1. Cities, complexity and beyond

Juval Portugali

1.1 CITIES AS COMPLEX SYSTEMS

Two notions form the title of this handbook – cities and complexity. The first, cities, refers to a form of settlement and way of life that emerged some 5500 years ago and since then has proved to be among the most stable institutions created by humans. Cultures, empires, states and political regimes rose and fell while cities adapted to all transformations and continued to exist. The twenty-first century is to a large extent the Age of Cities: cities have become the most dominant form of human settlement and way of life as more than half the world's population live in cities. The study of cities can be traced back to antiquity, for example, to first-century BC Vitruvius and his ten books on architecture – *De architectura*. However, a starting point of the modern study and science of cities can be seen in Johann Heinrich von Thünen's (1826 [1966]) *The Isolated State* that opens with 'Imagine a very large town at the centre of a fertile plain'.

Similarly to cities, notions of complexity can be traced back to antiquity, to ancient philosophy – 'no man ever steps in the same river twice, for it's not the same river and he's not the same man', wrote sixth-century BC philosopher Heraclitus of Ephesus and with this sentence preceded a basic property of complexity – 'far from equilibrium', namely, that complex systems are always changing, never at rest. However, the complexity we are dealing with here is much younger, referring to a set of theories that started to appear in the 1960s in order to study open and complex systems that exhibit phenomena of selforganization, chaos, and so on. With the exception of Humberto Maturana's *Autopoiesis* theory (Maturana and Varela 1973), these founding complexity theories were first developed in the material sciences (physics, chemistry, and so on) closely linked to thermodynamics: Prigogine's dissipative structures (Prigogine and Stengers 1985) which started from the notion of entropy with close association to fluid dynamics (for example, Bénard's convection), Haken's (1983) synergetics that commenced from the phenomenon of light amplification by stimulated emission of radiation (LASER), chaos theory of Lorenz (1972) and Feigenbaum (1983), Mandelbrot (1983) who expanded the Cantor (1883) set from the nineteenth century into the fractal theory of today, and more. For further details see Chapter 2 in this volume.

In association with the appearance of the above founding complexity theories a link was made with the study of cities. First as a metaphor to convey the distinction between a complex system that is open to its environment and a classical material system that is closed to it. 'The classical formulation [of entropy] due to Clausius refers to isolated systems exchanging neither energy nor matter with the outside world', said Nobel Laureate Prigogine (1977) in his Nobel lecture; and then he asked and answered: 'Are most types of "organizations" around us of this nature?', [that is, characterized by thermodynamic equilibrium?]. '[T]he answer is negative. Obviously in a town, in a living system, we have a quite different type of functional order.' This link to 'a town' did not come out of the

blue: during the 1970s, Herman and Prigogine (1979) put forward a ‘Two-fluid approach to town traffic’ that represents traffic flows in a town, city or metropolitan area.

As far as I am aware, the first to transform the city from a metaphor to a material dissipative structure to a city as a complex system, and thus to trigger the emergence of complexity theories of cities (CTC), were Peter Allen and M. Sanglier in a paper suggesting a ‘dynamical model of a central place system . . . derived from the concepts underlying dissipative structures, takes into account the self-organizing aspects of urban evolution, and shows the importance both of chance and of determinism in such systems’ (Allen and Sanglier 1981, abstract). This early association between a complexity theory and the dynamics of cities was rather ‘smooth’ since several of the early classical theories of cities, specifically from the German tradition, were theories about latent complex systems – forerunners to some of the basic properties of complexity. Thus, von Thünen (1826 [1966]) studied the interaction between a town and its agricultural environment, Auerbach’s (1913) (rank-size) ‘law of population concentration’ created the ground for the current power law and urban allometry/scaling studies, while the urban landscapes of the central place theories of Christaller (1933 [1966]) and Lösch (1954) had all the properties of a system approach and of fractal cities, decades before the appearance of Bertalanffy’s (1969 [2003]) *General System Theory*, Mandelbrot’s (1983) fractal theory and Batty and Longley’s (1994) *Fractal Cities*. Denise Pumain (2009; Chapter 7 in this volume) has termed these processes a ‘spiral cumulativeness of knowledge’ that characterizes social sciences, implying that ‘new interpretations are never entirely new’ (Chapter 7 in this volume).

