognitive dissonance levels off in the highly segregated areas, but remains relatively high in the boundary chaotic areas. Chaotic areas in the city are thus areas of high spatial cognitive dissonance.

17.3.4 The Model

In the above example of the model *City*, the phenomenon of spatial cognitive dissonance was a by-product of a model whose major aim was to study cultural spatial segregation in cities. The model *City-2* in SOCity (Portugali 2000, Chap. 7) was specifically designed to study the various aspects of cognitive dissonance in the context of cities. In this section I describe in brief the model *City-2* and some of the main results as they emerged from the various simulation runs. The description below is done in a nonmathematical fashion; a detailed description of the mathematical formalism and the results, can be found in Portugali (ibid).

Similarly to other FACS models, *City 2* is built of two layers: a CA layer that simulates the relations between the various urban objects (houses) and an AB layer simulating the location behavior of urban agents. The model commences from the notions of spatial cognitive dissonance, the captivity principle and the nature of urban boundaries as elaborated above. In a typical scenario, agents belonging to two cultural groups (Blue and Green) come to the city in order to find a residential location in it. All agents are segregatives in the sense that they prefer to live near neighbors of their own kind. Every iteration, each agent examines its situation in the city: if it is satisfactory, that is, if its neighbors are like itself, it will stay in its location; if not, it will attempt to improve its location by moving to a better place in the city. If it fails, it leaves the city.

The SIRN component is enfolded in this iterative process by which every agent examines its location situation (the externally represented city) and takes (internally represented) location-action decision accordingly and so on.

17.3.5 Results: Spatial Cognitive Dissonance and Socio-Spatial Emergence

As the process in *City-2* evolves we in fact get two kinds of Blue and Green agents: *immigrants* who come to the city for the "first time in their life" and veteran *residents*. They differ in the options they confront: The immigrant tries to find an appropriate location and if it fails it leaves the city. The resident examines its location situation and if it is unsatisfactory it will try to relocate by finding another appropriate location in the city. If it fails for several iterations it enters a situation of spatial cognitive dissonance: either to altogether leave the city, or else to change its location preferences, namely, to become integrative instead of segregative.

Figure 17.3 illustrates a set of snapshots of a typical simulation. As can be seen, very quickly a segregative city landscape emerges with Blue and Green homogeneous areas, and boundaries in between. As already noted, the emerging boundaries become boundaries by virtue of their property as the most unstable/chaotic (linear) areas in the city; this instability, in its turn, is due to the fact that here many of the neighbors of every resident are not of its own kind. Many agents in the boundary thus attempt to relocate and to move to a better location in the city and as a result the boundary is never at rest: there are all the time agents that leave it and agents that unwillingly find themselves in it – after their nearest neighbors who created a buffer between them and the boundary managed to move away.

As can be seen in Figs. 17.3, up to a certain stage nothing dramatically happens and the city maintains its steady state as a segregative city. But then, as the density of the city reaches its limit and there are not enough vacate locations for the residents who try to relocate, more and more residents enter a situation of spatial cognitive dissonance the result of which is that at least some of the agents change their preference and instead of segregatives become integratives. In order to identify the agents who enter this state we've marked them Yellow. As can be further seen in Fig. 17.3, not surprisingly the vast majority of Yellows are located in the boundary areas, in other words, previously Blue and Green agents now share a common property and as a consequence agree to live together.

As the number of Yellows in some area of the city crosses a certain threshold, we see a phenomenon of socio-spatial emergence – a new cultural group emerges in the city and out of the city's specific dynamics. The result is that the city's cultural landscape is now composed of Blues, Greens, Yellows (i.e. Neutrals) and Reds, that is, the new cultural group that, in a process of self-organization, emerged is some parts of the city (Fig. 17.4) out of its very dynamics.

This situation of socio-spatial emergence, that is to say, a phenomenon by which a new socio-spatial cultural group emerges out the very dynamics of the city is

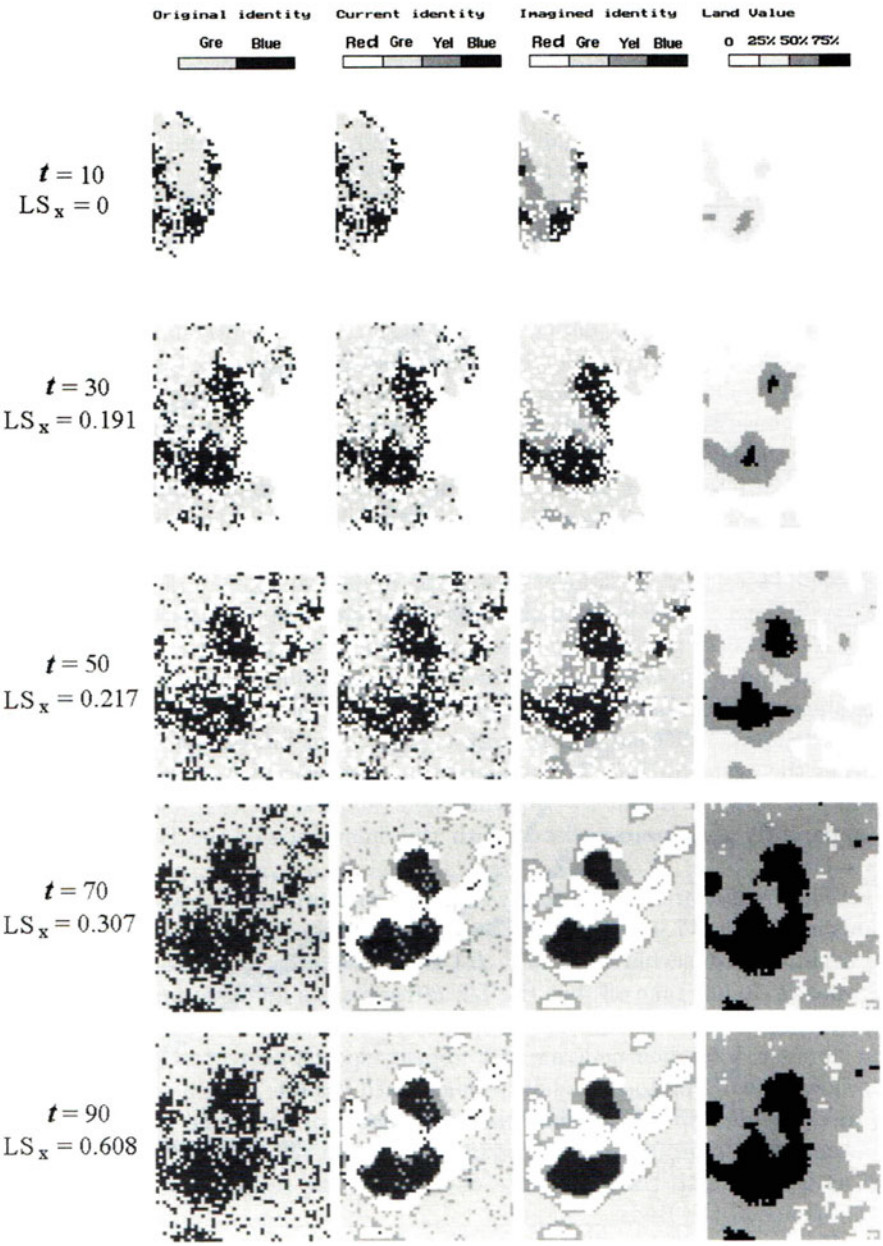

Fig. 17.3 Several snapshots illustrating the impact of spatial cognitive dissonance on the evolution of a FACS city. Green, Blue, and Red are three cultural groups; Yellow symbolized Green and Blue neutrals
Source: Portugali 2000, Fig. 7.7

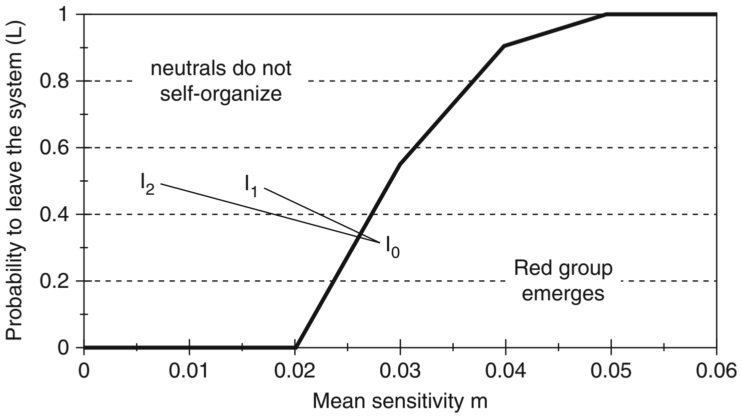

Fig. 17.4 A phase-space of the probability of leaving the city and the mean sensitivity: The domain where Neutrals self-organize and transform into a new cultural group, Reds – and the domain where they do not.
Source: Portugali ibid Fig. 7.11

typical of many modern or rather postmodern cities. It is specifically typical of cities that in recent decades have become subject to fast population growth and spatial expansion due to internal migration and international labour migration. Such cities have become multi-cultural and their spatial structure a mosaic of different socio-cultural relatively homogeneous areas. Some of these spatio-cultural areas are occupied by old cultural groups (little Italy, China town) while others by groups that emerge out of the very dynamics of the city. As already noted in the previous section, urban areas of high spatial cognitive dissonance correspond to areas of high instability or chaos – a property that gives the notion of chaos in the city a new spatial and socio-cultural interpretation and dimension.

17.4 Memes-Derived USM

The central aim of a cognitive approach to USM is to capture the nature of the city as a dual self-organizing system, that is, the property by which the city as a whole is a complex system and each of its individual urban agents is a complex self-organizing system, too. In the previous section that was the first step toward such an USM, the complexity of the agents showed up in their ability to undergo identity change. We've seen how the complex process of cognitive dissonance at the level of individual agents, in conjunction with the urban dynamics, gives rise to two phase transitions: at the local scale to the agent's change of identity, while at the global scale to the emergence of a new cultural group in the city.

In the above model, agents were still somewhat "simple" in the sense that they came to the city with a rather fixed identity – Green and/or Blue. In the model presented below we increase the complexity of agents in the sense that now they do not come to the city with fixed identities but rather with a potential. That is, with a set of properties that in conjunction with the global dynamics of the city participate in two phase transitions: one at the global scale – the emergence of a new cultural group; and one at the local individual scale – the process by which urban agents acquire their cultural identity (that at a later stage might change as a consequence of cognitive dissonance as above).

It is important to note, firstly, that in this new exposition the individual and the collective phase transitions emerge directly from the very urban dynamics without the intervention of a driving force such as cognitive dissonance. Secondly, that the previous model of spatial cognitive dissonance is a special case of this more general memes derived urban simulation model.

There are two main sources of inspiration for this new model: the first is the notion of the *genetic code*, while the second is Dawkins' suggestions regarding his notions of *memes* and *extended phenotype* as interpreted in SIRN proposition five (Chap. 7).

17.4.1 The Genetic Code Metaphor

From genetics we learn that each human individual enters the world with an inherited genetic code, which affects, among other things, a person's potential to behave and interact with other individuals. Taking the genetic code as a metaphor we suggest, first, that each individual agent is defined by, and thus comes to the city with, a personal *cultural code*, reminiscent in its properties to a *genetic code*. Second, that the cultural code defines the potential of that individual to interact with other individuals and locations in the city, and in the process give rise to two phase transitions: one at the level of the individual agent by which its cultural identity in the city is created, and another at the level of the city as a whole by which a new cultural group in the city is created.

17.4.2 Memes and the Extended Phenotype

The metaphoric connection between genes and socio-cultural traits that we propose here is not new and was discussed above in the SIRN proposition five of Chap. 7. As noted there, a rather amplified voice is Dawkins (1976) in his *The Selfish Gene*. The central thesis of this "gene-eye-view" on nature and evolution is that at the core of Darwinian evolution stand not whole animals, which are usually selfish but sometimes also altruistic, but the genes. According to Dawkins, the latter are the only biological entities that always tend to replicate themselves and as such are genuinely "selfish". "Selfish genes" do not interact directly with each other, however, but indirectly through their phenotypes. In a second book – *The Extended Phenotype* – Dawkins (1982) further suggests that, regarding animals, the notion phenotype should include in addition to the immediate bodily properties, also some of their products such as the bird's nest, the beaver's dam and the spider's web.

Towards the end of his *Selfish Gene*, Dawkins speculates with the idea that Darwin's theory of biological evolution enfolds the principle for a general theory of evolution, biological or otherwise. The fundamental evolutionary principle as he writes, is

> *... that all life evolves by the differential survival of replicating entities. The gene, the DNA molecule, happens to be the replicating entity that prevails on our own planet. There may be others. If there are, provided certain other conditions are met, they will almost inevitably tend to become the basis for an evolutionary process* (Dawkins 1986, p 192).

Are there such new replicators? Yes, answers Dawkins, "a new kind of replicator has recently emerged ... still in its infancy" (ibid), it is the *meme* – the replicator at the core of human cultural evolution. The memes are new replicators that only recently have appeared on the stage of the world, as a by-product of biological evolution, and are already moving fast with their own independent evolutionary process.

Examining the various examples of Dawkins' memes, it can be seen that they are, in fact, concepts, categories, cultural traits, schemata, generally held ideas, and the like. Common to all those entities and notions is that they are all public – all were selected and accepted by culture or society. The latter implies that in order to qualify as a meme, a personal idea, trait etc. must "go public" – it must be publicly and culturally accepted. A case in point is the notion "meme" which was originally Dawkins' personal idea, has proved to be culturally very successful and became itself a meme: it has invaded many brains and has resided there as an internal representation, has invaded the *New Oxford English Dictionary* and has resided there as an external representation; so much so that today we have a whole research domain of *Memetics* (Heylighen and Chielens 2009).

Dawkins' meme and extended phenotype were subject to an enthusiastic re-interpretation by Dennett (1991) in his book *Consciousness Explained* (see also Dennett 1995). Dennett's main concern in this book is consciousness, but in the way to explain it, he elaborates also on the meaning of the *Self*. According to Dennett the *Self* is the *Homo sapiens*' center of gravity of its extended phenotype. Like the individual spiders who protect themselves by making a web, we humans create a *Self*:

> *Out of the brain it (the Homo sapiens) spins a web ... this web protects it [the person].. stripped of it, an individual human being is as incomplete as a bird without its feathers, a turtle without its shell* (Dennett 1991, p 416).

Each person thus builds a web, which is the person's cultural and social extended phenotype. This web, then, becomes the medium through which the memes that have invaded and occupied that person's brain externalize themselves in public. Writing from the perspective of our FACS-SIRN cities, I've suggested adding two points to Dennett's *Self*. First, that internal and external representations (mimetic, lexical and artificial) are part of humans' extended phenotype, and as such part of the web that defines the human *Self*. Second, that the innermost intimate element of humans – the one that makes the *Self* of each of us, is defined by means of our extended phenotype. That is to say, by means of our interaction with the environment around us, which includes our clothes, cars, houses, friends, neighbors, the neighborhoods we live in, our cities, countries . . . (Portugali 2000, Chaps. 2, 3, 14 and Chap. 7 above). And so, a typical answer to the question ‘who are you?’ or ‘what is your identity?’, might be, ‘I’m an Israeli’, ‘Parisian’, ‘New-Yorker’, ‘citizen of the world’, etc. My/Your individuality is defined by means of your connection to the world.

The preliminary theory and model proposed here provides a conjunction between, on the one hand, our SIRN approach to the city, and on the other, Dawkins’ and Dennett’s memes, extended phenotype, and *Self*. The process modeled below starts with a set of concepts, categories, cultural traits, schemata, generally held ideas, in short, memes, internally represented in an agent’s memory and defining its *Self*, that is to say, its personal-cultural identity. This set is termed *memetic*- or *m-code*. In the model, these personal memes do not interact directly, but only indirectly through the interactions between the agents who carry them. In the model these are the interactions between the free urban agents in their attempt to find an appropriate house in the city. These interactions give rise to urban cultural groups, which are groups of agents with identical or similar m-codes (see discussion below). Each group can thus be also defined by its *collective m-code*. This grouping process is the mechanism through which memes are environmentally selected, or in other words, ‘replicate themselves’. This is so because when an agent becomes a member of a cultural group, the memes that compose its m-code, enter the group’s m-code (or pool of memes). If, on the other hand, the agent lives in a “foreign” neighborhood, it might either preserve its previous m-code (Self), or else acquire a new one – for example, by means of the process of spatial cognitive dissonance discussed above.

The notion of m-code thus tells us how cultural groups are determined as a result of the interplay between m-codes and the dynamic of the city. The next question is: once created, how change can still take place? In what follows it is shown that the same urban dynamics that gave rise to a certain memetic/cultural configuration of the city can once again bring change. More specifically, that in certain circumstances the dynamics of the city involves the synergetic process of enslavement (see definition above) by which, in the first stage, urban agents are enslaved by the emerging structure of the city in the sense that they change their identity and in the second, this personal change feeds back to the global structure and dynamics of the city. The general question here concerns morphogenesis: the way a new spatial socio-cultural entity is born. The answer to this question takes us back to the process of cognitive dissonance discussed above: Namely, that the process of spatial cognitive dissonance in the city is a special property of the m-codes in the city.

17.4.3 The Model

Computationally, this model is built in line with the FACS (Free Agents on a Cellular Space) models as the previous one. However, the model presented below differs from standard CA/AB USM in two respects. First, it is a SIRN model in two of its aspects: The aspect by which the interaction between the agents gives rise to a global city that then shape/transform the properties of the agents and so on in circular causality; and the aspect by which agents' properties are being transformed by means of an interplay between their internal representation and the externally represented environment. Second, the model differs from standard USM in its definition of the cultural identity of the agents – this is the novel feature of this model. That is to say, in the model the cultural groups are not pre-determined, but from the start of the game they emerge out of the dynamics that takes place in the city.

17.4.4 The Definition of the m-Code

In genetics, as well in studies of artificial life, it is common to represent the individual's genotype by means of a high-dimensional binary vector (Banzhaf 1994). In the present model the mcode of an individual agent is defined in the same way. An important property of the agents in this model is that each is an adaptive self-organizing system in the sense that it can change itself in line with the dynamics and evolution of the system it belongs to. That is to say, the m-code of an agent and its residential behavior can change through its interaction with its (externally represented) nearest neighbors, neighborhood, and/or the city as a whole.

17.4.5 Cultural Groups

The definition of cultural groups in the model is inspired by the cognitive discourse on categorization as elaborated in Chap. 10 above with respect to cities. From the latter follows three kinds of categories: classical categories, family resemblance categories and family resemblance with prototype categories. Taken in conjunction with the definition of individuals' m-codes as above, there are four basic ways to derive cultural groups. One is to say that similarly to a classical category, a cultural group is a collection of individuals with *identical* cultural codes. Second, to say that it is a collection of individuals with similar cultural codes. Third is to say that a cultural group is a collection of individuals with m-codes that form a family resemblance network, and fourth, with prototypical family resemblance as their grouping process. These four ways refer to four grouping principles, which might be termed the *identity, similarity, family-resemblance* and *prototypical family-resemblance* principles.

For simplicity, the illustrative examples below refer only to the first grouping principle according to which there can be a maximum of $\mathbf{2^K}$ different cultural identities in the city, when K describes the dimension of each urban agent's $\mathbf{A}$ m-code. Thus, $K = 1$ refers to a situation by which the m-code is defined by one property and there can be two cultural groups in the city, $K = 2$ refers to a case where the m-code is defined by two properties and there can be four cultural groups and so on. In the case of the other grouping principles, the number and nature of the groups depend on the specific similarity measure according to which individuals can join the group.