1.2 CITIES AS COMPLEX ADAPTIVE SYSTEMS

Parallel to the emergence and development of CTC in the 1980s, while students of cities were busy applying the founding theories of complexity to cities, a new view on complexity came to the fore: the complex adaptive system (CAS) (Gell-Mann 1994a). It followed, and was the creation of, the formation in New Mexico, USA, of the Santa Fe Institute in the mid-1980s. The new property added to the complexity discourse was adaptation, a concept associated with living systems ranging from biology through brain dynamics, cognition, society, culture and politics to artificial intelligence (AI) and A-life. As a consequence of this multiple association,

the term CAS has different meanings for different researchers . . . Some of us speak of ‘artificial life’ or ‘artificial social life’ or ‘artificial worlds,’ while others, of whom I am one, prefer to consider natural CAS and computer-based systems together. The latter include methods for adaptive computation as well as models and simulations of natural CAS

wrote Murray Gell-Mann (1994b, p. 17), Nobel Laureate in physics 1969, one of the founders of the Santa-Fe Institute and the person who added ‘adaptation’ to the language of complexity.

Complex adaptive systems entered all levels of CTC: at the local level, each urban agent was now perceived as a CAS whose behavior and action is a particular form of adaptation to the socio-economic and/or morphology of the urban environment; both in

real urban situations and in urban simulations, for example, in agent-based urban simulation models. At the mezzo urban scale, the city itself became a CAS that has to adapt to its global environment – the metropolis and the urban system. Urban planning and design became forms and tools for/of adaptation again at the local (Chapter 17 in this volume) and global (Chapter 16 in this volume) scales. Complex adaptive systems also play a central role in studies about urban resilience (for example, Meerow et al. 2016): a city's resilience depends on its adaptation capabilities, to changing environmental conditions, shocks and extreme events.

1.3 CITIES AS HYBRID COMPLEX SYSTEMS

Unlike the general tendency in complexity studies to start with analogies, CASs started by looking at, and searching for, a difference: what is the difference between a material and organic complex system? The answer, as noted in the previous section, was adaptation. Adaptation is a basic property of all organic systems and in order to include organic entities under the umbrella of complexity theory, one has to extend the theory's boundaries.

Complexity theories of cities have successfully applied the material as well as the organic/CAS versions of complexity theories to cities as noted previously and, as is evident from the chapters in this handbook, the study of cities has greatly benefited from these applications. However, can complexity theory benefit from the study of cities in the way that it benefited from the study of organic systems that are characterized by adaptation? Can the study of cities contribute to, and enrich, the general theory of complexity in the manner that CASs did? To do so we have once again to search for the difference: is there an ontological difference between natural – material and organic – complex systems and a city as a complex system? My answer is (Portugali 2011, 2016): natural complex systems – material and organic – are composed of natural parts; cities are composed of natural and artificial parts – they are thus hybrid complex systems.

Artifacts are 'facts of art' – products of human intention, imagination and action; whether they are artistic entities, socio-cultural organizations or machines. Modern science started with 'the world as a clockwork' – the machine as a metaphor for the natural universe at large (compare Marshal and Green's Chapter 4 in this volume). The generality of this mechanistic world view that dominated science for more than 200 years was falsified at the beginning of the twentieth century following Einstein's relativity, quantum theory and, more recently, complexity theory. What was falsified was not the existence of a mechanistic domain, but its generality, namely, the view that its basic properties apply to nature, society and culture. Despite the differences between the theories of relativity, quantum and complexity, they share a common property that differentiates them from mechanistic world views: non-causality: With machines, once you have all the 'ifs', you can, in principle, know all the 'thens'; with complex systems this is not so. Some say that this is because technical limitations in that complex systems have so many parts (for example, a human brain) that identifying all 'ifs' is technically not possible. However, in principle, if it was possible, then determining the 'thens' would be possible. Some (myself included) say that this is ontologically so – there is no limited number of 'ifs' and 'thens'; complex systems are inexhaustible.

1.4 CITIES, COMPLEXITY AND COGNITION

1.4.1 Bounded Rationality

Perceiving urban agents as CASs and cities as hybrid complex systems, compels us to explicitly consider the agents' cognition, motivation, behavior and action. A common approach is to follow classical economics and regard each urban agent as a perfectly rational, self-interested, utility and/or profit maximizer, *homo economicus* that possesses complete information. In an attempt to soften the perfect rationality of the *homo economicus*, Herbert Simon introduced the notion of bounded rationality that replaces the 'global rationality of economic man with the kind of rational behavior that is compatible with the access to information and the computational capacities that are actually possessed by organisms, including man, in the kinds of environments in which such organisms exist' (Simon 1955, p. 99). From this perspective, in the context of urban simulation models, the urban agents as utility or profit maximizers are now replaced by utility or profit satisfiers urban agents (Manson 2006; Hatna and Benenson 2007). Alternatively, in the context of urban design: 'more often than not design deals with *ill-defined* requirements and wicked problems (Buchanan, 1992; Rittel and Webber, 1973). As a consequence, the designer acts under conditions of *bounded rationality* . . . and thus has to accept nonoptimal *satisficing* solutions' (Portugali and Stolk 2014, p. 832, original emphases).

1.4.2 Heuristics

Simon's bounded rationality was formulated in relation to decision making in the context of economics and public administration, yet it contains psychological and cognitive elements. Indeed, at a later stage these elements were fully extended by cognitive psychologists Amos Tversky and Daniel Kahneman's (1974, 1981) studies on the role of heuristics as regards human behavior and decision making under uncertainty. In 2002, Kahneman received the Nobel Prize in Economics for his work with Tversky (who died in 1996), for integrating economic analysis with fundamental insights from cognitive psychology, thus laying the foundation for a new field of research. According to Tversky and Kahneman, when facing complex decision situations with a high degree of uncertainty (that is, ill-defined planning situations), people tend to rely on a limited number of heuristic principles (rules of thumb) that usually work well yet often entail distortions. They have identified five of these heuristics: representativeness, availability, anchoring, similarity and decision frame.

As *The End of Certainty* – the title of Prigogine with Stengers' (1997) book – indicates, uncertainty, which is at the core of Tversky–Kahneman heuristics, is also a fundamental property of complex systems. Also, in several previous studies (Portugali 2000, 2011), a link was made between Tversky–Kahneman heuristics, complexity theory and urban agents' decision making in the context of cities and planning, as well as to the notion of SIRM that is discussed in section 1.5 in this chapter (compare Chapter 6, this volume).

1.4.3 Cognitive Maps

The straightforward approach to explicitly take a position on agents' cognition, behavior and motivation in the context of cities is to consult the cognitive science – *The Mind's New Science* (Gardner 1987) that emerged in the mid-1950s out of a collaboration between several disciplinary domains including psychology, philosophy and AI. Tversky–Kahneman heuristics is only one example of the insight gained by adding to CTC a cognitive dimension. Other examples concern, first, the role of Tolman's (1948) cognitive maps in urban agents' decision behavior and action in cities. Adding cognitive maps to cities and complexity, we realize that 'the map is not the territory' (Korzybski 1933), namely, that there is a gap between the city, the city perceived and the city imagined, and that human behavior in cities is determined much less by the city compared with the perceived and imagined cities. As regards the city perceived, studies on 'distortions in cognitive maps' (Tversky 1992; Portugali 2011, 2018) indicate systematic gaps between the measured cartographic maps and the perceived cognitive maps. They further indicate, that human behavior in cities is determined by cognitive maps (which is part of complexity).

1.4.4 Chronesthesia

Another example of the insight gained by adding a cognitive dimension to CTC is the cognitive property of *Chronesthesia*, also termed mental time travel (MTT). Originally hypothesized by Tulving (1983) with respect to episodic memory, it refers to the brain's ability to think about – that is, to 'mentally travel' to – the past, present, and future. Furthermore, not only do humans have the capability to mentally travel in time, but they cannot avoid it: 'unlike other animals,' write Killingsworth and Gilbert (2010), humans spend about half of their waking hours 'thinking about what is not going on around them, contemplating events that happened in the past, might happen in the future, or will never happen at all.' Studies indicate (Raichle et al. 2001; Buckner et al. 2008) that stimulus-independent thought or mind wandering is the brain's default mode of operation.

The implications for cities, their planning and their design are far reaching (Portugali 2016, 2020). First, each urban agent is a planner at a particular scale with the implication that urban dynamics is an interaction between multiplicity of planners, some of which are regular urban agents (each with its specific plans and designs) while others are professional urban planners with their formal plans and designs. Second is the notion of planning or design behavior, namely, that urban agents are behaving and acting in the city in response to a plan or design, that is, in response to a reality that does not yet exist and might never exist.