17.4.6 Local and Global Information

In the model, agents take decision in line with a conjunction between the local and global information they face, when *local information* refers to the (externally represented) properties (e.g., cultural m-codes) of an agent's nearest neighbors, whereas *global information* to the (externally represented) properties of the city as a whole. Local cultural information is related to the notion of *local spatial cognitive dissonance* of free agents as discussed above. Applying this notion to the multidimensional m-codes of agents, we define local spatial cognitive dissonance of agent **A**, occupying house $\mathbf{H_{ij}}$, as an average of the differences between **A**'s identity and the identities of its nearest neighbors.

The role of global information is treated in the same way: If individuals similar to **A** in their m-codes are spatially segregated in the city then, beyond a certain threshold their spatial distribution might affect the behavior of **A**. For this purpose we define the *global cultural information* available (or, afforded) to agent **A**, about residential segregation of individual agents of identity $\mathbf{C_A}$.

Local and global information influence the agent's cultural identity in opposing ways. High local cognitive dissonance might push agent **A** *to change* its (internally represented) cultural identity, whereas high global level of segregation of individual agents of identity $\mathbf{C_A}$, pushes **A** to preserve its current identity. The change in an agent's cultural identity thus depends on these two opposing tendencies. The cultural identity of an agent **A** can be changed when the local tendency to change an identity exceeds the global tendency to preserve it.

17.4.7 Some Results

Given the above considerations it is now possible to examine the spatial process of socio-cultural emergence in the city, when the urban agents vary in their m-codes and when in order to qualify as a newly emerging socio-cultural entity, the individual members of the group must fulfill three conditions simultaneously: At the individual level the members of the group must have the same cultural identity, at the local level most of the group members should be located within neighborhoods of their own, and at the global level the number of group members in the city and their spatial segregation have to be sufficiently high.

Figure 17.5 shows three different cultural landscapes of the evolving City model with three different m-codes, after some 500 iterations. In order to represent the

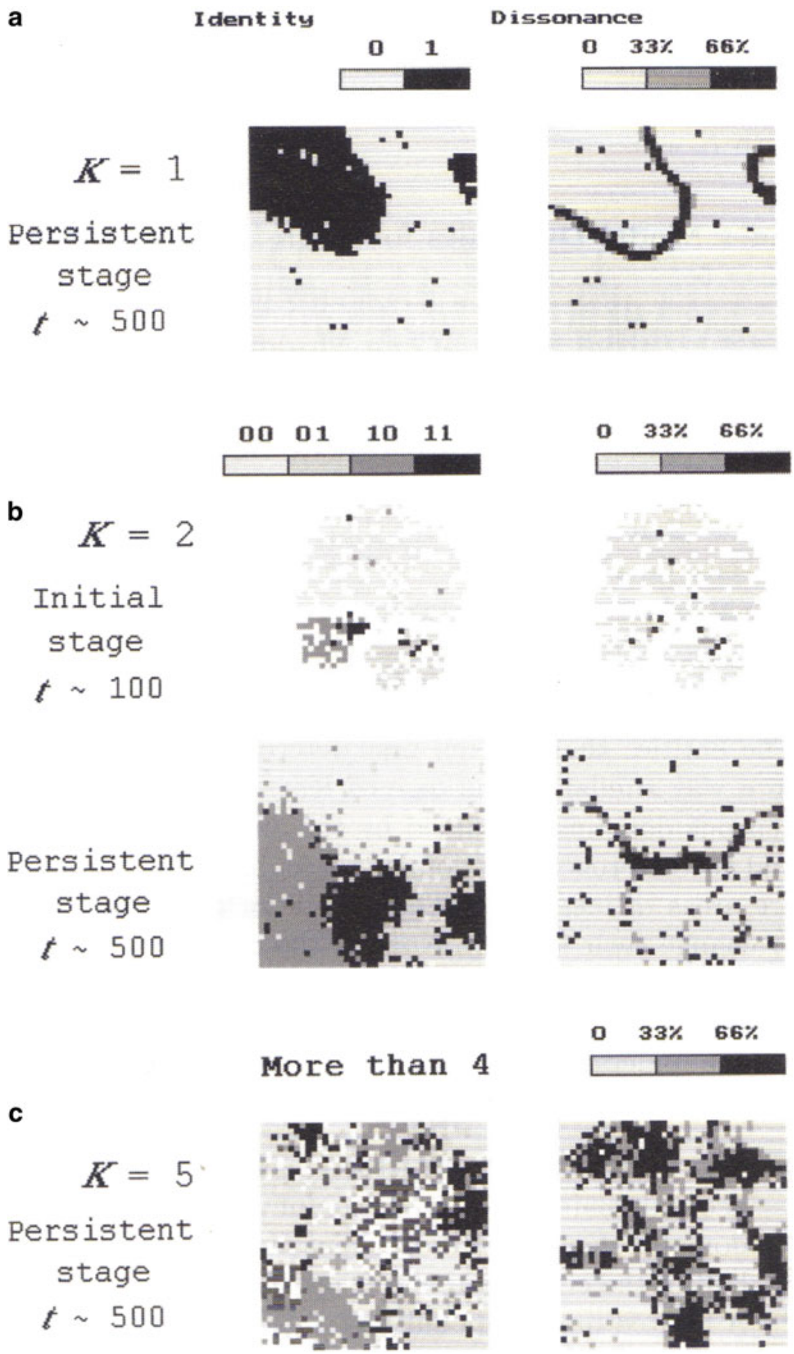

Fig. 17.5 Three different cultural landscapes of the memes-derived urban simulation model, after some 500 iterations with three different definitions of the m-code: **(a)** in the first scenario $K = 1$, **(b)** in the second $K = 2$, **(c)** and in the third $K = 5$

changing properties of the city we use below two kinds of maps. First, as in the previous model, we have here a map showing the distribution of agents' cultural identity, with each identity marked by its own color. This presentation is the most detailed one, but because of the high number and nonlinear ordering of identities, it cannot be constructed for m-codes of more than two traits ($K > 2$). The second map shows the spatial distribution of cultural cognitive dissonance of residents. This map is a surrogate to the Stability-Instability Surface (SIS) discussed in Chap. 4, Fig. 4.22. As in Fig. 4.22 here too, the higher the dissonance is, the higher is the chance that the state of a given house will change.

17.4.8 *Model Dynamics for Low-Dimensional Cultural Identity:* $K = 1$ and $K = 2$

The case of $K = 1$ (Fig. 17.5a) corresponds to our previous analysis of residential segregation between two cultural groups (Chap. 4, Fig. 4.21). The city dynamics in that case entailed a fast self-organization of two identities in two or several segregated patches. The boundaries between the homogeneous patches are the areas of instability/chaos, characterized by high cognitive dissonance and as a consequence intensive exchange of individuals.

When K equals two (Fig. 17.5b), the number of possible identities is four. The city in this case evolved in two steps: At the initial iterations of the simulation the evolving city still resembles some of the previous model results with two cultural groups. However, in the long run (we stopped the simulations at $t = 2500$) the number of socio-cultural entities, existing simultaneously in the city fluctuates between three and four, and the life span of the entities is of the order of 500 iterations. Let us now skip the intermediate cases of K equals 3 and 4, and proceed with $K = 5$.

The number of possible identities for this case is $2^5 = 32$. However, as in the previous simulation, here too, the city evolves in two phases (Figs. 17.5c and 17.6): At the beginning of the simulation some 2 to 4 cultural groups emerge (we run the model five times). But then there is a phase transition (at iterations 150–200) and the number of cultural groups jumps to a higher level in which it fluctuates in a steady state at a level of 10 to 15 groups. In terms of synergetics we would say that from iteration 200 onwards (until iteration 2500), the city was dominated by an order parameter that kept its number of cultural groups and personal identities in between 10 and 15. A mixture of homogeneous spatial domains, the population of which forms distinct socio-cultural entities, and domains that are heterogeneous at different levels, thus characterized the city's cultural landscape during this long period.

Note, first, that while the number of possible identities of $K = 5$ is 32, this potential number was never realized (Fig. 17.6). This is due to the city dynamics, namely, the conjunction between the grouping principles and the specific properties

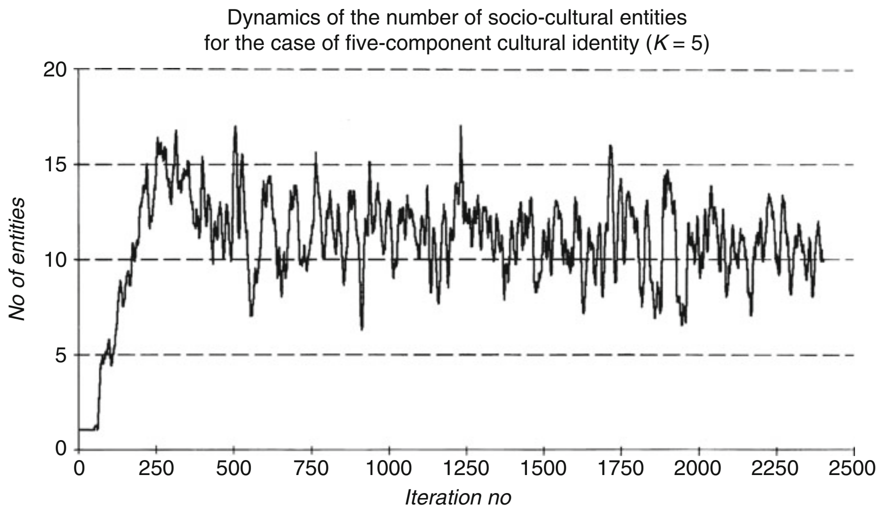

Fig. 17.6 The dynamics of the number of cultural identity in the memes-derived urban simulation model for a $K = 5$ m-code

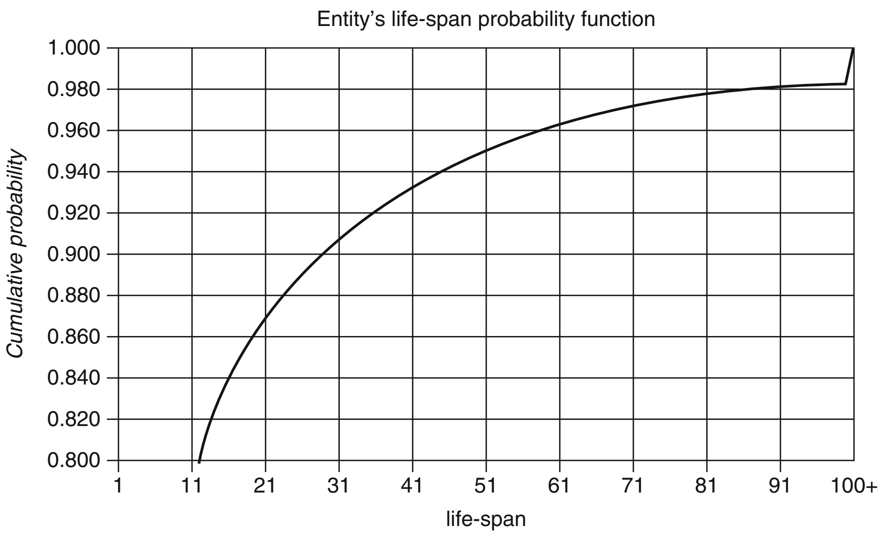

Fig. 17.7 The lifespan probability of cultural entities (groups) in the evolving memes-derived urban simulation model

of the city (e.g., the fact that its size and form were kept fixed during the simulation). Second, that the life span of the various socio-cultural entities in the city is finite so that the entities replace each other in the city space (Fig. 17.7). About 20% of the entities persist in the city for 11 iterations or longer and 10% persist for 25 iterations or longer.

17.5 Concluding Notes

The two models revisited in this chapter refer to an urban reality that is too often overlooked. Namely, they show that the city is not just an empty container in which other social, cultural and political processes take place, but a social force in itself. That is to say, a force that participates in the spatio-cultural processes by which collective and personal identities of individuals and groups are determined. In the first model we could see a process that starts when two cultural groups come to a city and then, out of the city dynamics, a third group is emerging. The second model simulated a scenario by which agents arrive to the city with their own personal properties and it is here in the city and out of its dynamics that their personal and group identities are determined. Such processes were typical of the urban dynamics of many countries that were subject to mass migration throughout the 20th century (USA, Canada, Israel . . .) and they are still typical today, in the 21st century, in countries that are subject to massive labor migration.

As could be seen, at the core of the above two models stand the SIRN process with its sequential play between internal and external representations. However, in the above two model the SIRN dynamics is somewhat implicit; in fact, the aim of revisiting the two models was to explicate their SIRN nature. The model that is presented in the next chapter was designed from the start as a cognitive SIRN USM.

Chapter 18
CogCity (Cognitive City): A Top-down→Bottom-up USM

18.1 Introduction

In Part II above we have introduced several cognitive capabilities of humans and have discussed their implications to various aspects of cities as complex self-organizing systems. The present chapter extends this discussion and examines the implications to USM. This is done by developing CogCity (cognitive city) as an urban simulation model that explicitly incorporates in its structure the role of three cognitive processes that as illustrated in Part II above, typify the behavior of human agents: information compression, cognitive mapping and categorization. The discussion below starts by introducing the three cognitive capabilities and their general implications to USM (Sect. 18.2). Next a specific urban simulation model is introduced (Sect. 18.3) and some of results of its simulation runs are presented and discussed. The specific urban scenario the model simulates describes entrepreneurs as urban agents who come to the city in order to find a location and build on it a certain building they "have in mind". By so doing they in fact construct the city as a 3D landscape. Finally, Sect. 18.4 summarizes the two main innovative features of CogCity: Firstly, that it is a cognitive USM that makes explicit use of some of the cognitive capabilities of humans. Secondly and as a consequence of taking cognition seriously, CogCity is a top-down bottom-up urban simulation model in the sense that agents take decisions in a top-down order and then act in a bottom-up sequence.

18.2 Cognitive Processes and Their Implications

18.2.1 A SIRN Urban Simulation Model

The basic SIRN model as presented above (Chap. 7, Fig. 7.11) can be seen as symbolizing a self-organizing active agent that is subject to internal information from the mind/brain and external information from the environment. In line with the SIRN process, the interaction between these two flows gives rise to an order parameter that governs the agent's action and behavior, as well as the feedback

J. Portugali, *Complexity, Cognition and the City*, Understanding Complex Systems, DOI 10.1007/978-3-642-19451-1_18,

information flow to the agent's mind. The order parameters are determined by a competition in line with the synergetics' pattern recognition paradigm noted above.

This basic SIRN model has been elaborated into three prototype submodels termed the *intrapersonal*, the *interpersonal collective*, and the *interpersonal with a common reservoir* submodels. The first two submodels can be exemplified by the cognitive process associated with the production of a lamp (Fig. 18.1). The intrapersonal

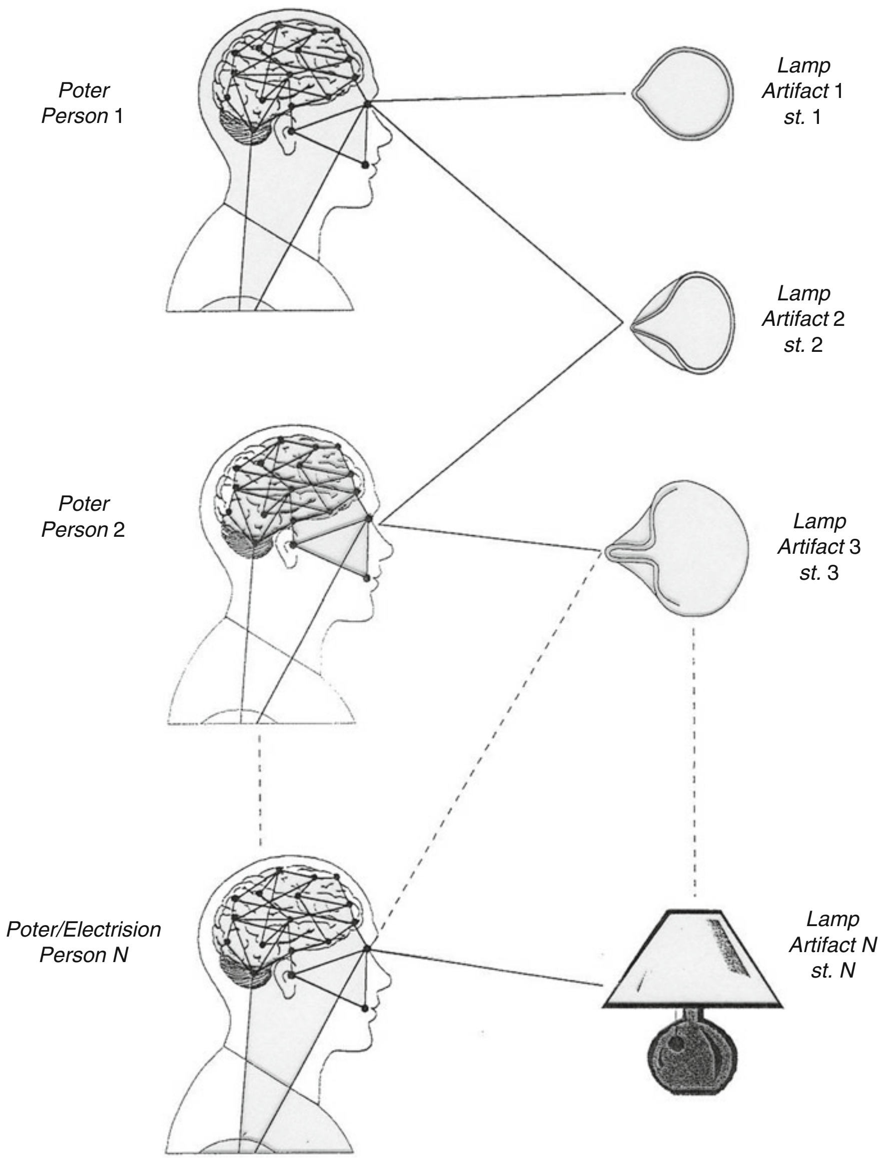

Fig. 18.1 The production of lamps as a cognitive process. In ancient times the notion of 'a lamp' referred to a ceramic oil lamp, while in modern times to an electrical lamp

process might refer to cases were the potter is working alone, while the interpersonal to cases were several potters are engaged in the production of a certain type of lamp, or other small-scale artifacts.