1.5 CITIES, COGNITION AND ARTIFACTS

While the linked complexity, cognition and city added new insights to our understanding of cities as complex systems, they also exposed a lacuna: cognitive science ignores and excludes artifacts, and consciously so. According to Chomsky, one of the founders of the cognitive science:

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 . . . (Chomsky 1986, pp. 26–7, emphases added)

Chomsky here makes a distinction between external and internal languages (E- versus I-languages, respectively). E-languages are the spoken languages (Hebrew, English, French, Chinese, and so on), 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. This view of Chomsky is in line with the general tendency in science: ‘the term “artificial” has a pejorative air about it’, writes Herbert Simon (1969 [1996], p. 3) in his *The Sciences of the Artificial*.

The outcome is a paradoxical situation: On the one hand, cognitive science tells us (according to Nobel Laureate Kandel 2012, p. 284), about vision, that ‘we live in two worlds at once, and our ongoing . . . experience is a dialogue between the two: the outside world . . . and the internal world of the brain’s perceptual, cognitive and emotional models’. On the other hand, cognitive science tells us (according to Chomsky 1986, pp. 26–7) that the external world, that is, the world of artifacts, is ‘somewhat arbitrary, and perhaps not very interesting’. This anti-artifacts tendency had an effect also on studies related to cognition and the city. For example, Lynch’s (1960) main interest in *The Image of the City* was the city itself – its morphology and urban landscape. However, in the context of behavioral and cognitive geography the interest shifted from the city to behavior in space and then to spatial cognition. The city itself became just a passive environment by means of, and within, which behavior and cognition can be studied; in line with the role of the external environment in cognitive science in general. In the latter, the focus of interest was and still is one-sidedly on the details of the inner world, even in the context of the ecological-embodied-extended mind approaches. As elaborated (in Chapter 19 in this volume), in his study about the emergence of human agency in a human infant (compare Figure 19.1), Scott Kelso (2016, p. 494) observed that while the baby’s action and behavior were intensively studied, not a single study has recorded the dynamics and reaction of the external environment, ‘thereby obviating the possibility of obtaining any information about its relation to the baby’s movements’. (See further discussion in Chapter 19 in this volume.)

Chomsky is thus right in saying that E-languages are artifacts, but he is not right in saying that they are not interesting and have no room in the cognitive science – the study of ‘mind/brain and their components’. Similarly to cities, E-languages are hybrid complex systems that come into being out of the interaction between the parts – the human agents. Similarly to cities, they are composed of artifacts – the lexical components (the buildings, roads and so on) of each specific E-language, and human agents that speak the E-language. Furthermore, as implied by Kelso’s (2016) study, the property ‘human agency’ (urban agents included) emerges out of an interaction between the human baby as a complex system and the artifact mobile which is a simple system; the artifact is needed for the cognitive property ‘human agency’ to

emerge. That is, artifacts are integral part of cognition. Yet, as noted by Kelso, there is no such theory.

The notions of synergetic inter-representation networks (SIRN), IA and their conjunction SIRNIA were developed as components of a cognitive theory in which artifacts are integral parts of cognition. They are described in some detail by Portugali and Haken (Chapter 4, this volume), including empirical illustrations of several case studies. I present the basic principles of these components.

- SIRN: an artifact is an external representation – externalization in the world of an internal representation – an idea, wish or emotion that originates in the mind-brain. Internal and external representations are ‘the two worlds’ in which (according to Kandel 2012, p. 284, cited previously) we at once live; and as he further notes, ‘our ongoing . . . experience is a dialogue between the two: the outside world’ – the world of externally represented artifacts, and the internally represented world – the ‘internal world of the brain’s perceptual, cognitive and emotional models’. This ongoing dialogue/interaction has been termed inter-representation (IRN) (Portugali 1996). The addition of S that makes it SIRN, came to indicate that the process as a whole evolves in line with the principles of synergetics – Haken’s theory of complex self-organizing systems (Haken and Portugali 1996).
- IA: the notion IA complements the SIRN process by elaborating on the dialogue/interaction between the two worlds. It suggests (Haken and Portugali 2015) that this dialogue between the internal and external worlds evolves by the exchange of information; the information constructed in and by the mind-brain, and the data conveyed/transmitted by the external world of artifacts, that the mind-brain transforms into syntactic information. Three forms of information are involved in the dialogue: quantitative-syntactic information that conforms to Shannonian information (SHI), that is, information as defined by Shannon (Shannon 1948; Shannon and Weaver 1949) and two forms of qualitative forms of information: *semantic information* (SI) referring to meaning per se, and *pragmatic information* (PI) referring to the action possibilities afforded by the environment and objects and artifacts in it – in line with Gibson’s (1979) notions of embodied cognition and affordances. For details and the conjunction SIRNIA, Chapter 6 in this volume.

1.6 CITIES, COMPLEXITY AND THE BIG DATA GOLOM

‘The medium is the message’ is the famous phrase coined by Marshall McLuhan (1964) in his book *Understanding Media: The Extensions of Man*. In the current reality, suggested McLuhan in the 1960s, the media in no longer a tool to convey a particular content, but is the content itself. A view that reminds us of the legendary Golom of Prague that was created by the Rabbi Löw of Prague (known as the Maharal) and at a certain stage ceased being a tool that obeys, and implements, the Rabbi’s orders, but started to be the message itself (Dekel and Gurley 2013).

One of the attractions of cities to physicists and mathematicians was, and still is, data or, more specifically, the possibility to apply and test theories and models on urban data. This is probably why, at the turn of the twentieth century, physicist Auerbach (1913)

undertook his study on ‘the law of population concentration’, and this explains why so many physicists and mathematicians are active participants in the domain of CTC. Currently, with the advance of information communication technologies (ICT), AI, the availability of big data and data-mining techniques, this is even more so. According to physicist S. Koonin, director of the new New York University’s Center for Urban Science and Progress (CUSP): ‘Physics is an attitude as well as a subject. The kind of skills physicists bring to thinking through complicated situations, data driven and so on, are not all that common in urban science and technology at this point. Physicists have a lot to bring to the table here.’ This statement appeared in an interview, ‘Smart cities will need big data’, published in *Physics Today* (Koonin 2013) that defines itself as ‘the flagship publication of the American Institute of Physics, is the most influential and closely followed physics magazine in the world.’

Information communication technologies and big data represent what Gregory (1978) has termed physicalism – a physicist view of cities. Yet, Koonin, as well as his interviewer, are wrong in implying that it is only now that physicists step into the study of cities. We have mentioned previously Auerbach’s 1913 study and at later stages there were several physicalist waves in the study of cities; the previous wave, known as the ‘quantitative revolution’ in human geography and the study of cities and planning, was during the 1950s and 1960s. It started with great enthusiasm and ended with major frustration. An example is David Harvey, a leading theoretician of the quantitative urbanism of the 1960s, who in the early 1970s wrote that the positivist/physicalist approach is ‘incapable of saying anything of depth and profundity’ about cities, their dynamics and planning (Harvey 1973, p. 129).

The enthusiasm for big data is not unique to cities but applies to all research domains; for many, as suggested by Chris Anderson (2008), we are witnessing ‘The end of theory’, since ‘the data deluge makes the scientific method obsolete’. Whether CTC practitioners accept this view or not, current CTC studies on urban dynamics are strongly dominated by the ‘the data deluge’. The consequence is that ICT, AI and urban data availability are becoming forces that direct research and topics of interest. The medium (data-Golem) to study cities, has become the message. The recently flourishing domain of smart cities, is an example.

1.7 CITIES, COMPLEXITY AND SMALL DATA, OR, SMALL DATA IS BEAUTIFUL

How to study cities as complex systems? The fashionable answer as we have just seen, is big data: the new ICT with data-mining and visual analytic techniques make it possible for the first time to make use of the huge amount of data that is accumulating on the Internet and other networks. Yet, there is an alternative, or at least an addition, to the big data approach; that is, ‘Small data is beautiful’ (Portugali 2013; Haken and Portugali 2021, ch. 2), a name that rephrases the title of Schumacher’s (1973) book *Small is Beautiful: A Study of Economics as if People Mattered*. This book was a critique of the mid-twentieth-century’s economic gigantism in the form of mass production, mass media, fast economic growth and urbanization that, according to Schumacher, entailed the de-humanization of people and their

cultures. The subtitle of this section should thus imply, a study of cities as if people mattered.