Our main concern here, however, is the third submodel – the *interpersonal with a common reservoir* the dynamics of which has been nicely illustrated by the set of city game experiments presented above (Chap. 7, Figs. 7.7a, b). Figure 18.2 illustrates graphically this public-collective SIRN submodel with respect to the city game. Each individual player/agent is subject to internal input constructed by the mind/brain, and external input that is coming from the city as a common reservoir. The internal input refers to the agent's past urban experience and can thus take the form of intentions, needs, c- or s-cognitive map, while the external input refers to the legible information afforded by the city on the ground. The interaction between these two forms of input gives rise to a competition between alternative cognitive maps and decision rules that ends up when one, or a few, alternative(s) "wins". The winning alternative is the order parameter that enslaves the system. The emerging order parameter governs an external output, which is the agent's location action in the city, and an internal output, which is an information feedback loop back to the agent's mind/brain. The agents' individual actions enter into interaction that gives rise to a competition between several urban configurations. The winning configuration emerges as the city's global

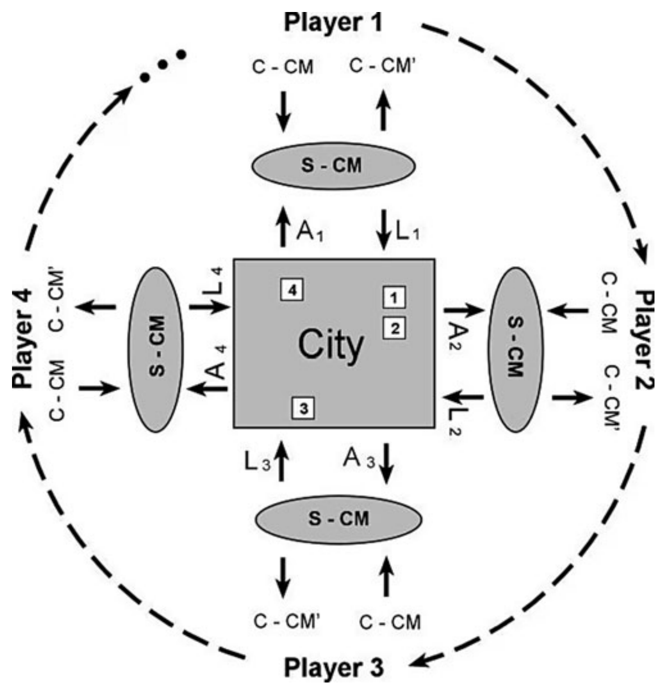

Fig. 18.2 The interpersonal with a common reservoir SIRN submodel applied to the city game C-/S-CM (c-/s-cognitive map); A-information afforded; L –location action

order parameter that in its turn “enslaves” the minds of the individual agents and so on. In the language of synergetics, this process is termed *circular causality*. In terms of social theory, it is close to notions of socio-spatial *reproduction* and *structuration* (Gregory 1994; Giddens 1984). Due to circular causality, as the process evolves, the subjective cognitive maps of the individual agents become more similar to each other, and an inter-subjective, collective cognitive map(s) emerges. Both private-subjective cognitive maps and public-collective ones are thus *constructions*. The process involves the two-scale self-organization process noted above: an individual-local scale referring to each individual agent as a self-organizing system, and a collective-global scale, referring to the whole city as a self-organizing system.

18.2.2 Information Compression Implies a Top-down Decision Process

The essence of the behavioral principles of SIRN is that agents as decision makers are operating in a city that affords a huge amount of information that is far beyond the information processing capabilities of humans. As shown above in Chaps. 8 and 9 (and by Haken and Portugali 2003), the amount of information, with respect to houses only, afforded by a medium size city (of 10,000 to 100,000 buildings) is huge, whereas humans’ information processing capabilities (in short-term memory) is about 2.5 bits (Miller 1956 and Chaps. 8,9 above). From this follows that a bottom-up decision process that is common to most AB/CA urban simulation models, is simply not realistic from the cognitive point of view. The reason is simple: a bottom-up process requires that an urban agent that is searching a location or a house in a new city, has first to identify *all* the vacant locations and/or houses in that city and then choose the best one. For the vast majority of urban agents this is not practical, as noted. The notion of *bounded rationality* as introduced by Simon (1991) and more recently interpreted by Kahneman (2003) tells us that in such circumstances agents employ decision heuristics. From our discussion on Shannonian and semantic information in the context of cities (Chaps. 8, 9 above) follows that some kind of information compression process is thus required.

The information compression process that is implied by SIRN and is suggested here for USM is that agents take decisions in the city sequentially: first, in a top-down manner and then in a bottom-up fashion. More specifically, each agent comes to the city with a pre-conception of what a city is, that is to say, with what has been defined above (Chap. 6) as conceptual cognitive map (c-cognitive map). With this map “in mind” the agent “observes” the city as a whole, constructs a specific cognitive map of that city and chooses a single urban *Area* (see definition below). Having selected the appropriate *Area*, the agent then selects a certain parcel of land (if landowner) or an apartment or office (if land-user) in a bottom-up manner.

18.2.3 Agents' c- and s-Cognitive Maps

Agents never come to the city *tabula rasa*. In "conventional" AB/CA models they usually come equipped with needs, pattern of decision making, intentions and similar information that allows them to interact *locally* with their nearest neighbors in a *bottom-up* manner, but not with information about the global structure of the city. According to SIRN, per contra, agents come to the city equipped also with information about its global structure, for example, with c- and/or s-cognitive map of it. As a consequence, agents perceive the city *globally* in a *top-down* manner and on the basis of this perception they then act locally (as usual).

Note that the c-cognitive maps refer to the global and meso-structure (neighborhoods etc.) of the city, while the s-cognitive maps to the city's global, meso- and local-scale structure. Hetna, Casakin, and Portugali (2001) have empirically examined subjects' c-cognitive maps. Their findings indicate that most subjects tend to have either monocentric c-cognitive maps, or polycentric ones. *Monocentric c-cognitive maps* refer to a core-periphery internal representation of the category *city*, that is, a city with a dominant center around which there is a wide periphery, or alternatively, a city with a strong center around which, in its periphery, there is a hierarchy of lower level centers; London is a good example of such a city. A polycentric c-cognitive map refers to an internal representation of *a city* with many centers when none of them dominates the city. Los Angeles might be a case in point. In line with these findings, in the example presented below, we assume two polar c-cognitive maps that agents have in mind: *monocentric*, referring to a hierarchical core-periphery image schema of the city; and *polycentric* referring to a nonhierarchical schema of the city.

Model-wise, a convenient way to refer to the monocentric vs. polycentric dichotomy of cognitive maps is by means of the relations between size and rank that were often used to describe systems' structure and hierarchy (Zipf 1949) including urban systems (Haggett et al. 1977; Batty and Longely 1994; Pumain 2006; above Chap. 2). Thus, assuming a city hierarchically subdivided (categorized) into areas of different sizes and types, its structure can be described by the relations: $A_r = A_1(r)^{-b}$, where A is the size of an area, r its rank and b is a constant that must be estimated. Given such a description of the city (Fig. 18.3), an agent with a monocentric c-cognitive map perceives the city as a concave rank-size distribution with b, or rather $b(c) \approx 2$, while an agent with a polycentric map as a convex rank-size distribution with $b(c) \approx 0.5$.

Agents take decisions on the basis of their s- and c-cognitive maps of the city. This property is significant since, as noted above and will be further specified below, it implies a process that differs from the standard AB/CA modelling approaches currently prevalent in the domain of urban simulation: Instead of the bottom-up process that typifies standard urban simulation models, in the cognitive USM below we have a top-down/bottom-up process in which the agents "think" about the city globally but act in it and on it locally.

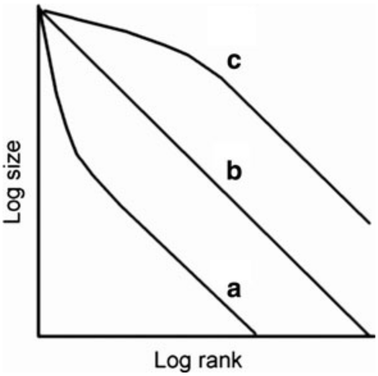

Fig. 18.3 Representation of c-cognitive maps in terms of city size distribution: **(a)** Concave distributions with "primate city center", representing monocentric perception of a city. **(b)** Power low distributions representing monocentric and hierarchical perception of a city. **(c)** Convex distributions with relatively homogenously size distribution of centers, representing polycentric perception of a city. Compare to the three classes of city size distributions according to Haggett (1967) Fig. 14.5

Specific and c-cognitive maps are interrelated. This follows from Fig. 18.2 in which each of the players symbolizes an urban agent coming for the first time to a new city. From its past experience, this agent is, say, monocentric. With this knowledge in mind, our agent observes, learns and perceives the city. The result of this learning is the agent's s-cognitive map of that city which is an interpretation of the city structure by means of the agent's initial c-cognitive map. Due to *hysteresis* and similar effects of systematic distortions in cognitive mapping (Chap. 6), it is not unlikely that our agent's s-cognitive map will be somewhat distorted. It all depends on the degree of resemblance between the agent's c-cognitive map and the real structure of the city.

An agent's cognitive map of the city is not an exact copy of its real structure in yet another way. Because of the large size of cities, an agent's information about the city is always partial and never homogeneous: Some parts and elements of the city are better known than others; some are known in detail, others in general terms and others are not known at all. The often distorted and partial nature of cognitive maps is significant to the dynamics of cities since agents take decision, behave and act in the city according to their cognitive map of it and not according to the "real" structure of the city (however determined).

Agents constantly categorize the city. They do so by means of the interactive play between the s- and c-cognitive maps with which they come to the city, the affordable and legible information they actively extract from the city, and their behavior and action in the city. That is to say, by means of the task-specific and context-dependent play between internal and external representations that evolves in line with the 'public with common reservoir' SIRN submodel described above. This iterative process of categorization and re-categorization gives rise to the model's infrastructural categories as specified below.

18.2.4 Embodied Spatial Models

Where do c-cognitive maps come from? One answer might be that similarly to cognitive maps in general they reflect the agent's previous/past spatial experience. Thus Londoners are likely to have monocentric cognitive maps while Los Angelers polycentric ones. A different and rather interesting answer might be inferred from Johnson's and Lakoff's view of embodied cognition.

According to Johnson's (1987) and Lakoff's (1987) version of embodied cognition, a person's basic bodily experience in the environment entails spatial *image schemata*, which by means of imagination (metaphors, metonymy, etc.), are later in life used to relate to the world and categorize it. Some of the main embodied image schemata they discuss (Fig. 18.4) are *container*, *center-periphery*, *hierarchy, or part-whole*. These mental models are identical to the various c-cognitive maps discussed above and to models employed by students of urbanism to refer to the structure of cities and regions. In the latter it was always taken for granted that such urban morphologies are the result of economic, social or political forces. More recently, hierarchy is interpreted as an emergent property of cities and systems of cities as fractal structures and of complex self-organized networks (Chap. 4, above).

But from the above-noted similarity follows the research hypothesis that cognitive image schemata and spatial cognitive models are "hidden variables" of spatial order, that is to say, they might be also the original source for the core periphery and hierarchical structure of cities. In other words, that these image schemata are not only the means by which we construct our language, as suggested in cognitive science, but also the means by which we perceive, act on, and thus construct, our artificial environment – spatially, economically, culturally and politically. The model presented in the previous chapter already applied this possibility. That is, by means of their cognitive categorization capabilities, the interaction between agents with different m-codes and between them and the local and global properties of the city gave rise to four forms of cultural groupings that were based on their cognitive categorization grouping principles. We've termed the latter principles the *identity, similarity, family-resemblance*, and *prototypical family-resemblance* principles. The model CogCity presented below further illustrates this possibility.

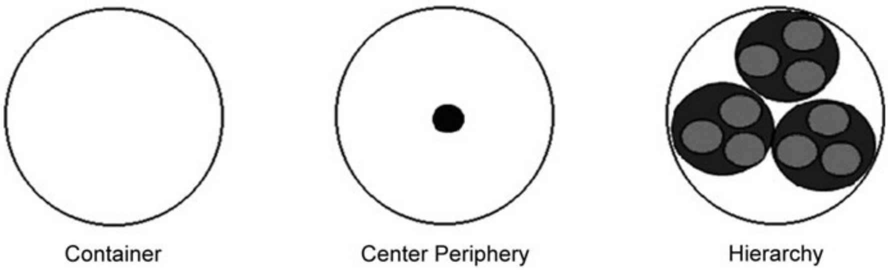

Fig. 18.4 Some embodied image schemata suggested by Johnson and Lakoff: *container*, *center-periphery*, *and hierarchy*

It also makes use of its immediate corollary – that people are never *tabula rasa* when coming to a new city; rather they come equipped with a set of image schemata, and usually also mental models of "a city" constructed in their mind/brain on the basis of their previous experience.

18.2.5 The Infrastructural Urban Categories

In ordinary, "noncognitive", urban simulation models the global structure of the city is not an active participant in the dynamics. Usually it is an outcome – an emergent urban structure or property of the local interactions between the agents and the local urban elements – usually cells that symbolize city lots. In a SIRN/cognitive urban simulation model the global structure of the city is from the start an active participant. This is so since as noted above, upon their first arrival to the city agents perceive the city globally, by means of their c-cognitive map, then they construct their s-cognitive map by comparing their c-cognitive map to the real structure of the city they confront and only then, on the basis of this global perception, they act on the city locally – by their location decision and action. To enable agents to do so, in each new model iteration the global structure of the city must be re-defined in a way comparable with the agents' cognitive maps, which in the present case is the monocentric-polycentric dichotomy and its description by means of the rank size rule. The latter can take the form $A_r = A_1(r)^{-b}$, as noted. From this follows three basic global urban patterns (Fig. 18.3):

Monocentric: concave "primate" pattern: $b \geq 2$
Polycentric: convex pattern: $b < 1$
Hierarchical: rank-size pattern: $b \approx 1$

Each model iteration the global structure of the city must be re-defined and with it each of the Areas and Subareas of which the city is composed. Using the language of classical location theory, an *Area* can be defined as a *Central place* plus the *Periphery* it influences, when the *Range* – the spatial extent of the periphery, is some function of the Central place's intensity. Areas are commonly classified into Residential, Commercial, Industrial and so on. In some (polycentric) cities they co-exist in nonhierarchical relations while in others they form a (monocentric) hierarchical structure. In the latter case, the city as a whole can be regarded as the area at the top of the hierarchy, its districts as subareas and so on. The same with the city's central places: a small city with a single central place might evolve into a complex hierarchical structure at the top of which is the city's main central place (its CBD), below it smaller scale subcentral places and so on down the hierarchy.

As in every AB/CA urban simulation models, here too, the Cells are the elementary infrastructure objects. A cell might be empty or occupied ("full"). It also has properties that reflect the entity that "fills" the cell and its relations to its neighbors. Each cell might also be a member in one or several of the above larger-scale urban objects that form the city structure. Each iteration, the empty/full/content/

membership state of every cell in the system is determined anew in line with predetermined transition rules, as is usual in such models.

18.2.6 The Overall Model Dynamics

Standard AB/CA urban simulation models are essentially bottom-up in their structure. A typical scenario in such models starts, for example, when agents arrive to a city, select the empty cells, evaluate the appropriateness of the cells and their nearest neighbors in light of their needs and then take a decision and action. In parallel, the properties of every cell are determined according to its relations to its nearest neighbors. This is described in Fig. 18.5, *left*. As illustrated in Fig. 18.5, *right*, a SIRN/cognitive urban simulation model is characterized by an ongoing

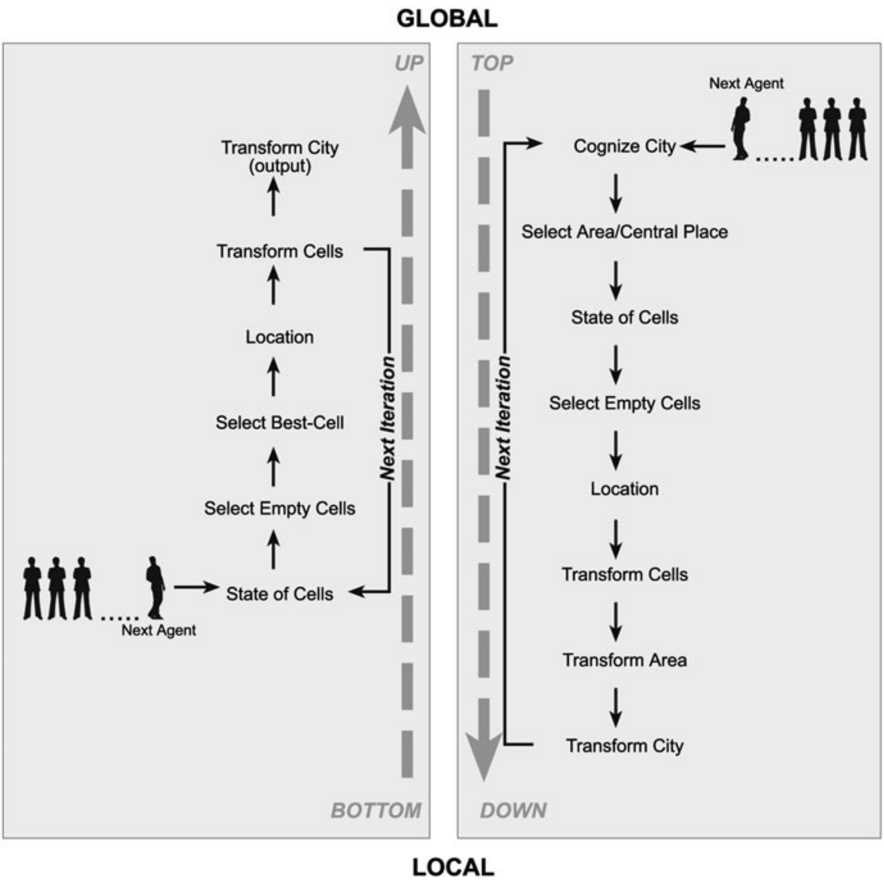

Fig. 18.5 A cognitive (*right*) vs. noncognitive (*left*) AB/CA urban simulation model

interaction between top-down and bottom-up processes: A typical scenario starts top-down when agents arrive to the city with a global cognitive map in their mind, compare it to the global structure of the city and select a local *Area*. Now starts the bottom-up process: the agent selects the empty cells in that local *Area*, evaluates the appropriateness of the cells and their nearest neighbors in light of its needs and then takes a decision and action. In parallel, the properties of every cell are determined according to its relations to its nearest neighbors and so on.

In a regular AB/CA simulation the process ends here: the global outcome is recorded or mapped as the output of this specific iteration and the model is ready for a new iteration. In a SIRN model the process continues and feeds back to the global structure of the city that allows the top-down process in the next iteration: Firstly, the state of the various central places is determined. Secondly, peripheries are determined around central places. Thirdly, areas are defined or redefined. Fourthly, subareas are redefined. Fifthly, given areas and subareas, the global state of the city as a whole and its rank-size structure b, is defined as above. The latter changes redefine the local membership state of each cell in the various infrastructure objects and become the externally represented input for a new agent in the next iteration, and so on in circular causality.

18.3 Cognitive City (CogCity) – The Model

CogCity (Cognitive City) is an AB/AC urban simulation model constructed in line with the above SIRN principles. Computationally, CogCity is similar to the FACS (Free Agents on a Cellular Space) models discussed in the previous chapter. Accordingly, the model is built of two sets of objects: *agents* that mimic the behavior and action of individuals, firms and similar such agencies in the city; and *infrastructural categories* that mimic the physical form and functional structure of the city.

18.3.1 The Agents

The agents in CogCity can be imagined as entrepreneur immigrants coming to a new city for the first time "in their life", with an intention to construct in it a certain building they "have in mind". It is interesting to note in this connection that such a scenario was typical of Tel Aviv in the second half of the 1920s and mainly during the 1930s. These years witnessed influx of Jewish immigrants who came to the country from Germany and Central Europe. Being socio-culturally urbanized, Central European middle classes, many of them came to Tel Aviv with "a building in mind" (and sufficient money in the pocket). Their activities gave rise to fast expansion of the city (Mann 2006) and to the fact that it became the world's largest collection of Bauhouse/International style buildings. This collection of some 4000 buildings was recently declared by UNESCO (2009) as a *World Heritage*.