While most attention in the domain of CTC is directed to big data, there is another type of data that bears directly on human behavior in cities: originating from the cognitive and brain sciences, these data shed light on the innate drivers of human cognition and behavior and as such have the potential to better understand and model urban agents' cognition, behavior and action in cities. An example is the recent wave of studies about urban scaling and allometry, triggered mainly by Bettencourt et al.'s (2007) study on 'Growth, innovation, scaling and the pace of life in cities'. Based on big data, this and subsequent studies observed super-linear relations between city size and the pace of life in cities as it shows up in several urban indicators that concern economic activities, creativity, crime and pedestrian walking speed. That is, the citizens of big cities behave differently from the inhabitants of smaller cities in respect of these indicators. Bettencourt et al.'s (2007) paper entailed studies that criticized and challenged the generality of these findings (for example, Arcaute et al. 2015; Cottineau et al. 2015), others that supported them, and the discussion still goes on (Chapter 9 in this volume). What is common to all is that they refer to, or rely on, big data; the controversies are not on the use of big data but on its quality, for example, 'Does a given data set genuinely represents the size of cities?' What is also common is that generally the question 'Why do people in small and large cities behave differently?' is not asked, and for good reason: big data has no answer; we can speculate, based on assumptions about human behavior (Bettencourt 2013), but these answers are not based on data.

To explain why people behave differently in small and big cities, we have to start, data wise, from the bottom up, that is, from data about the individual urban agent and the forces that motivate its action and behavior in cities of various sizes. An attempt in this direction was suggested by Ross and Portugali (2018) and further elaborated by Haken and Portugali (2019, 2021). This attempt is based on three theoretical foundations. The first foundation is psychologist Higgins's (1997, 1998) regulatory focus theory in respect of humans' innate motivational system, showing empirically that individuals' goal-directed behavior is regulated by a configuration of two distinct motivational systems – promotion and prevention. In order to achieve their goals, promotion-orientated individuals tend to focus on winning and risk taking, whereas prevention-orientated individuals tend to focus on not losing and risk avoidance. The second foundation is the finding of a collective regulatory focus, namely, that a person's promotion or prevention tendencies depend also on his or her personal regulatory focus, and on the atmosphere of the group he or she belongs to (Faddegon et al. 2008). The third foundation is urban regulatory focus (Ross and Portugali 2018), demonstrating empirically that a city's pace of life affects the promotion or prevention tendencies of its inhabitants and users. Finally, the decisive link to cities as complex systems and to urban scaling was made by Haken and Portugali (2019, 2021).

What these studies show is that small and big data complement each other, that is, the proper way to study urban scaling (and urban dynamics in general) is by a circularly causal process in which small data-based studies show how, by means of their interaction, urban agents give rise to the global structure of cities, while big data-based studies show how the global structure of cities, top down, affects the behavior and actions of urban agents, and so on.

This is but one illustration; other potential examples that have yet to be developed concern, for instance, cognitive maps, the way they affect agents' behavior and movement in cities and thus the evolving structure of cities. Another potential example is chronesthesia – the way human ability (or inability) to avoid mental time travel to the past and future, and the implied planning and design behavior noted previously, affect urban agents' behavior and action in the city, and more (Portugali and Haken 2018; compare Portugali, Chapter 19, this volume).

1.8 CITIES, COMPLEXITY AND BEYOND

Complexity Theories of Cities Have Come of Age is the title of our 2012 book that has focused on the implications for planning (Portugali 2012; Portugali et al. 2012). It could just as well be the title of this collection of chapters that can be seen as the state of the art in the domain of CTC at the end of 2020. Such a title is characterized by a Janus face: one face looks backward at what has been achieved and another forward at what has yet to be achieved. As regards the first of these faces, this collection partly follows the evolution of CTC from a narrow stream of studies – written mainly by physicists applying theories from physics – to an established interdisciplinary research domain engaging urbanists, geographers, planners, urban designers, regional scientists, mathematicians and physicists, among others. The second face, as noted, looks forward at what has yet to be achieved. The discussions in sections 1.3–1.7 look forward by suggesting issues that have yet to be fully developed. To the latter I suggest adding a discussion that starts by looking at the potentials of the links between complexity theory and the general study of cities.

Two potentials can be identified, the first being: born in the hard sciences, CTC offered to students of cities an arsenal of sophisticated mathematical tools. This potential was fully realized. As a consequence we now have a single theory – a conceptual framework with mathematical formalism – to several urban phenomena hitherto explained by several theories independent of each other: central place theory, urban scaling, urban land use, spatial segregation, and so on. This is an advantage from the perspective of William of Ockham's (1285–1347/9) (Baker 2010) famous scientific principle: '*pluralitas non est ponenda sine necessitate*' ('plurality should not be posited without necessity'). Known as Occam's razor, this principle gives precedence to simplicity in scientific explanation. The second potential was the possibility to create a link between the two cultures of cities.