Every model iteration, a new agent enters the city and attempts to locate in it the specific building it has "in mind". Some of the agents have a residential building in mind while others have a commercial building in mind. In the present example, we assume, firstly, that 10% of the agents intend to build a commercial building while 90% a residential building; secondly, that residential buildings are 1- or 3-stories high, while commercial buildings are 5- or 7-stories high.

In addition to a building, each of the agents has "in mind" a c-cognitive map *b(c)* of 'a city' that represents the agent's past urban experience. In the complete CogCity model, some of the agents have in mind a monocentric c-cognitive map of a city, while others a polycentric one. In the scenario described below all agents arriving to the city have monocentric c-cognitive maps only. The agents construct their s-cognitive maps *b(s)* of the city by comparing their *b(c)* with the city's *b*. This is done in the following way:

If $b(c) = 2$ *and* $b > 1$*, then* $b(s) = 2$*,* $\rightarrow$ *the agent's cognitive map will remain monocentric.*

Otherwise, b(s) will adapt to b, $\rightarrow$ *the agent's cognitive map will become polycentric.*

If $b(c) = 0.5$ *and* $b < 1$*, then* $b(s)= 0.5$*,* $\rightarrow$ *the agent's cognitive map will remain polycentric. Otherwise, b(s) will adapt to b,* $\rightarrow$ *the agent's cognitive map will become monocentric.*

The result of this process is agents with mono- and polycentric cognitive maps and with residential and commercial buildings in mind. From this follows four location decisions and action patterns:

- *monocentric agents with a commercial/central building in mind*
- *monocentric agents with a residential building in mind*
- *polycentric agents with a commercial/central building in mind*
- *polycentric agents with a residential building in mind*

18.3.2 The Infrastructural Categories

Agents perceive the city hierarchically. In CogCity this hierarchy is composed of the following set of infrastructural categories: *central places*, their *peripheries, areas, subareas*, and *cells* (buildings). In each model iteration these infrastructural categories are being re-defined in the following way:

Central places. In each model iteration, the central places in the city are redefined according to ***Rule 1:*** *If a certain number of type-A cells, located adjacent to each other, exceed a certain predetermined number and/or volume, they become a central place.*

Periphery. The periphery is determined by creating a circle whose range (i.e. radius) is *R* around the central place's central cell. The coordinates of the latter cell are the average of all cells in the central place. That is: Ycenter = sum Y/S; Xcenter = SumX/S. The range *R* of each periphery is some function of the intensity/volume of the central place measured, for example by the total number of floors (or built area) in it: $R = \sqrt{hs/\Pi}$ where h is the average number of floors of all buildings in the central place, S is the number of cells in it, and **pi** is the mathematical constant 3.14.

Areas and Subarea. An area is the central place with its periphery. But ***(Rule 2)***, *if the central place of area B is spatially contained within area A, then area B is redefined as a subarea ("son") of area A. Its hierarchical level is that of area A plus 1. If two (or more) central places are included within each other's areas, the competition is determined randomly.*

Cells. The membership state of cells is defined according to transition ***Rule 3:*** *If cell "i" is located within, or adjacent to, a given infrastructural object and its type A neighbors exceed a certain proportion (e.g., more than 50%), cell i will be defined as belonging to type A.*

In a typical simulation, some landowner agents build residential buildings while others commercial buildings, industrial buildings and so on. In the simulation presented below, we assumed a city with residential and commercial buildings only, when the residential buildings are of 1- or 3-stories high, while the commercial buildings are of 5- or 7-stories high. If an agent's location attempt succeeds, the result is a change in the city's 3D structure as well as a recategorization of the city's infrastructural objects; if it fails, the city's 3D structure remains as before. Some typical results of such a simulation are presented below.

18.4 Results

Figure 18.6 describes four snapshots from the scenario as it develops on the screen. The central map shows how the built-up landscape of the city evolves, when the red and gray colors indicate commercial buildings of 5 and 7 stories high, while the dark- and light-blue colors indicating residential buildings of 1 and 3 stories high, respectively. The *upper-left* map shows the parallel evolution of central places, while the *bottom-left* map shows the evolution and spatial distribution of agents' s-cognitive maps. The latter process is described in graph form in Fig. 18.7 (*bottom, left*). Figure 18.7 (*top, left*) shows the evolution of the city's b, that is, its evolving rank-size distribution, and Fig. 18.7 (*top, right*) the hierarchical structure of the city – the evolution of hierarchical levels of Areas, first degree subareas, second degree subareas and so on. Fig. 18.7 (*bottom, right*) shows changes in the number of residential and commercial buildings in the city.

Looking at the main map of Fig. 18.6, one can see, first, that the cognitive considerations operating in CogCity give rise to an "ordinary" city form with dominant centers, subcenters, residential areas and all the rest. This is significant as no economic considerations were active in the simulation. And yet, the resultant urban process and form still make full economic sense. This raises the rather interesting issue noted above concerning the relations between cognitive heuristics

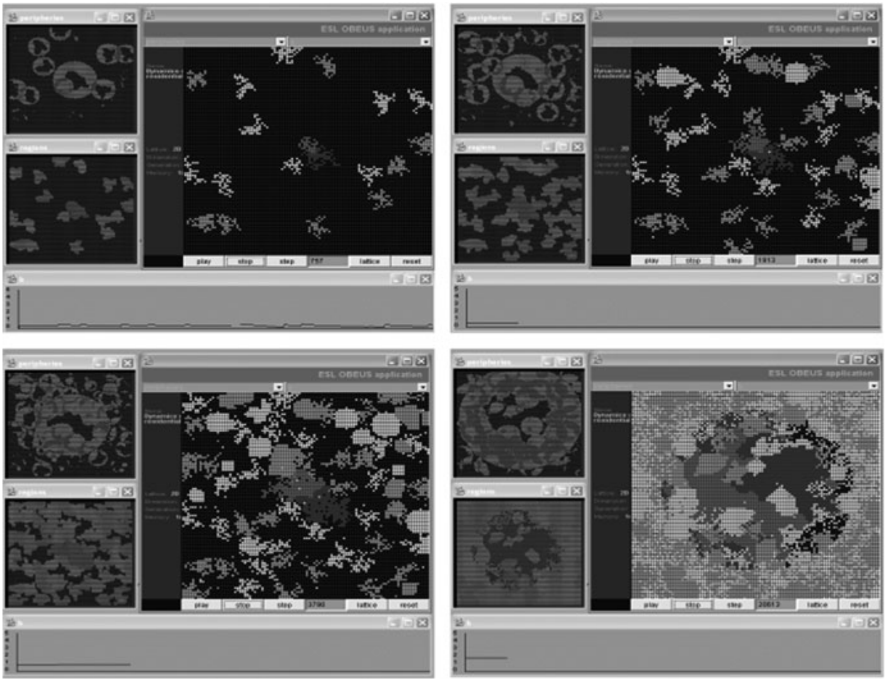

Fig. 18.6 Preliminary result from CogCity – the maps: the *central* map shows how the built-up landscape of the city evolves; the *upper-left* map shows the parallel evolution of central places, while the *bottom-left* map shows the evolution and spatial distribution of agents' s-cognitive maps

and economic rationality in processes of decision making at large (see Chap. 19 below).

Second, the map in Fig. 18.6 (*top, left*) show how the structure of the city evolves – its central places, their peripheries, areas, subareas etc. Observing this evolutionary process by reference to the city's parameter *b* in Fig. 18.7 (*top, left*) and to the number of hierarchical levels in Fig. 18.7 (*top, right*), it can be seen that the process evolves as a typical self-organizing system: following a short period of strong fluctuations at the start of the process (up to iteration 3500 –/+), the city evolves in a logistic manner and stabilizes on 1.6 <*b*> 1.8.

Third, as in the city game (Fig. 18.2 and Figs. 7.7 above) here too agents take location decisions on the basis of their c-cognitive maps representing, as they are, the agents' past experience in cities. From this follows the property of *self-continuity* (Portugali 2004) that can be observed at two space-time scales of city evolution and dynamics. At a global historical scale it shows up in the phenomenon by which the city of the Middle Ages, for example, represents in its form and structure, in addition to the feudal mode of production of its time, also the city of Antiquity that preceded it. At a local contemporary scale, self-continuity shows itself in the fact that the vast majority of current urban growth, projects and change, essentially extend and

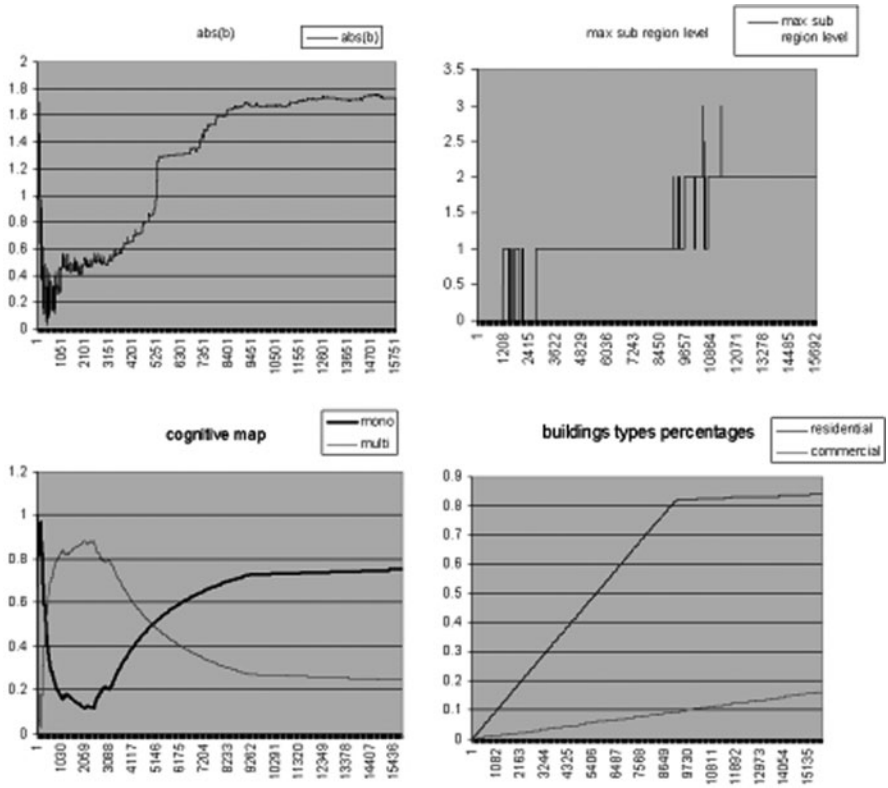

Fig. 18.7 Preliminary result from CogCity – the graphs: *top, left*: the evolution of the city's b – its rank-size distribution; *top, right*: the evolving hierarchy of areas and subareas; *bottom*, *left*: the evolving s-cognitive maps; *bottom, right*: changing numbers of residential and commercial buildings in the city

reproduce the already existing city structure and form. This is so with respect to the growth and change of both "old" and new towns and cities.

The property of self continuity appears also in the present model but not in a trivial manner: The s-cognitive maps, on the basis of which agents take decisions/action, are different from the c-cognitive maps with which they come to the city at the start of the game. This aspect of the process shows up in the *bottom-left* map of Fig. 18.6: despite the fact that all agents arrive at the city with a monocentric c-cognitive map, many of the s-cognitive map, created out of this simulated urban process, are polycentric. Some agents change their perception of, and action in, the city as a consequence of a spatial cognitive dissonance, that is, a relatively large gap between their c-cognitive map and the real structure of the city. Further insight into this process can be gained by looking at the evolving parameter b in Fig. 18.7 (*top, left*), in relation to the evolving s-cognitive maps in Fig. 18.7 (*bottom, left*). The simulation starts with all agents having monocentric c- and s-cognitive maps. Then as a consequence of spatial cognitive dissonance the relative number of agents with monocentric s-cognitive maps decreases and the number of agents with multicenteric s-cognitive maps increases. This trend continues up to about iteration 3500 from which the pendulum changes again and the city with the s-cognitive map of the majority of its inhabitants becomes monocentric.

In terms of synergetics, we can interpret the above process as a competition between two order parameters – monocentric and polycentric. This competition ends when the monocentric order parameter of the city "wins" and enslaves the perception, behavior, and action of the city's inhabitants. Finally, it is interesting to note, in Fig. 18.6 (*bottom, left*), that in the emergent urban landscape the agents are spatially segregated according to their cognitive maps: monocentric agents in monocentric areas and polycentric agents in polycentric areas. That is to say, the above process of self-organization in CogCity gave birth to potentially new cultural groups in the city.

18.5 Concluding Notes

As noted at the outset, the aim of this chapter is to make a first step toward a cognitive approach to urban simulation models. The next steps will include, firstly, the development of CogCity into a full-scale and comprehensive urban simulation model and secondly, the elaboration of some of the issues that where only touched upon here but deserve a much fuller discussion. One such issue concerns cognitive heuristics versus rational economic considerations in decision making in general and in the context of cities in particular. A possible starting point here might be Tversky and Kahneman's (1981) studies on cognitive heuristics in decision making and their synergetic extension and interpretation by Haken and Portugali (Chap. 19 below). The basic challenge here would be to develop an urban simulation model the agents of which take decisions in line with Tversky and Kahneman's heuristics and their synergetic extension/interpretation. Another such issue follows the similarity noted above between core, periphery, etc., as embodied cognitive models in line with Johnson and Lakoff's embodied cognition approach, and the same concepts as they appear in classical location theory. This similarity raises an Occam Razor question: does the universality of embodied cognitive models (that in this respect can be treated as "innate") make the economic location models secondary? That is, specific realizations of the more basic models? Or are the two sets of models independent of each other and thus in the context of cities reinforcing each other? A third issue might refer to the methodological implications of the fact that innate behavior is from the start complex. This might require adding to the currently bottom-up urban simulation models a strong top-down component and developing them as genuinely dual self-organization models. The CogCity model preliminarily introduced above can be seen as a first step toward this aim.

Chapter 19
Pattern Recognition, SIRN and Decision Making*

19.1 Introduction

In this chapter we elaborate on Haken's demonstration that the synergetic paradigm of pattern recognition can be used as a conceptual and mathematical framework for the study of decision making in general and in the context of cities in particular. The elaboration includes an extension concerning cognitive mapping, a reference to Tversky and Kahneman's studies on the psychology of decision making, and a reformulation in terms of the notions of IRN and SIRN as elaborated in Chap. 7. The discussion throughout the chapter follows the above description.

19.2 Pattern Recognition as Decision Making

Our port of departure, as noted, is Haken's (1996, 1998) demonstration that the process of pattern recognition as conceptualized by synergetics is, in principle, a decision-making process: a person, or a computer, is offered part of a pattern which is stored in memory, together with many other patterns. The person/computer is then asked to decide to which of the stored patterns the offered part belongs. The principles here are, first, that the recognizer has to take a decision about a whole pattern on the basis of incomplete partial information on it, second, that this is implemented on the basis of the similarity of the offered part to known stored patterns. According to Haken, this situation is characteristic also of decision making in the context of cities and their planning. In the latter, every decision about a future planned situation is, by definition, taken on the basis of partial and incomplete information, and it is typical that the decision is taken on the basis of its similarity to known situations from the past.

In both cases, pattern recognition and decision making, there is often a gap between the known data and the required data needed to decide upon a specific action (Fig. 19.1). In the ideal case the known data coincide with the required data. In general, however, the known data are insufficient, i.e., there are a certain number of unknown

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*by Hermann Haken and the author.

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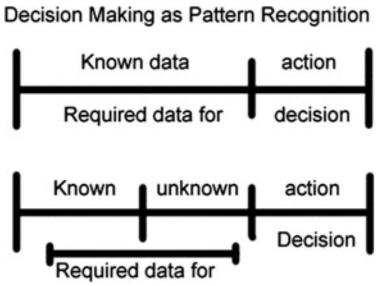

Fig. 19.1 In the *upper part*, the known data coincide with the required data for taking action and making a decision. In the *lower part* the known data are insufficient

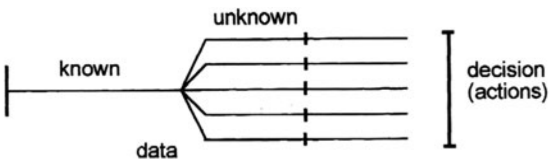

Fig. 19.2 The known data may be complemented in a variety of ways. Each of these ways might entail a different decision and action

data. How do humans fill the gap of unknown data? This is what we want to analyze in the following. A simple though nontrivial example is provided by a tennis player. Some studies show that the player's time for the necessary reaction is too short to allow an analysis of the sensory input data before starting motor action. Thus tennis players have to act on specific clues that are based on their experience and training. But, in general, the problem is still more complicated. Consider to this end Fig.19.2. It indicates that, at least in general, the known data can be complemented in a variety of ways to fill in the gap of the unknown data. Depending on how we fill in the unknown data, different decisions or actions may be taken. This figure is in a sense oversimplified, because even if all the data are known there may still be several decisions that are compatible with all the known data.

How do we (or rather our brain) fill in the unknown data? Our main theme will be that we often rely on a similarity between a given situation and a previous situation. When we want to cast this similarity into a mathematical frame, we have to look for similarity measures (Chap. 14 in Portugali 2000). Of course, in a nonmathematical way we may rely on analogies or metaphors. A number of psychological factors are of importance here, such as awareness, attention, bias, and beliefs. When we take seriously the analogy, which we shall discuss below, with pattern recognition, we can expect time-dependent choices as in the case of ambiguous figures. This implies that we make decisions that show oscillations, or in the course of time there may be random choices. In more detail, we propose to draw the following analogies between pattern recognition and decision making (cf. Table 19.1). In decision making the data correspond to patterns treated in pattern recognition. The data may be quantitative or they may consist of specific rules, laws, or regulations. They may be in the form of algorithms, or when we think of computers, in the form of programs or flow charts. Diagrams may also be considered as constituting such data. In pattern recognition the patterns may consist of pictures or of the arrangements of objects. The patterns may be visual or acoustic signals.

Quite often these patterns are encoded as vectors, which may be constant or time-dependent. Of course, in decision making the data may be multidimensional.

So far we have been discussing the analogy between the objects dealt with in decision making and in pattern recognition. In both cases the prototype patterns or the sets of known complete data may be learned or given. Incomplete data in decision making have their analogy in pattern recognition in the form of incomplete test patterns. How can we exploit this analogy to study decision making? In analogy to pattern recognition we may introduce a similarity measure, for instance, the overlap of prototype patterns and the test pattern. We can then establish a dynamics that is based on the similarity measure and may also include bias, attention parameters, or awareness. So, from a formal point of view, the whole procedure that we encounter in pattern recognition may be transferred to a scheme describing decision making (for mathematical details cf. chap. 14 in Portugali 2000).

What will be the consequences? They are listed up in Table 19.1. In pattern recognition and in decision making, we may find a unique identification and a unique decision, respectively. But in a number of cases we may be confronted with oscillations between two or more precepts, or between two or more decisions. These oscillations are not unusual in our daily life, as everybody knows. Here we can trace them back to a fundamental mechanism of the human cognitive abilities.

Table 19.1 Correspondence between the elements and processes of pattern recognition and those of decision making (after Haken 1996)

Pattern Recognition	Decision Making
Patterns, pictures arrangement of objects, visual and acoustic signals, movement patterns Actions (Often encoded as vectors)	Data, quantitative and/or qualitative; rules, laws, regulations, algorithms, programs, flow-charts, diagrams Orders multi-dimensional in short: data
Prototype patterns learned or given	Sets of known complete "data" learned or given
Test patterns	Incomplete data in particular "action" lacking
Similarity measure Dynamics Bias Attention, awareness	$\rightarrow$
Unique identification or Oscillations between two or more percepts	Unique decision or Oscillations between two or more decision
Hysteresis ……	Do what was done last time even under changed circumstances
Complex scenes, saturation of attention	Failure, new attempt based on new decisions

A very important analogy arises when we look at the hysteresis effect as analyzed by the synergetic computer in the context of pattern recognition (Fig. 19.3). Translating this effect into decision making means the following: A person does what he or she did last time even under changed circumstances.