As elaborated in detail in the past (Portugali 2006, 2011), since the early twentieth century, the study of cities evolved as a pendulum between two cultures of cities reminiscent of Snow's (1964) two cultures of science: a soft, hermeneutic study of cities inspired by the humanities and social sciences, versus a quantitative-analytical approach inspired by the hard, quantitative disciplines, specifically economics. As suggested in previous studies, CTC created a potential to act as a link between space and place (Portugali 2006, 2011), that is, to bridge the two cultures of cities. This is based on two grounds: first, on Jacobs's (1961) and Alexander's (1965) studies and, secondly, on resemblances between CTC and the social theory-orientated urban studies – in particular the structuralist-Marxist and humanistic (SMH) approaches to cities that dominated the field from the 1970s onwards (Portugali 2006, 2011).

The first ground is Jacobs (1961) in her *The Death and Life of Great American Cities* and Alexander (1965) in his 'A city is not a tree', who strongly criticized the quantitative approach to cities and, specifically, its rational comprehensive planning, from a theoretical position reminiscent of complexity; so much so, that currently, in retrospect, they are considered forerunners of CTC. Mike Batty (2008, pp. 769–71) wrote of the achievements of CTC:

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.

However, most CTC practitioners never followed Jacobs's and Alexander's criticism of the quantitative-scientific-rational-comprehensive approach. This criticism came, as is well recorded, from the soft hermeneutic culture of cities, specifically from social theory-orientated SMH perspectives on the study of cities (Portugali 2011). For most CTC practitioners the arsenal of sophisticated mathematical tools associated with complexity theories was an opportunity to rebuild the quantitative approach to cities on a new and more advanced mathematical foundation.

The second ground, as observed by Portugali (1985), is that complexity theories have found properties in matter hitherto assigned to the organic and human domains, including history, evolution, irreversibility and nonlinearity. As a consequence, and as illustrated in Figure 1.1, there are resemblances between the conceptual frameworks and languages of CTC and social theory: The notion of revolution in social theories resembles 'bifurcation and phase transition' in the parlance of complexity; mode of production in (Marxist) social theory resembles steady state and (synergetics') order parameter; processes of social and spatial reproduction resemble circular causality, while social theory view reality as ever-changing and transforming resembles complexity notions such as far from equilibrium, chaos, butterfly effect, and so on.

Given the latter potential with its two facets, CTC was, and still is, at a perfect vantage point for addressing the problematics of twenty-first-century urban society that is marked by a whole set of socio-economic and cultural transformations, including globalization, the rise of civil society, intensive processes of privatization that led to the decline of the national welfare state and, more recently, the crisis of democracy. As is evident by studies such as *The People vs Democracy* (Mounk 2018), *How Democracies Die* (Levitsky and Ziblatt 2018), *La France périphérique* (Guilluy 2014) and *Freedom: An Unruly History* (de Dijn 2020), Western democracies are currently torn between non-liberal democracy and non-democratic liberalism.

Also, the twenty-first century is the age of cities. Cities and urban society capture the core of each of the above transformations and crises, a not very surprising situation in a reality where, for the first time in human history, more than 50 percent of the world's population lives in cities, when several cities around the world turned into megacities with populations of over 20 million, the economy and sphere of influence of many world or global cities extend beyond the boundaries of their nation states and, yet, parallel to and within this trend we see a countertrend toward localization or 'glocalization'. As noted by Guilluy's (2014) book, the crisis of democracy is associated with a growing

Social theories	versus	Complexity theories
social/political/cultural ... Revolution	~	Bifurcation and phase-transition (Gould and Eldredge: punctuated equilibrium)
epoch, period, Mode of production	~	Steady state, order parameter, <i>synergetics</i>
Structural determination	~	Slaving principle, <i>synergetics</i>
Socio-spatial reproduction	~	Circular causality
reality as Ever-changing /transforming	~	Far from equilibrium, chaos, butterfly effect

Figure 1.1 Resemblances between the conceptual frameworks and languages of CTC and social theory-oriented urban studies

gap and tension between urban society in the big global cities, with their ‘creative class’ (Florida 2002), and urban society in peripheral towns and cities. To this might be added that some of the basic aspects of twenty-first century society and cities are often described in the language of complexity theories and CTC; for example, Castells’s (1996) *The Rise of the Network Society* and his notions of space, flow and the information city.