The analogy between pattern recognition and decision making can be carried further. In pattern recognition we usually deal with complex scenes such as the well-known 'vase or faces' ambiguous pattern (Fig. 19.4). The synergetic computer

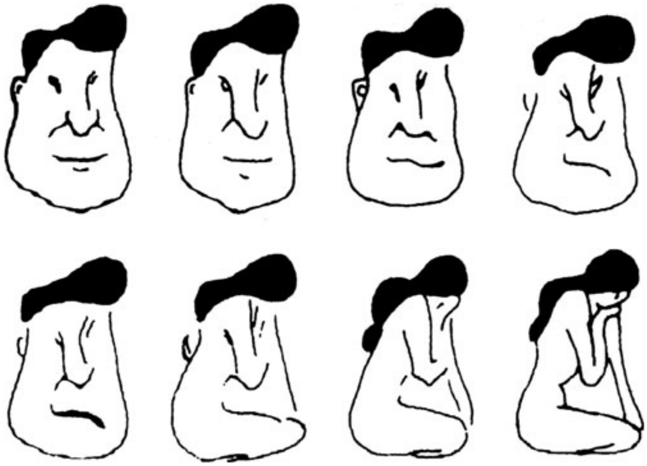

Fig. 19.3 Hysteresis in pattern recognition. When the sequence of figures is visually scanned from the *upper left* to the *lower right*, the switch from a face to a girl occurs in the *lower row*. When scanned in the reverse direction, the switch occurs in the *upper row*. As illustrated below, in Sect. 19.4, this might be interpreted as an illustration to the effect of the anchoring visual heuristic in decision making

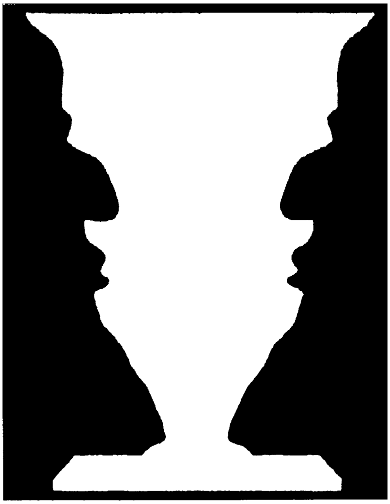

Fig. 19.4 Example of an ambiguous pattern: vase or two faces?

and probably the human brain analyze such a scene by means of a *saturation of attention* and an interplay between internal and external representation as in the SIRN intrapersonal submodel discussed in Chap. 7 above: Once part of a scene has been recognized, we focus our attention on the other externally represented objects. Another such case was illustrated above in Fig. 9.1. In our analysis of decision making, multiple choices correspond to complex scenes and the saturation of attention in pattern recognition, can now be translated as follows: Based on our attention we make a first choice. When we encounter a failure, the attention parameter for that endeavor is put equal to zero. We then make a new attempt based again on our attention for a new kind of endeavor, and so on. Depending on our previous experience there may be a hierarchy of attention parameters through which we work starting with the highest attention parameter. This interpretation is related to the notion of *heuristics* and its use in the process of decision making (Wagenaar 1993). In Sect. 19.4 below we further discuss heuristics in relation to Tversky and Kahneman's psychological approach to intuitive judgment.

Summarizing these ideas we can state that the mechanisms discussed in the case of pattern recognition can be translated into those of decision making. This can be done not only at a qualitative level but also quantitatively at the level of computer algorithms in analogy to the synergetic computer. Quite obviously, our analysis is by no means complete and other strategies may be of equal importance. Artificial intelligence and here especially the approach by expert systems must be mentioned. A problem encountered here is that of branching, where the various branches become extremely numerous and decision making eventually becomes very difficult. We believe that this branching problem can be circumvented by the approach we outlined here, because, as in pattern recognition, the various possibilities are taken care of in a parallel fashion.

19.3 An Extension Concerning Cognitive Mapping

The above view can be extended by adding that the synergetic process of decision making is similar also to the synergetics conceptualization of cognitive mapping (Portugali 1990, 1996b; Portugali and Haken 1992). In both decision making and cognitive mapping, it is typical that a person makes a judgment (takes a decision or constructs a whole image/cognitive map of a city, for example) on the basis of only partial information on it (the consequence of the decision or the structure of the city). Furthermore, in pattern recognition the task of recognition is completed, usually, when the offered partial pattern fully resembles one of the stored complete patterns. In cognitive mapping this is rarely so. The usual case is that, because of size, there is no complete stored pattern, and as a consequence cognitive maps are usually incomplete and their structure and parts are often distorted, vague or unknown (ibid). This is so also with decision making, for the simple reason noted above (Chap. 14) that the future at which the decision is aiming is by definition not fully known. A decision, in this respect, is an action based on a cognitive map of the future.

Cognitive mapping is related to decision making in the context of cities in yet another respect. As noted in previous chapters, one of the most important aspects of cognitive maps is, that it is mainly according to them that people navigate in the environment, choose routes for commuting, decide to leave their homes and migrate to another city, choose a new home, and so on (Portugali 1990; Portugali and Haken 1992). As emphasized in the previous chapter, cognitive maps provide the basis for decision making in the context of cities.

19.4 Decision-Making Heuristics

As noted above, the correspondence between pattern recognition and decision making is related to the notion of heuristics. That is to say, to cognitive strategies, schemata, or models that people tend to employ when making judgement in everyday life. This notion is also the cornerstone of Tversky and Kahneman's cognitive approach to decision making. According to them, when facing complex decision situations with high degree of uncertainty, people tend to rely on a limited number of heuristic principles, which reduce the complex tasks of assessing probabilities and predicting values to simpler judgmental operations (Tversky and Kahneman 1974, p 1124).

In a series of studies conducted during the 1970s they have identified five such heuristics: representativeness, availability, anchoring, similarity, and decision frame (Tversky 1977; Tversky and Kahneman 1971, 1973, 1974, 1981; Tversky and Gati 1978). With respect to these heuristics they further suggested that in general, these heuristics are quite useful, but sometimes they lead to severe and systematic errors (Tversky and Kahneman 1974, p 1124).

Smith and Lundberg (1984) have suggested that these heuristics are typical also of individuals' decision making in the context of cities, whereas Krafta et al. (not published) have integrated them in a model of urban navigation and cognitive mapping. Table 19.2 gives some detail of these heuristics and the way they are relevant to the context of urban dynamics.

While in both the synergetic and the TK (Tversky-Kahneman) approaches to decision-making heuristics play an important role, the two approaches differ from each other in some important respects. In TK there is a separation between judgment, decision and action. In fact, they do not study decisions and actions at all. Apparently, their implicit assumption is that judgment entails a decision and action. In the synergetic approach to decision making, judgment, decision, and action (or behavior) are inseparable – they are elements in a single decision-making system. This property is further elaborated below.

TK is essentially an empirical approach followed by an interpretation that makes use of elementary probability theory. Synergetics, as introduced above, is a theory about complex systems with its own mathematical formalism and modeling

Table 19.2 Seven heuristics and their interpretation in the context of cities. The first five follow Krafta et al. (not published) elaboration on Tversky and Kahneman's heuristics; the last two follow Haken and Portugali (in Portugali 2000, Chap. 14)

Heuristic	Description	Urban Interpretation
Similarity	The similarity of two items is expressed as a function of their common and distinctive features.	Recognition of fundamental rules of urban composition, such as a grid layout, built form or urban fabric, is performed through similarity.
Representativeness	Probability that an object or event belongs to a particular class is judged by the degree to which a description is representative of a stereotype.	Urban categories are identified on the basis of architectural stereotypes, such as church, skyscraper, boulevard, tower, arch, etc.
Availability	Probability of an event, or frequency of a class, is assessed by the ease with which instances or occurrences can be brought to mind, or recall.	Availability would make universal symbols more easily identified and recalled, such as Pizza Hut premises, Macdonald's signs, London pubs, etc.
Decision Frame	The frame that a decision maker formulates of a problem (gain versus loss, etc.) is influenced by norms, habits, and personal characteristics of the decision maker.	Urban frames for decisions (congested versus free, public versus private, etc.) depend on the cultural code of each agent (e.g. a tourist, a taxi driver, a policeman, etc.).
Anchoring	The tendency of people to make estimates by starting from an initial base value that is adjusted to yield the final answer.	City's internal representations can contain certain categories such as style, urban violence, town size, etc., which can be 'fired on' early in the process of cognition; once switched on, it stays on and is only eventually reassessed.
Synergetic I: Collective effects	When facing a complex decision situations people tend to rely on what other people doing or saying.	Drivers, pedestrians, intra- and inter-urban immigrants, tend to 'follow the stream'. That is: to take decisions in line with what others are doing.
Synergetic II: Attention parameters effects	When facing a complex decision situations people often employ several heuristics in a sequence. First, the attention parameter calls into use a certain heuristic. Then, when exhausted, another attention parameter heuristic emerges and so on.	Intra- and inter-urban immigrants, for example, often start with a given location decision heuristic (say, synergetics I); if it doesn't work they switch to an alternative heuristic and so on.

approaches. The synergetic analogy between pattern recognition and decision making thus implies that the decision-making process is a complex, self-organizing, synergetic system. As a consequence, the aim of synergetics is not to study errors in order to identify judgmental heuristics, but rather to model what people really do when taking decisions. Furthermore, while TK consider a solitary decision-making individual, synergetics looks also at collective effects. That is to say, the way individuals' decisions and actions influence each other. This theme too is further elaborated in Sect. 19.5 that follows.

Having stated the differences, it can now be said that some of the synergetic pattern recognition analyses of ambiguous patterns can be interpreted as associated with decision-making heuristics. For example, in the old/young woman pattern recognition case (Fig. 19.5), it was found that men tend to see the young woman first, and only then the old woman. This might be interpreted as a result of a 'visual availability heuristic', similar to TK's verbal heuristic.

Another case is the phenomenon of hysteresis as modelled by the synergetic computer (above, Fig. 19.3). In the context of the present discussion the interpretation might be that the form with which the scanning process starts has the effect of a visual anchoring heuristic. If the scanning of Fig. 19.3 starts from the top-left form, then the face acts as an anchor; if from bottom-right, the girl.

The above two examples will suffice to draw attention to the possibility that a given heuristic might be active in the context of both verbal intuitive judgment and visual pattern recognition. Further similarities with respect to other heuristics can be made but will not be pursued here, as they deserve a separate study. In closing this section on heuristics, however, we would like to add to TK's list two *synergetic heuristics* that are of specific importance in the context of cities.

The first, *synergetic heuristic I*, refers to the fact that when facing a complex decision situation people tend to rely on what other people are doing. This synergetic heuristic is specifically characteristic of cities that in their turn are characterized by intensive interaction and information exchange among the individual agents, and thus exhibit pronounced collective effects.

The second, *synergetic heuristic II*, is associated with the synergetic concept of attention parameter that we have discussed above in connection with the analogy

Fig. 19.5 Young woman or old woman?: an ambiguous pattern in cognition as a 'visual availability heuristic' in decision making

between pattern recognition and decision making. Employing a given heuristic implies activating an attention parameter in a specific way that corresponds to a given heuristic. Once activated, the emerging attention parameter controls the decision process that now proceeds in line with that given heuristic.

This perception has the advantage that it allows one to move from a decision making by means of a single heuristic, to a complex decision situation that might involve the use of several heuristics (again, a situation that TK do not consider). As already noted, this situation is analogous to pattern recognition of a complex scene. Based on a certain heuristic, the decision-maker becomes attentive to a certain aspect in a complex decision situation, and makes a first choice at the problem. If this attempt fails, saturated, or exhausted, a new attention parameter associated with another heuristic becomes active, and so on. What follows is a sequential process of decision making. In the next section we further develop the sequential and collective aspects of decision making in the context of our model of SIRN (synergetic inter-representation networks).

19.5 A SIRN Approach to Decision Making

Figure 19.5 is a graphical exposition of the basic SIRN model now transformed into a decision-making model. Here, the input layer refers to the information available to the decision-making actor, the inner layer of order parameters to the emerging alternative plans, and the output layer to the resultant decision and action. The derivation of this SIRN decision-making model follows exactly the derivation of the basic SIRN model in Chap. 7. For convenience it is reproduced here as Figs. 19.6 to which the decision-making terminology was added.

In this model every decision-making actor is subject to two types of inputs, internal and external. The internal input refers to information, knowledge and planning experience as it is internally represented in the memory (or memories) of the decision-making actor(s); the external input, to the information enfolded in the externally represented environment. The decision-making heuristics discussed above in Sect. 19.4 may appear here as either internal or external inputs. The ‘availability heuristic’ might be an example of a typically internal input, whereas ‘anchoring’, a typical external output. The complex and parallel interaction between these two sets of inputs enters the middle layer that might symbolize a brain, an individual, a city’s planning committee as in Chap. 13, Sect. 13.4, or the managerial board of a firm, in which one or several decision rules, in the form of order parameters, have been established. Note that the same order parameter(s) may govern quite different external outputs, such as a location decision in the city implemented by a resident or a firm, movement in the environment, and the like. The order parameters, decisions and plans of the middle layer produce two kinds of output, again internal and external. The external outputs are the plans in the form of ad-hoc and routinized patterns of action, whereas the internal output is the new

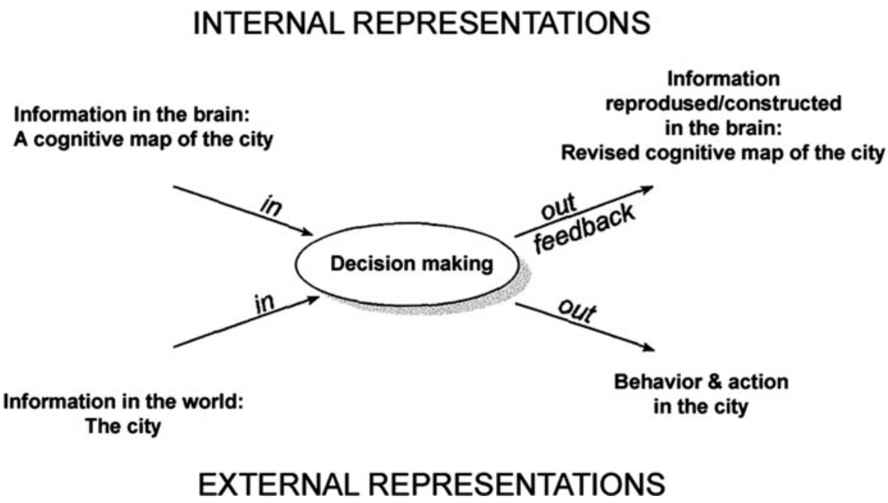

Fig. 19.6 The basic SIRN model (Fig. 7.11) transformed into a decision-making model of an urban agent

experience, information and knowledge which re-enter memory in a kind of feedback process, and become the internal input for the next step in the process.

An important property of this SIRN decision-making and planning model is that the process is sequential in the sense that it is an ongoing, space-time interaction between internal and external representations. Another important property is that it evolves as a typical self-organizing system: at the start, the internal-external sequential process of interactions is characterized by strong or chaotic fluctuations, then a certain order parameter takes over, enslaves the internal and external elements of the system, and from that stage onward, the system evolves in a routinized steady-state fashion. This scenario is typical as we illustrate below of decision making and planning at both individual and collective levels. In Chap. 7 above, we have presented three prototypes of the SIRN model: the intrapersonal, interpersonal and interpersonal with a common reservoir. The first and the last are relevant to the subject matter of this chapter and in the following we reformulate these prototypes as decision making models.

19.5.1 Intrapersonal Decision Making

The intrapersonal process is typical of a decision-making process of a solitary person. Solitary in the sense that no external representation created by another person is involved in the process. An architect designing a building or a planner designing a city, or a part of it, is a case in point. Figure 19.7 graphically illustrates the process and will help to convey ideas. This designer may start, for example,

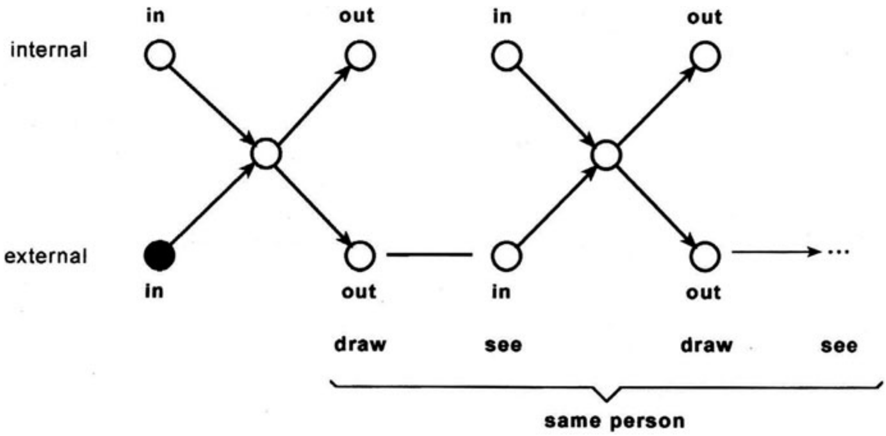

Fig. 19.7 Intrapersonal decision-making process of a person designing a building or a city

with a vague idea internally represented in mind and an externally represented map of the plot or of the city. The first decision might be where in the plot to locate the building, or where in the city to locate a commercial center, for example. Based on the interaction between his or her internally represented information, and the map as an external representation, the designer takes a first decision by putting it on a sketch paper. By externally representing this decision, that is, by drawing it, the person can see 'what it looks like'. The latter provides feedback information for approving the first decision, changing it, and/or moving to the next decision. The latter might be were to locate the living room, or were to locate a central public park in relation to the already "existing" (on paper) commercial center. Once this decision is internally taken and externally put on paper, the designer can move to the next decision and so on in an ongoing interplay between internal and external representations.

The principle in the above example (in fact, in many if not most of creative works) is that the process involves a sequence of decisions and actions at various scales, and that the play between internal and external representations is at the basis of that process. Figures 7.5, 7.6 referring to Picasso's *Guernica* and Brancusi's *Kiss* provide two nice illustrations.

19.5.2 Interpersonal and Collective Decision Making

One of the key features of the notion of inter-representation concerns the fact that once an external representation is produced, it becomes a public domain. For example, whenever a person produces an external representation such as a talk, smile, ... etc., it becomes public domain in the sense, first, that other people can hear, see ... what that person thinks, feels, and so on. That is to say, other people can know or sense some parts and aspects of what is internally represented in that person's head. Second and most importantly, other people can connect themselves to that person's thoughts, feelings and emotions. External representations thus provide an important medium for interpersonal communication and to the emergence of collective phenomena such as language, culture, myths, style, fashion and what is often termed 'collective memory' (Halbwachs 1992).

In developing the notion of SIRN we've made a distinction between three forms of external representation: mimetic, lexical (or linguistic) and stand-alone artifacts. The first two have no existence independent of the biological memories of the people who produce them, whereas the third one has. Stand-alone artificial external representations such as books, stone-tools, city-plans, buildings, cities and the like, have an existence independent of the biological memories that have originally produced them. Applying the above types of external representation to the domain of decision making and planning, one can make a distinction between three types of externally represented plans: mimetic plans which include all decisions and plans that make use of the mimetic capabilities of planners, ranging from a facial expression, through plans that mimic other cities or plans, to routinized patterns of space-time movement. Lexical plans would be all plans the external representation of which is lexical. The plan that emerges out of a planning team's 'brainstorm', such as the case-study discussed in Chap. 13 above, is a case in point here: all members of the team come out of this group dynamics with a shared set of ideas, concepts and categories to which nonmembers have no access. This is so since this lexical plan is fully dependent on the biological memories of the planning team members. Artificial plans are all plans that are artifacts in the sense that they have existence independent of their producers. A planning report that includes data, drawings, maps and text is an example.

In our SIRN decision-making model this dynamics between the personal mimetic, lexical and artificial plans, and the collective artificial plan is captured by the diagram in Fig. 13.1 referring to what has been termed in Chap. 13 *collective planning*. As can be seen, the SIRN process is sequential as before, and proceeds by an ongoing interplay between internal and external representations. The difference is that here the individual's externally represented output enters what Haken and Portugali (1996) have termed a *common reservoir* (Chap. 7), when the latter is also the source from which the individual extracts the externally represented input for the next iteration in this sequential planning/decision-making process. In the context of planning this common reservoir might be the plan and the planning report which emerge out of the SIRN group dynamics of the members of a planning team, and it might also be the structure of the city as a whole and its overall order-parameters plans. In the following we consider three examples that illustrate various aspects of the interpersonal and collective decision-making process.

Consider, first, the decision-making process of a person attempting to buy an apartment in the city. Let us say that this is person 1 in Fig. 13.1. At the beginning the decision-maker, person 1, is subject to two flows of input: internal input in the form of a cognitive map representing some previous experience and knowledge about cities in general and about that city in particular, and, a flow of external input, in the form of apartments' architecture, location and price that the individual encounters. The latter, as can be seen, comes from the city as a common reservoir. Note, that as already mentioned above, the internal flow might often have the effect of the availability heuristic, for example, whereas the external input, of an anchoring heuristic. The ongoing interaction between the external and internal flows of input, ordered and enslaved by the order parameters, which emerge in the process, entails also an interactive interplay between internal and external flows of output. In this sequential interplay between external and internal representations, a certain order parameter, referring to the price, architecture and location of that person's demanded apartment, is determined. That order parameter acts as an anchoring heuristic to subsequent apartments considered by that person.

This example is interesting as it shows that the boundary between the intra- and interpersonal SIRN is not always clear-cut. On the one hand, the above scenario can be interpreted as an intra-personal process: a learning process of a solitary decision maker. On the other, this is also an interpersonal SIRN process; first, since every external input in the process comes from the city as common reservoir, and second, since every act of learning (e.g., looking at an apartments for sale) participates in shaping the demand/supply relations in the city. Once the person buys an apartment, the SIRN process becomes fully collective. CogCity – the urban simulation model presented in the previous chapter – is related to this scenario.

Second, consider now Fig. 13.1 as the decision-making process of a stranger, who is coming to a new city, learns some routes, drives them and after some time becomes an ordinary daily commuter in the city. At the beginning (Fig. 13.1, person 3, *left*, for example), the individual is subject to a flow of two forms of input. A cognitive map, internally representing some previous experience and knowledge about cities in general and about that city in particular, and a flow of external input which comes in, from the city, as the individual advances in the city's space. The ongoing interaction between the external and internal flows of input, ordered and enslaved by the order parameters that emerge in the process, entails also an interactive interplay between internal and external flows of output. In this sequential interplay between external and internal representations, objects and patterns in the external environment are being determined, marked, and internally represented as the IRN of the emerging cognitive map. The output of the first excursion along the route provides part of the input for the second excursion, and so on in iterations.

At the beginning, the individual might try several excursions, or commuting configurations, or plans, which can differ markedly from one another, in terms of time allocation and routes chosen. This is a kind of a trial-and-error learning stage in the planning process, and it is thus often characterized by strong fluctuations between excursion to excursion. Eventually the decision-maker will settle on a certain configuration, which will then become the individual's routinized space-time order-parameter plan for commuting. Once this order parameter is established, it enslaves all other competing configurations and from now on the space-time commuting pattern becomes routinized.

What is typical of the above two examples and of urban dynamics in general, is that the individual decision-makers (persons 1–4 in Fig. 13.1, for example) need not be aware of each other and of the fact that they participate in a collective decision-making/action process that determines the city's land-use structure, its social and cultural structure, transportation structure, and the like. As we have already seen in Chap. 7, individual decisions that are taken locally eventually affect the global structure of the city. This situation of 'nonawareness', or implicit collectiveness, is thus a common property of decision making in the city context.

On the other hand, Chap. 13 above that looks in some detail into the group dynamics of a planning team, represents a case were the collectiveness of the process is apparent and explicit. In the latter, Fig. 13.1 can now be envisioned as a discussion table with four planners sitting around and engaged in a discourse the aim of which is to decide on a given city plan, or urban policy. Each person comes to the table, so to say, with ideas, images, etc., internally represented in his or her memory. As the discourse develops, each person externally represents his or her ideas as an input to the discourse, takes other ideas imputed by other members of the team, internalizes them, outputs new, say integrative, ideas, and so on. The discourse thus becomes a common reservoir of possible decisions and actions to which the participants contribute and from which they extract new information as input and so in an ongoing process.

19.6 An Outline for a SIRN Decision-Making Model

Following the above graphical exposition of the SIRN decision-making process, the next step is to model and thus operationalize it. One way to do so has been outlined in Chap. 17 above in which each individual agent was defined by means of what has been termed as *m-code*. The interaction between agents with their m-codes and between them and the city's infrastructure gave rise to a few cultural groups and to the city's overall structure.

From the perspective of the present discussion we can now add the following: first, that since in the above model the memes-derived cultural groups emerge out of the interaction between individual m-codes, it is possible also to define each cultural group by means of an m-code. Second, that since the infrastructural elements of the city (the cells in the above model) and the city as a whole acquire their properties from the properties of the individuals who live in and around them, it is possible to define each infrastructural element by means of an m-code too.

Now, the m-codes of agents refer to their intentions, wants, previous knowledge, information and so on, that is to say, to their internal representations. In the same manner one can regard the m-code of cultural groups that emerge in the city, the city infrastructure (the cells in the model) and of the city as a whole, as external representations. In both internal and external representations, the m-code will be representing information (such as categories, intentions, plans, etc.) that is enfolded in material objects: in the brain of the agents, in the cultural areas of the city, in its elementary cells and in its overall material structure.

The above formulation by means of m-code, has the advantage that both the internal and external representations can be conceptually and formally described by means of the same units and can thus interact in a meaningful way. In terms of our graphical SIRN models (Figs. 7.10 in Chap. 7) this implies describing the terms for internal and external representations, by means of m-codes. This is shown in Fig. 19.8 that describes a typical decision-maker participating in the interpersonal, collective, decision-making process described in Fig. 19.6 above. As can be seen, this agent is subject to two flows of information: internal, which comes from internal representations in the mind, and external, which comes from external

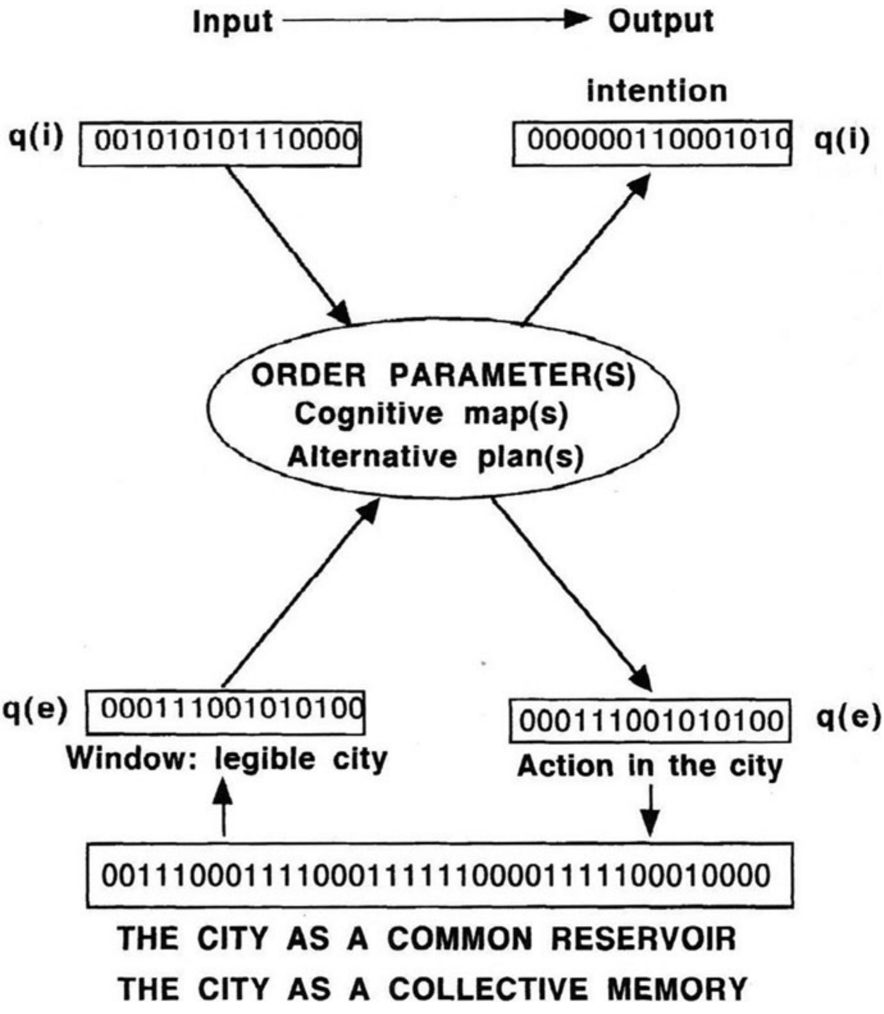

Fig. 19.8 A SIRN model of a typical decision maker participating in the interpersonal, collective, decision-making process, when all representations, internal, external, private, and collective, are described by means of m-codes

representations in the city. Both forms of representation, or sources of information, are defined by means of m-codes: the whole city as an externally represented ‘common reservoir’ or ‘collective memory’, q(i) – the term for internal representations, and q(e) – the term for external representations. As before, q(i) and q(e) refer to both input and output. Note, however, that as an input q(e) is termed also “legibility window”. That is to say, it is that part of the city as a collective memory and a common information reservoir that is legible to the decision-making agent. In the original formulation (Haken and Portugali 1996) we have termed it a ’personal window’ and symbolized it by W(k); the notion ‘legibility’ is borrowed from Lynch’s (1960) *The Image of the City*.

As illustrated in Fig. 19.8, the interaction between internal and external representations gives rise to order parameters, which as suggested below in Chap. 20, can be interpreted as cognitive maps. In the context of the present discussion, the order parameters can be interpreted as alternative decision rules, or plans, and as such as cognitive maps of the future. As can be further seen in Fig. 19.8, the order parameters as plans imply two forms of output, again internal and external. An internal output that feeds back to newly shaped information, intentions, etc., stored in memory and external output, which is behavior and action in the city. The latter might be a move to a new apartment, or office and the like. “Action in the city” participates in the city’s dynamics, that is to say, in the interaction between the many other such actions taken in the city, and between them and the city’s physical infrastructure. These synergistic interactions give rise to order parameters at the scale of the whole city which then enslave the various elements of the city and their m-code, from which individuals extract their legibility window and so on. The result is a complex process of circular causality between self-organizing systems at two scales: the scale of the individual decision-making agent as a self-organizing system, and the city as a whole as a self-organizing system.

In Chaps. 17, 18 above (and in Portugali 2000, Part II), we have simulated and studied some aspects of this complex circular causality by means of our FACS City models, and have used synergetics as a conceptual-hermeneutic framework. In Haken and Portugali (1996) we have indicated how SIRN can be cast into the formalism of synergetics. In this chapter we have re-interpreted SIRN as a decision-making model and suggested how, by the use of m-codes, it can be integrated with our FACS models. What remains to be done is to implement the outline suggested here as a full-scale formal decision-making model. A step toward this aim is presented in the next chapter.

Chapter 20
Decision Making, Conflicts and Time in a Synergetic City*

20.1 Introduction

This chapter extends and elaborates on ideas presented in the previous one. In particular we address the question how urban agents, e.g., persons or families, may take decisions about occupying specific locations in the city. This decision has to agree with an attractiveness function between agents and locations. While this appears a standard question of most if not all complexity-driven urban simulation models, the procedure outlined here is innovative by several means. First, in line with our claim in Part II that cities are dual complex systems, and in line with the notion of SIRN, the model presented in this chapter treats every individual agent in the city as a genuine self-organizing system. Capitalizing on the concepts of synergetics, the behavior of each agent is described by an order parameter that emerges as a result of interactions between the agent's internally represented properties and aims, and the externally represented properties of locations in the city. Second, it explicitly implements the competition between agents as well as the (more abstract) competition between the available flats at the various locations in the city. The model shows how the competition between agents and flats simultaneously affects the attraction between them or, more colloquially speaking, the attractiveness of flats. Third, it explicitly considers changes in time in that the competition between agents over locations, as well as the attractiveness of locations to agents, is time-dependent. In more general terms, presented below is a dynamical model that searches for the optimal distributions of urban agents over locations. The model maximizes the global attractiveness of the ensemble and accounts for various conflicting situations. Its solutions show that, depending on initial conditions, both optimal as well as suboptimal configurations can be reached.

Before going into details we start with a short reminder of the principles of synergetics (Sect. 20.2) with special emphasis on the so-called assignment problem that in the present context is being applied to urban dynamics (Sect. 20.2.1). Section 20.3 presents the just mentioned decision-making model to study the process of agents' choice of locations in a city. Sections 20.4 and 20.5 employ that model as

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means to explore the interrelations between agents and locations emphasizing conflict, competition and time-dependent processes.

20.2 Synergetics – A Reminder

The interdisciplinary field of synergetics provides a unifying approach to understand how the cooperation between the individual parts of a system under study leads to macroscopic patterns or coherent structures (Haken 1983a, b). For the present discussion, distributions of different populations over a city should be viewed as examples of such macroscopic patterns that emerge through the interaction between their generating components, i.e., agents and flats. That is, a synergetic approach generally attempts to illuminate explicit relationships between the behavior of individuals at the ‘micro level’ (agents/flats) and the emerging patterns at the ‘macro level’ (distribution in or shape of the city). For this sake synergetics builds on the profound concept of order parameters, which represent macroscopic patterns, and are generated in a self-organized fashion through the so-called slaving principle, which says that the individuals follow the order parameter once it emerges. The slaving principle hence formalizes the relationship between the macro level (order parameter, i.e., distribution of population) and the micro level (individual structures, i.e., agents/flats). We note, firstly, that while the goals of synergetics are closely related to those of dissipative structures (Allen et al. 1985), its fundamental concepts, such as order parameters and the slaving principle, are alien to the dissipative structure approach (that rather originated from thermodynamic concepts such as entropy production etc., and the Turing instability). Secondly, that the concept of synergetics contrasts concepts such as discrete automata or master equations (Weidlich and Haag 1988) as the latter typically ignore differences between micro and macro levels. The synergetic approach to problems of settlements and cities has already been outlined in Haken (1998) and in Chap. 19 above. Here we want to contribute further to the domain of synergetic cities (Chap. 4) and explicitly focus on the interplay between decision making of agents at local scales (micro level) and collective optimization at a scale of the city as a whole (macro level). To this end we sketch a mathematical model that describes the occupation dynamics of locations in the city by urban agents.

We assume that a certain distribution of urban units (flats, offices, etc.) is available and that these units have a specific attractiveness to various agents (individuals, households, firms, etc.). For the sake of simplicity we focus on individuals and households in their search for flats, keeping in mind, however, that our approach is also applicable to other urban agents (e.g., firms, planning agencies and the like) and other land uses. We start by attributing an *attractiveness* of a specific urban unit (e.g., flat) to a specific agent (e.g., customer) in form of a single parameter. The problem to be solved then is to find an occupation that contains the highest total attractiveness. Interestingly, this problem yields conflicts. For example, one location may seem equally attractive to two or more agents, but only one of them can occupy it, whereas the others will have to settle for a less attractive location.

20.2.1 The Assignment Problem

The problem of location occupation relates to the so-called *assignment problem* in discrete optimization, where, for instance, jobs are assigned to machines in a factory. There the functioning of the entire system (machines, times, jobs) can be quantified by its total costs that ought to be minimized meaning that, in turn, the factory's efficiency is maximized. Traditionally, the latter problem is solved by using discrete algorithms since discrete units need to be assigned to each other (i.e., a fixed set of jobs and a fixed set of machines). A first important step towards mapping this problem to the framework of synergetics has been made by Starke (1997; see also Haken et al. 1999; Starke et al. 1999), who demonstrated that the so-called synergetic computers can be extended to the assignment problem. Synergetic computers are dynamical systems designed to perform complex computations by employing a profound analogy between pattern formation and pattern recognition (see Haken 1991; and Chaps. 4 and 7 above). Recall that the formation of patterns can often be described as a competition process between several macroscopic structures whose contribution to the actual state is quantified by order parameters. In terms of synergetics, this is thus a competition between order parameters. One of those structures or order parameters wins the competition by suppressing the others, resulting in a certain macroscopic state, i.e., the formed pattern. Interpreting these structures as prototypical patterns of stored data, an equivalent competition of the corresponding order parameters can be used to classify an initial state, for example, a presented test pattern, by complementing its best-fitting prototype. Such a system 'generates' information for partially given input features, that is, it acts as associative memory applicable for pattern recognition (for details, see Haken 1991). In a similar way, Starke considered specific assignments as patterns that strive for an optimal solution. That is, the competition between the corresponding order parameters yields an optimal global state. In Starke's approach, however, the realization of an explicit assignment depends exclusively on initial conditions for the selection process that finally determines the resulting costs. A decisive step further was taken by Haken (1998; see also Chap. 19 above) who included the cost or attractiveness functions in the differential equations that describe the development of the assignment or occupation. Indeed, the model below is based on this approach, which was originally suggested for the treatment of decision making in the context of cities.

The following sections will illustrate how attempts of individuals for local and global optimization evolve simultaneously. As we will show the system tends to acquire its globally optimal state by mere construction. By the same token, the individuals try to make their own decisions, so as to optimize their own (local or micro) attractiveness function. Each individual decision must, however, agree with the actions of all other individuals – a property that gives our model a strong collective and thus social dimension. Therefore all participants appear in permanent competition. We shall see how the individual path from a yet undecided state of a person changes into a final realization. The identical global optimal values can be achieved by different realizations of occupancy. It also turns out that the time at which a decision is made plays an important role.

20.3 The Model

Daffertshofer, Haken and Portugali (2001) and Daffertshofer (2008) developed and extended mathematical forms that formalize all the above issues. This section provides a descriptive account of these models (interested readers can find the full mathematical formalism in the above two papers).

The model includes agents who come to the city attempting to find an appropriate location (e.g., an apartment) and locations with various levels of attractiveness to agents. Both agents and locations are dynamical quantities, i.e., they (or the attraction between them) change over time. The actual state of the entire system – city – is given by a set of (abstract) variables ξ_{ij} that indicate the relations between each agent i and location j. The variables ξ_{ij} serve as the aforementioned order parameters, i.e., they describe the macroscopic state of the agents/location compound, and the city is thus described as a set of order parameters. In particular, $\xi_{ij} = 0$ corresponds to the situation in which agent i does not occupy location j, whereas ξ_{ij} larger than 0 but smaller than 1 is interpreted as *tendency* of agent i to occupy location j, and, if location j is occupied by agent i, the corresponding order parameter acquires the value of $\xi_{ij} = 1$. In a sense, ξ_{ij} describes the affiliation of the agent to a certain location or vice versa.

As noted, the treatment of agents in this model is in line with the perception of cities as dual complex systems and as such in line with the SIRN decision-making model discussed in the previous chapter. Every agent is treated as a complex self-organizing system. In the formalism of synergetics this is revealed by the fact that each agent is described by means of an order parameter. Furthermore, in line with the collective SIRN submodel, each agent is subject to internal information (its intentions) that comes from its mind/brain and external information that comes from the city.

Assuming that a location can only be occupied by a single agent and every agent can only occupy a single location, the time evolution of every order parameter should reach a steady state, and an optimization hence implies a certain distribution of affinity levels of agents to locations. The mathematical formalism of this process involves two simultaneously evolving competition processes both between agents and between locations. The entire dynamics of this process is (at least) four-dimensional and as such cannot be visualized as a whole. A common solution in such cases is to use two-dimensional subspaces that can still illustrates the essence of the process. This is done in Figs. 20.1 in which the system's evolution is viewed as movement of a ball that rolls in an over-damped fashion along the landscape to its closest minimum. In Fig. 20.1A–C, each location is symbolized by a valley representing a local attractor for every agent. Figure 20.1A describes a situation

Fig. 20.1A Evolution of two order parameters (ξ_{ij}) in a *potential* landscape (the *ordinate*). Each minimum of this landscape represents an attractive location *j* for every agent *i*. Under sufficient initial conditions each subject (ball) will relax to its closest minimum (location = flat) without interfering with one another

Fig. 20.1B Evolution of two ξ_{ij} that are close to each other. Both systems will relax to the same minimal point. Here, this minimum corresponds to an attractive location to both agents (e.g., a flat with low cost value), that is, the minimum is deeper than the minimum of the neighbor

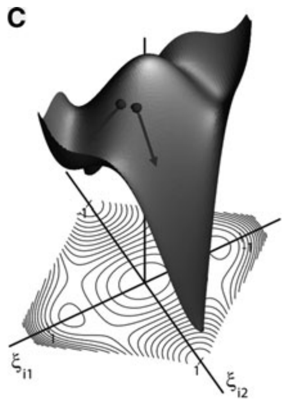

Fig. 20.1C Evolution of two ξ_{ij} in a *potential* landscape. With fixed index *i* each minimum of that landscape represents an attractive flat

by which due to appropriate initial conditions the agents will not interfere with each other and in consequence of the competition between the locations j each agent will select one attractive location j. However, when the agents come close to each other, they will be attracted by the same location. This situation occurs very often if the locations differ considerably in their value (e.g., cost) so that one or a very few locations remain significantly more attractive than the others (Fig. 20.1B).

On the other hand, the closer the agents the more they compete with each other. Accordingly, they repel each other so that for one agent the former low-cost location/flat becomes unattractive. When we visualize this evolution the costs of a certain location are effectively increased because of the competition between subjects (see Fig. 20.1C). However, this effective change in the shape of the potential landscape should not be taken too literally because we can only sketch this shape in a two-dimensional subspace. Indeed, the potential is highly degenerated. Nevertheless, various aspects of the dynamics can be easily viewed such as the location $\leftrightarrow$ agent attraction as well as its effective variation owing to the agent $\leftrightarrow$ agent (or location $\leftrightarrow$ location) competition.

20.4 Simulation Results

To show the major properties of the dynamics especially in the case of large populations we integrate the system for $N = 20$ agents and $M = 60$ locations and with two or three different sets of locations: expensive, average, and cheap. Accordingly, we expect solutions in which, if possible, only the cheap locations will be occupied whereas the expensive ones remain vacant. Because the dynamics is 1200-dimensional, we define a sufficient data reduction in terms of an appropriate visualization. This is realized in Fig. 20.2, in which every urban location j

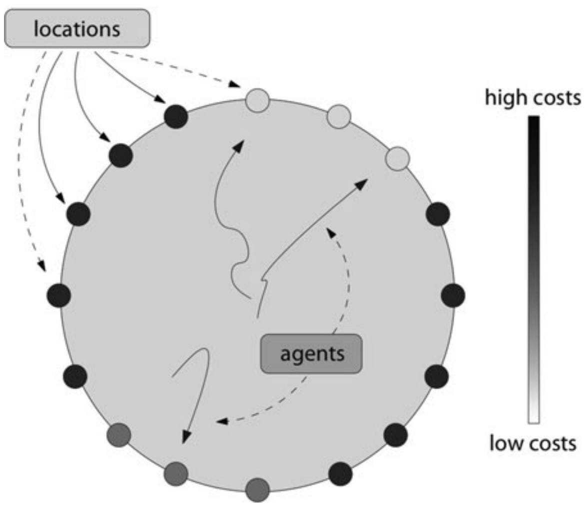

Fig. 20.2 The to-be-found locations are depicted along the unit circle in which the agents' evolutions are shown as trajectories. The locations' costs are color coded from green to red, i.e. low costs to high costs, respectively

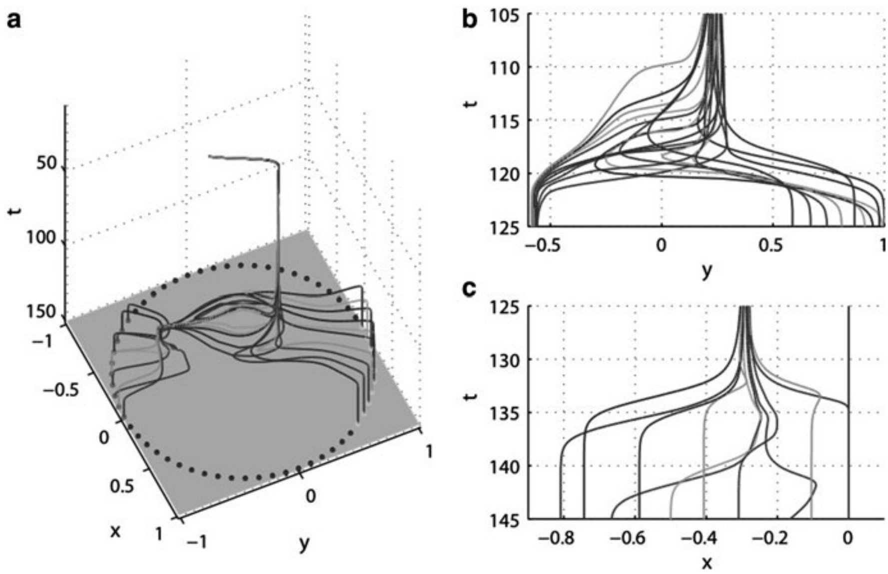

Fig. 20.3 Evolution of ξ_{ij}. In (a) every location j is represented as a sphere placed along the unit circle at [Xj, Yj]. The color of each sphere indicates the location's actual costs (red = expensive, green = cheap. The trajectories show the subjects' paths in the course of time t. Panels (b) and (c) are projected sections of the evolution focusing on the time intervals that include the decision process. With similar initial values all $\xi_{ij}(t)$ stay close for quite some time and tend to the locations with lowest costs (right-hand side). Then they split in two steps (b,c) and reach the low-cost locations (see text)

is symbolized by a small dot along the unit circle and each agent's evolution is given as trajectory. To stress the dynamical aspects and to be able to identify areas of competition we further use time t as the third dimension (for instance, areas where the two states ξ_{ij} approach each other in Fig. 20.3. To discuss the properties of the settlement dynamics let us start by focusing on what is certainly the most important characteristic of the system, that is, the selection and occupation of the lowest cost locations.

The resulting evolution is shown in Fig. 20.3 where the locations have three different cost values such that most locations are expensive, some others are cheap, and a few are even cheaper. Initially all agents tend to the locations with lowest cost values and stay very close to each other; see the initial shift of all trajectories to the right-hand side in Fig. 20.3a. This initial trend is followed by a first discrimination step after which the locations with the lowest cost values become occupied (Fig. 20.3b). The remaining agents redirect toward locations with the next lower cost values, compete for a while (Fig. 20.3c), and finally they split to occupy one location each. Thus, with almost identical and unbiased starting positions, the dynamics results in a unique detection and optimal occupation of locations. The cost parameters act as dynamical constraints for the selection process; that is, they determine which locations will be occupied. The explicit assignment between agents and preferred locations, however, remains random dependent on the initial distances between agents because the dynamics allows for arbitrary individual permutations.

Next, we enhance the conflicting situation by favoring a certain location. [Respecting the impacts of the costs of locations, we realize this new emphasis in terms of initial distances.] Apparently, the smaller the distance between a specific agent and a location, the more attached that agent will be to this location and the more likely it is that that agent will occupy this location. We exploit this fact and generate an initial bias to a given location which does yield the aimed-for conflict. That is, we choose the initial values of the order parameters (that define agent-location relations) in such a way that all subjects have an initial trend or minimal distance to that location. As a consequence, the affiliation of agents to all other locations becomes lower. As shown in Fig. 20.4 successive discrimination processes can resolve this conflict given that the order parameters differ for each agent-location pair. We note that all the subjects are lined up in direction of the preferred location (see below). Although for all agents their individual distances are minimal for the preferred location, which, in addition, is very attractive owing to its low cost value (Fig. 20.4a), the agents switch to alternatives after one individual has won the initial competition; see yellow trajectory at the right-hand side of Fig. 24.4a. Despite the nearness of the attractive area (right-hand side in Fig. 20.4a), at first all subjects move from there owing to the competition between themselves (the individuals are too busy with the competition and do not realize the optimal direction). After a while the agent, which was initially closest, reaches the optimal location. The alternatives open to the others include locations with higher cost

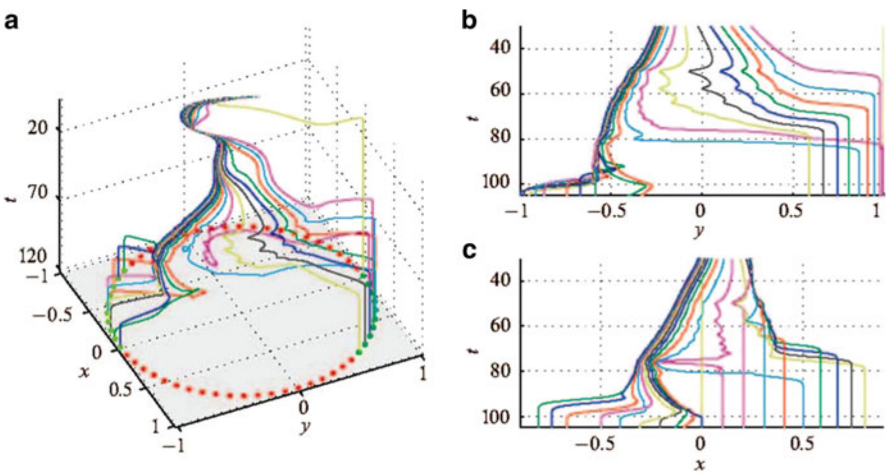

Fig. 20.4 Evolution of ξ_{ij}. One location is emphasized (see text) but finally only one agent with the smallest initial distance can reach it. Two agents in the center then tend to the slightly higher costs (left-hand side) but reorient to the right; cf. (c). The purple trajectory shows slight oscillations because of competition with the others

values owing to the effective change in the actual potential. But in the course of time the low-cost locations are detected and occupied, as in Fig. 20.3.

Next we treat the case in which all starting positions differ from each other because the evolution is a deterministic process. As already indicated above, in the absence of additional fluctuations two or more states that have identical (initial) values will always follow the same route. Put differently, in the case of equal values the entire system will reach any stationary point, irrespective of whether it is a minimum or a saddle point of the potential. In order to avoid such steady states at the saddle points even in the case of identical (initial) values, we now add tiny fluctuations to the dynamics that, consequently, becomes a stochastic differential equation. This additional stochasticity can be interpreted as intrinsic variability or flexibility of agents and locations. Even in a steady state each individual remains somewhat fuzzy, or he or she is always attempting to explore his or her neighborhood. As an immediate consequence, we can now allow for identical initial conditions because the permanent fluctuations guarantee that two states will never remain the same (see also, Bressloff and Roper 1998). Figure 20.5 shows the evolution in the case of equal, nonvanishing order parameters values, which is basically comparable with Fig. 20.3. Subjects, whose starting positions agree exactly, split and find an optimal and low-cost flat. Apart from the possibility for such identical initial values, the additional randomness accelerates the discrimination. Hence, an increase in individual flexibility or variability supports the solution of conflicts or competitions.

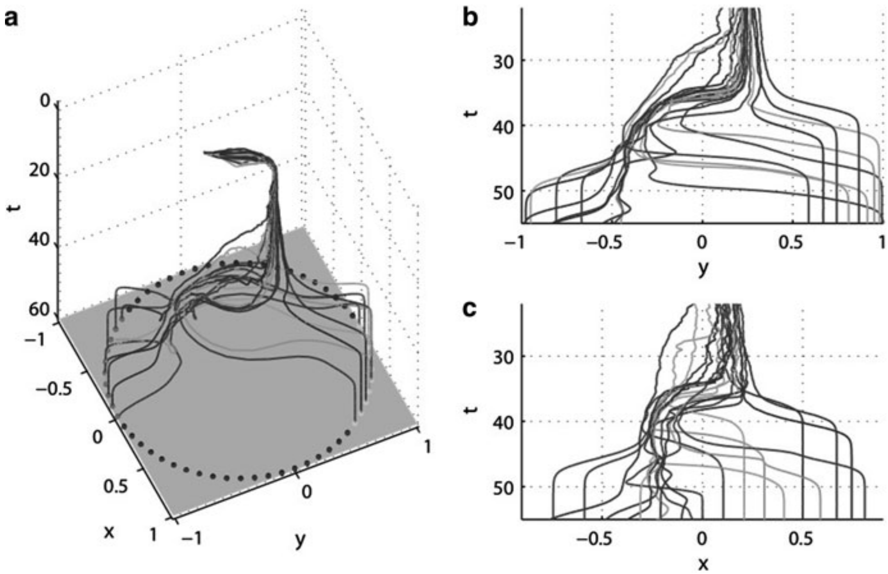

Fig. 20.5 Evolution of ξ_{ij}. In contrast with Fig. 20.3, here all initial conditions are identical, but owing to the fluctuations the ξ_{ij} values can be discriminated so that they finally relax to the low-cost flats. Compared with Fig. 20.3 the conflicting situation is resolved much quicker

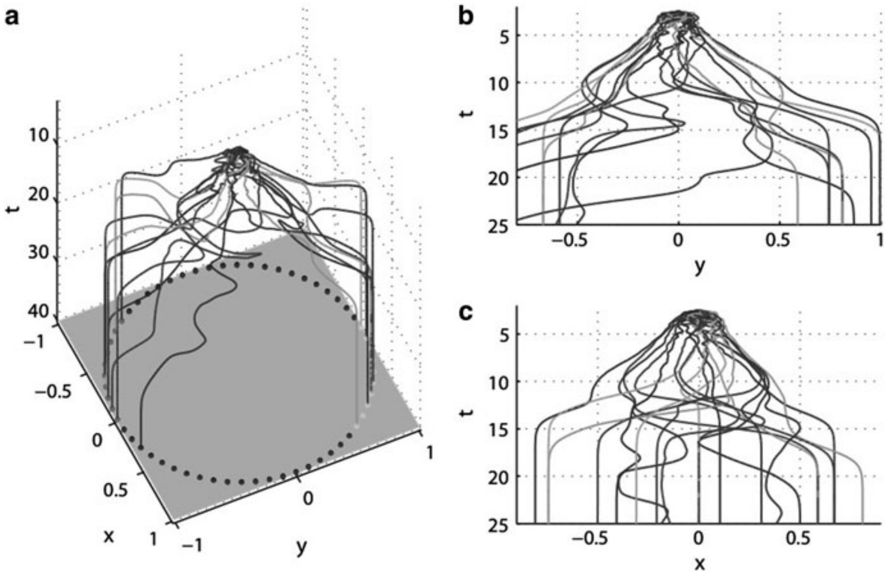

Fig. 20.6 Evolution of ξ_{ij}. In contrast with Fig. 20.5 all initial conditions vanish. The conflict is increased so that one subject decides to pay a higher price; blue trajectory in panel (a)

For the fully unbiased initial state of absence of any initial preference, however, we expect a very competitive situation (Fig. 20.6). The situation of complete absence of any initial preference means that the initial fluctuations assume great importance. In fact, the very first random step can generate such a large distance between an agent and the locations with low costs that locations with much higher costs will be occupied. The dynamics can reach stationary states at local minima, that is, the agents cannot find the globally optimal solution (Fig. 20.6) because it is beyond their horizon. In principle, the possibility of existence of these spurious states can be reduced by methods that adjust the noise strengths depending on the actual state of the system (for example, simulated annealing). For instance, if an agent is trapped in an unwanted local minimum its fluctuation strength can be increased to enable an escape from that valley. Metaphorically one might say that this subject has to become more flexible and has to look behind the wall that surrounds him or her. According to Chaps. 17, 18 one would argue that such an agent enters a state of cognitive dissonance and as a consequence might either leave the system (the city) or else change his or her m-code and/or set of preferences.

Another interesting feature of our model follows from a further enhancement of conflicts. For this purpose, we again modify the initial values in analogy with Fig. 20.4 but avoid preference for any location other than one. That is, we create a situation by which all agents will only try to reach one location (see Fig. 20.7 *Right*). The enormous task to differentiate this dominating initial trend towards this single location can no longer be managed by the competition between agents. Consequently, various locations become occupied by more than one agent. Again, the systems are

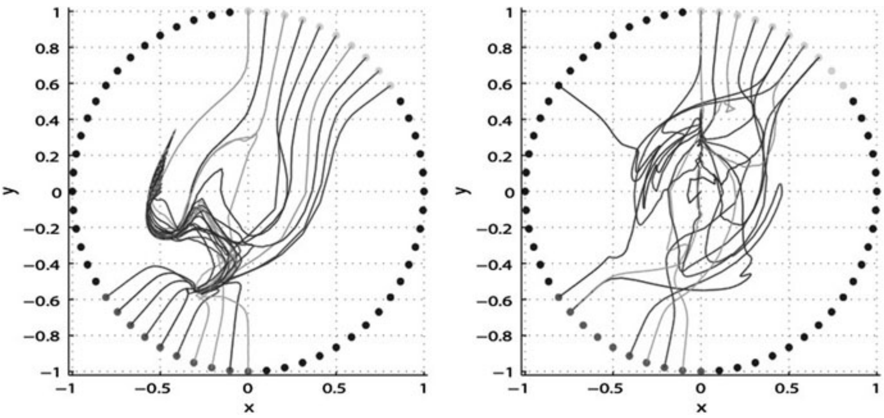

Fig. 20.7 Evolution of ξ_{ij}. On the left-hand side we have chosen the same initial conditions as in Fig. 20.4 leading to the desired location occupation. However, if no further initial tendency to the other location is given (see text), then various conflicts cannot be solved (*Right*). As a result, various locations (e.g., flats) are finally shared

trapped in local minima, which now correspond to some location-sharing communities. This solution can, however, be avoided by an increase of the competition strength between the subjects.

So far, we have always assumed that the number of low-cost locations is identical to the number of agents. As shown above, the entire system typically relaxes into its optimal state. The question arises of what happens in the case in which the number of low-cost locations is smaller than the number of agents wanting to occupy them. With our previous results the answer to that question can be found immediately: the low-cost locations will become occupied. As there is no additional preference for the other locations, the remaining agents will choose one of the more expensive solutions, as shown in Fig. 20.8. Interestingly, after the initial rapid occupation of the low-cost locations, the subsequent decision process requires a relatively long time. The agents who cannot find a free low-cost solution decide to go to randomly chosen, less preferable locations. Therefore they have many more opportunities and the decision process is longer. In a sense, the final states are still optimal because they are steady.

At first sight, the phenomenon of double or even multiple, occupancy of locations noted above seems to be in conflict with our mathematical model, which in its original formulation excludes such cases. It should be noted, however, that this rigorous constraint was replaced by the introduction of a cost function, with which, in principle, multiple occupancy is compatible. In practice, this means that the cost function represents an additional burden to people because of multiple occupancy. The reality of cities indicates that ‘multiple occupancy’ can take at least three basic forms: flat sharing, flat repartition, and ‘squatting’. In the first form, several individuals or families share a flat that was designed originally for a single person or a family. This solution is typical of, for example, the ‘guest workers’ community at the center in Tel Aviv and similar cases in other cities. Consequently, the poorest

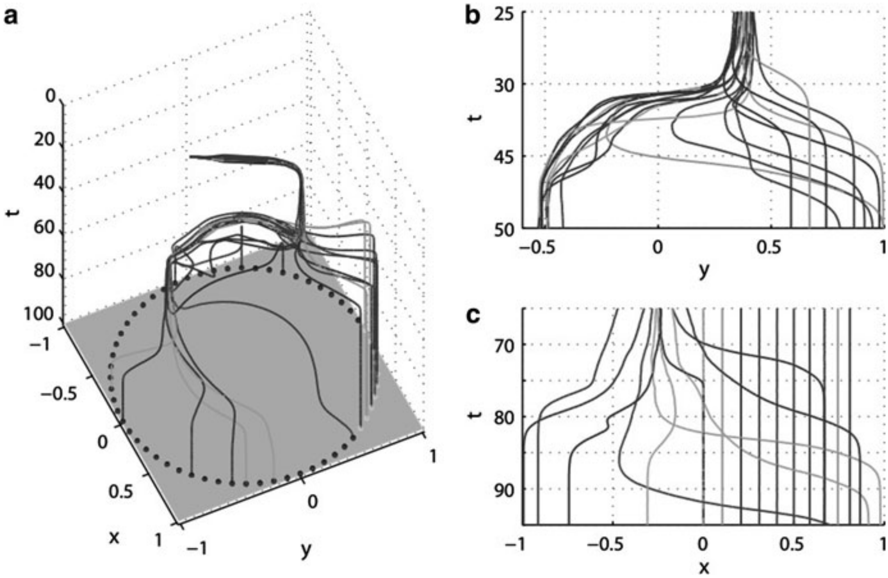

Fig. 20.8 Evolution of ξ_{ij}. Given the same parameter settings as in Fig. 20.5, the number of low-cost flats is smaller than the number of subjects. Thus, only a few can find optimal solutions whereas the remaining ones randomly choose other flats

people live on the most expensive land at the center of the city. The second solution, repartition, implies, as the name indicates, that a single flat is subdivided into two or more flats. This typifies processes of gentrification, for example, where 'yuppies' are prepared to pay high prices for relatively small flats at the center of the city. The third solution is common in many developing countries in which the poor people, who immigrate to major cities, cannot afford to buy or rent flats of the required size. Hence they squat in vacant areas in between residential areas, often in or near the center of the city. Note that each of these solutions implies a structural change in the city: the flat-sharing and the squatting solutions lead to a change in the socio-cultural spatial composition of the city, and the repartition solution leads to a change in structure of its housing stock.

20.5 Time-Dependent Costs, Neighborhoods, and Dynamic Clusters

In more realistic settings the costs of locations are rather unlikely to be constant quantities. Apart from external changes that will not be pursued in the present chapter, the actual state of occupancy may immediately affect the attractiveness of locations. To model this specific type of parameter changes, the dynamics is extended in terms of dynamic cost parameters that we here denote as $C_{ij}(t)$. In view of the literal meaning of costs and occupation it seems reasonable to concentrate on the case in which the costs increase if a location is occupied. The corresponding dynamics implies that the actual costs are adjusted by the occupancy of the locations due to 'fatigue' or 'boredom': the longer an agent stay at a location, the less attractive it becomes. Because of the ξ_{ij}-dependency of the attraction dynamics, the cost eventually starts oscillating – a dynamics which is in complete analogy to the evolution of the attention parameters in the realm of synergetic computers which allows for oscillating percepts; cf. ambiguous patterns (Ditzinger and Haken 1989, 1990). The result is continuous jumps of agents to other locations as shown in Fig. 20.9.

In extension to these switches one can also introduce some spatial constraints. That is, the actual locations' costs are modified to depend on their (immediate) neighborhoods' states – as in AB and CA USM (above Chaps. 17, 18). The resulting dynamics, depicted in Figs. 20.10 and 20.11, shows similar transitions like Fig. 20.9, but accounting for the costs of the neighborhoods. Alternatively, local features can be introduced by means of explicit vicinities: attraction of a certain area is increased if a reasonably large occupancy is present. In consequence, initial oscillatory patterns eventually damp out and the ensemble gathers in a bounded neighborhood with, ironically, highest costs. Thus, the dynamic change in attraction between agents and locations can yield dense colonies despite repelling forces between ensemble members. Of course, if the repelling force is altered to become attractive, agents will also stay together when moving through space.

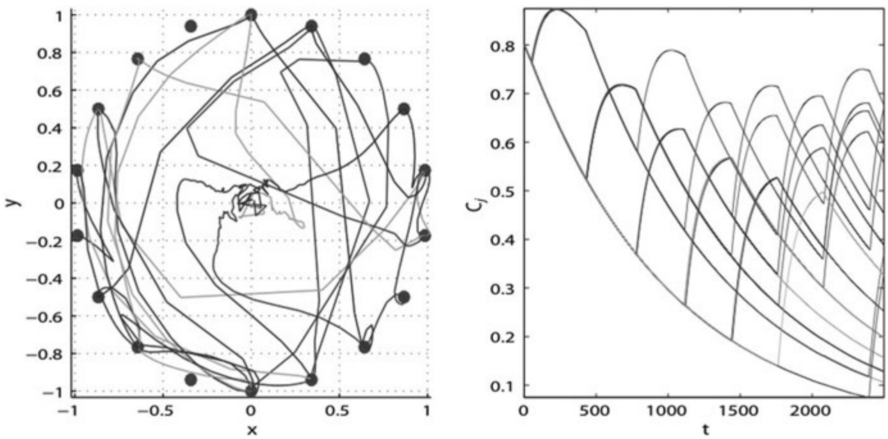

Fig. 20.9 Evolution of ξ_{ij} given time-dependent costs. The figure shows the resulting switches from agents between the different locations (*left panel*) as well as the evolution of the cost parameters (*right panel*). After an initial increase the cost parameters oscillate corresponding to the alternating occupation of the locations

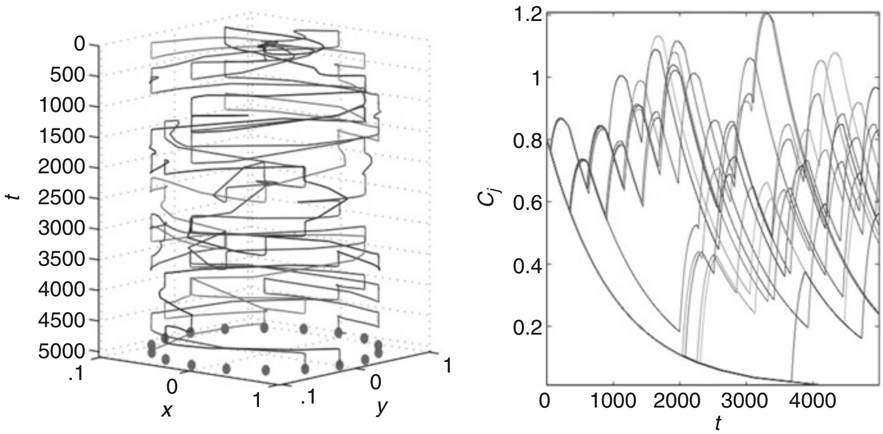

Fig. 20.10 Evolution of ξ_{ij}. The neighborhood includes five left and right neighbors resulting in large jumps (*left panel*). The costs (*right panel*) show a similar behavior compared to Fig. 20.9

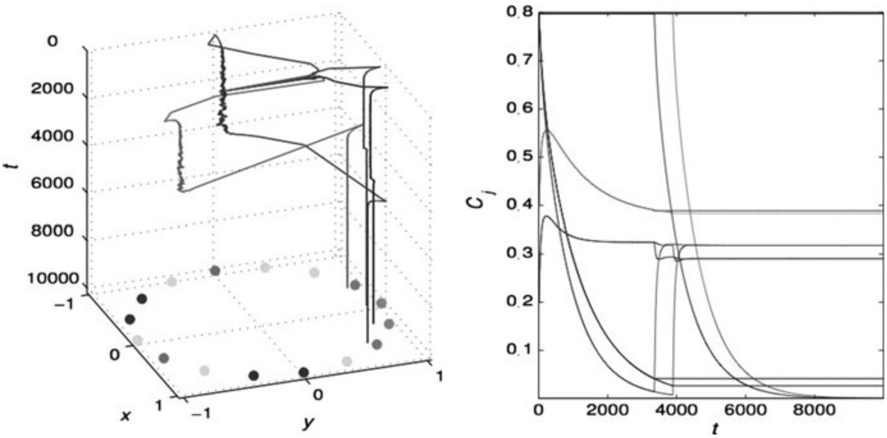

Fig. 20.11 Evolution of ξ_{ij}. The vicinity includes only a left and right neighbor. Initially, four locations have low costs and are occupied immediately. After some time the two 'lonely' agents undergo critical fluctuations and finally join in the neighborhood

20.6 Conclusions

In the present chapter we discussed a model that covers decision-making processes of agents in their search for a location in the city. Decisions basically result from competition between agents and between locations and typically lead to globally optimal occupation distributions. Even though this model should be viewed as a top-down approach because we start off with the evolution of order parameters, we have taken a first step towards the underlying micro level by introducing cost functions that are interpreted in terms of affinity levels. In general, however, order parameters have to be considered as complex macroscopic variables, in this case by means of affiliations between agents and locations. Affiliation is of course an intrinsic feature describing the relationship between locations and urban agents. Focusing on the individual urban agent, one may therefore say that the dynamics of the order parameters shows the evolution of the agent's intrinsic or cognitive maps when solving the problem of location occupation – note that the dynamics does not necessarily distinguish between evolving agents and evolving locations, but we consider the agents to be the actors rather than the locations. In this sense, each order parameter describes an internal mental map which is linked to the expectation of agent i to find location j. Owing to the dynamical representation we can therefore follow up the change of these mental maps over time leading from uncertainty to certainty. It might be a challenge to link our approach with approaches of action theory, which is, however, beyond the scope of the present chapter and book.

A number of general conclusions can be drawn from our approach. For an individual it seems to be important to make his or her decision early enough in the case of conflicts. Although in a number of cases the collective of people finds an optimal solution, there are various instances in which the collective solution is suboptimal. There is a delicate interplay between the values of the attractiveness function and the constraints and it is thus interesting to see what happens if these constraints are made weaker. As noted above, in such a case, multiple occupancy, repartition, or squatting will be allowed – situations that are quite common in overcrowded cities. Here, our model is only a first step towards a more comprehensive approach connecting cognitive maps of individuals with global patterns of occupancy.

The sequential nature of the decision-making process in the model is closely related to the Haken and Portugali conceptualization of decision making in the context of SIRN (synergetic inter-representation networks, see, Portugali 1996, 1999; Haken and Portugali 1996). According to the latter, each decision-making agent in the city is subject to two forms of input information: 'internal', or from the mind; and 'external', or from the city. Their interaction gives rise to an order parameter that can be interpreted as the cognitive map according to which the agent takes its location decision in the city.

The action that follows this decision changes the city, which in turn affects the agent's cognitive map (compare with 'circular causality', Haken 1991, 1996). In the next step of our research, we intend to integrate the model developed here with the SIRN model and add to it an explicit consideration of the urban space.

Concluding Notes: Complexity Theories of Cities at the Gate of the 2010s

Which of the two approaches[1] will dominate the future self-organizing cities, is hard to say; my personal inclination is, as you can guess, toward the second approach. But this might equally well be my personal wishful thinking and probably, in order to know better, we will have to wait for another book on Self-Organization and the City which will appear, say, toward the end of the 1st decade of the 21st century (Portugali 2000, p 336)

These are the two concluding sentences of *Self-Organization and the City* (SOCity) that came out ten years ago (Portugali 2000) and here we are in 2010 with “another book” on cities as complex, self-organizing systems and its title this time is *Complexity, Cognition and the City* (CCCity) – the book we are now concluding. CCCity can be seen as a continuation of SOCity; firstly, in its attempt to apply complexity theories to cities, secondly, in the sense that three of its twenty chapters are an extended and revised version of chapters in SOCity, and thirdly, in the sense that the above two sentences that some ten years ago concluded SOCity are to some extent the sentences with which CCCity opens. Ten years ago I’ve referred to them as ‘two approaches’ in the present book I’ve extended the perspective and refer to them in terms of Snow’s two cultures that dominate science and dominate also the study of cities in general and of cities as complex systems in particular. In the study of cities these two cultures show themselves in the gap between the first culture of cities that attempts to transform the study of cities into a science of cities similar to other “pure” sciences such as physics or at least economics, and the second culture of cities that suggests that cities differ fundamentally from natural entities and as such should be studied from basic principles of social theory that perceives them as first and foremost social products. In the more specific domains of complexity theories and CTC, Snow’s two cultures show themselves in the qualitative and quantitative messages of CTC.

According to the quantitative message, cities and systems of cities are similar to many other material and organic complex systems and as such “obey” similar quantitative regularities such as fractal structure, nonlinearity or power law

[1]The first approach claims that the theories of complexity and self-organization will teach us how to predict and control the complexity of our cities; the second approach claims that cities are complex systems and as such uncontrollable (See Portugali 2000, pp335–6).

J. Portugali, *Complexity, Cognition and the City*, Understanding Complex Systems, DOI 10.1007/978-3-642-19451-1,

distribution, and can thus be described by general simulation models such as agent based, cellular automata or graph theoretic network models. According to the qualitative message, cities and systems of cities are indeed similar to many other material and organic complex systems and "obey" similar quantitative regularities, however, beyond these similarities cities differ from material and organic complex systems in two interrelated respects: in the brain and mind of their agents and in the fact that cities are artifacts. From the conjunction between these two properties follows that cities are *dual complex systems* in two important respects: First, in that each of their parts is itself a complex system; in this respect they differ from material parts but are similar to other species. What separate urban agents from other species, however, is their capability to produce artifacts – small and personal such as tools or jewelry, and large and collective such as cities. The production of artifacts is probably the most prominent expression to the fact that unlike other species we humans are subject to two evolutionary processes: biological and cultural. As a consequence, unlike other species in which the complexity of the parts can be methodologically ignored, in the case of humans this is possible only up to a certain limit; beyond that limit one has to take into consideration the feedback effect of artifacts on human behavior – in the case of cities the impact of the city on human behavior.

These ideas are elaborated in some detail in Chap. 5 whose title is "Complexity theories of cities have come of age: achievements, criticism and potentials". In that chapter it is claimed that so far CTC have concentrated on, and exhausted, the first message and potential of complexity theory and that it is time to move forward and elaborate on the second message and potential of complexity theories to cities: on the cognitive uniqueness of urban agents, on the city as a collective artifact and consequently, on the possible role of CTC as a link between the two cultures of cities. This book can be seen as a step toward this aim. Thus Part II made the links between complexity, spatial cognition and the city. This was done by introducing SIRN and by studying the implications to Shannonian and semantic information to the nature of the city as a cognitive category, and as a complex artificial environment. Next, Part III examined city planning from the perspective of the two cultures of cities and the conjunction between complexity and cognition. From this latter perspective it was shown that planning is at once a cognitive capability of humans as individuals and collectivities. Finally, Part IV studied the implications to urban simulation models.

Each of the four parts of the book and each of its chapters is essentially a starter and an invitation the aim of which is to illuminate the potential, and each thus awaits further elaboration. My personal inclination and intention is to further elaborate on the following issues: Firstly, on information and the city – an issue that I study in collaboration with my colleague Hermann Haken. Two of the chapters in Part II (Chaps. 8, 9), on the Shannonian and semantic information of, and in, cities, are based on our collaborative paper (Haken and Portugali 2003), while the notion *information adaptation* mentioned towards the end of

Chap. 9, is based on our not-yet published collaborative study (Haken and Portugali, in preparation b).

Another research area on which I'm working in collaboration with Hermann Haken concerns the dynamics of extreme events in cities and the implied notions of *self-organized integration* vs. *self-organized disintegration* (Haken and Portugali, in preparation c). The rapid process of urbanization that world society currently undergoes – the fact that more that 50% of the world's population lives in cities, and the fact that the process is still advancing very fast, already made cities more vulnerable than ever before to natural and artificial disasters. Natural disasters such as the tsunami in South- East Asia, hurricane Catherina in New Orleans, the recent earthquake in Port-au-Prince, Haiti, are tragic recent reminders to this fact and an indication that with the advance of the urbanization the vulnerability of cities will further increase. In our study, we try to look at two interrelated aspects of the process – human behavior in cases of extreme events and the possible impact of the event on the dynamics of cities. From the perspective of complexity theories this latter issue is challenging for the following reason: Most studies in complexity were and still are interested in a process we term *self-organized integration*. That is, the process of "order out of chaos" by which local interaction between the parts gives rise to an emergent global order. Now, phenomena of extreme events are associated with the reverse process, namely, the process by which a system in steady state, dominated by a given order parameter, suddenly disintegrates. We term this process *self-organized disintegration* and explore, study and model its dynamics (Haken and Portugali, in preparation c).

Last but not least is a research domain that concerns complexity, cognition, city planning and *urban design*. It is a challenging research domain, for one thing, because the notions of complexity and self-organization are often interpreted as the exact opposite of planning and design. Already in SOCity we've demonstrated that this is not the case – that complexity and self-organization imply a different view of planning, namely, that plans and planners are not rulers of, but rather participants in, the overall urban dynamics. In the present book we've extended this view by adding to it the cognitive component. In Part III above we showed that planning is a basic capability of humans and started to explore the implications thereof to planning as a profession and to the overall dynamics of cities. The next step would be to add design or more specifically *urban design* into the picture. Doing so immediately raises a whole set of new questions that concern, on the one hand, the relation between planning, design and the production of artifacts – small like buildings and large like neighborhoods, cities and mega-cities. On the other hand, urban design will probably introduce into the discourse on complexity theories of cities issues of esthetics and creativity that are part of design.

Which of the above research directions will dominate is hard to say; probably, in order to know better, we will have to wait for another book on Self-Organization and the City, or on Complexity, Cognition and the City, or with a third title, which will appear, say, toward the end of the 2nd decade of the 21st century . . .

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