Potentially, CTC should have a lot to say about the twenty-first-century city and yet, with few exceptions, it does not. Most researchers in the domain of CTC preferred, and still prefer, to focus on traditional, conservative and anachronistic urban issues, such as central place theory, land use, rank-size distributions of cities, traffic and national systems of cities, which were dominant in the 1950s and 1960s, plus, technical issues, for example, smart machines, cities, and so on. The reason, as noted previously, is the availability of data and thus quantification. The outcome is an ironic situation by which the study of cities is characterized by a division of labor between two cultures of cities: a new complexity-derived scientific approach to cities that deals mainly with old-fashioned urban issues that lent themselves to quantification (plus studies on the role of new ICT) versus an ‘old’ hermeneutic study of cities that deals with the new urban reality and problematics of the twenty-first century, that does not enable quantification. That is, while for a few of its practitioners CTC was seen as an opportunity to bridge the gap between the two cultures of cities (for example, Portugali 2000, 2011), for the majority it was seen as an opportunity to revive the quantitative approach to cities on the sounder bases of complexity theory.

The exception is urban planning. Here we observe the merging of two streams. The first, communicative planning (Healey 2007; Innes and Booher 2010), attempts to adapt the traditional planning discourse and approach (the rational comprehensive planning) to the changing realities of the twenty-first century, namely (Portugali 2011), to the weakening of the welfare state, the resultant rise of the third sector of civil society as an active planning actor and (as specified in Chapter 18 in this volume) the transition of planning from a two-sector game (public and private) to a three-sector

game (public, private and civil). The intensive use of the notion of governance comes to reflect these changes. The other stream attempts to look at planning theory and practice from the perspective and insight of CTC. (Compare the activities of the AESOP's thematic group on planning and complexity.) Unlike mainstream CTC that has a strong analytical and quantitative orientation, here the main approach is hermeneutics. For further bibliography see Roo et al.'s (2020) *Handbook on Planning and Complexity*.

The notions of dual and hybrid complex systems, SIRN and AI were attempts to go beyond CTC mainstream, to materialize the previously noted second potential and pave the way for a deeper involvement of CTC in twenty-first century urban problematics. A more recent attempt is Haken and Portugali's (2021) study that explores steady state and phase transition – two notions that are central to complex systems generally, and which are specific to the synergetics' approach to complexity – slaving principle and circular causality. All four have not as yet been studied in relation to cities and urbanism and, as can be seen in Figure 1.1, all four have commonalities with concepts in a social theory-orientated urban dynamics. It is hoped that these and similar attempts will enable CTC to materialize their full potentials and be directly involved and active in twenty-first-century urban problematics.

REFERENCES

- Alexander, C. (1965), 'A city is not a tree', *Architectural Forum*, **122** (1), 58–62.
- Allen, P. and M. Sanglier (1981), 'Urban evolution, self-organization, and decisionmaking', *Environment and Planning A*, **13** (2), 167–83.
- Anderson, C. (2008), 'The end of theory: the data deluge makes the scientific method obsolete', *Wired*, 23 June, accessed 2 June 2021 at <https://www.wired.com/2008/06/pb-theory/>.
- Arcaute, E., E. Hatna, P. Ferguson, H. Youn, A. Johansson and M. Batty (2015), 'Constructing cities, deconstructing scaling laws', *Journal of the Royal Society Interface*, **1** (102), 20140745, doi:10.1098/rsif.2014.0745.
- Auerbach, F. (1913), 'Das Gesetz der Bevoelkerungskonzentration', *Petermanns Geographische Mitteilungen*, **59**, 74–6.
- Baker, A. (2010), 'Simplicity', in E.N. Zalta (ed.), *The Stanford Encyclopedia of Philosophy*, Palo Alto, CA: Stanford University.
- Batty, M. (2008), 'The size, scale, and shape of cities', *Science*, **319** (5864), 769–71.
- Batty, M. and P. Longley (1994), *Fractal Cities*, London: Academic Press.
- Bertalanffy, L. von (1969), *General System Theory – Foundations, Development, Applications*, repr. 2003, New York: George Braziller.
- Bettencourt, L.M.A. (2013), 'The origins of scaling in cities', *Science*, **340** (June), 1438–41.
- Bettencourt, L.M.A., J. Lobo, D. Helbing, C. Kühnert and G.B. West (2007), 'Growth, innovation, scaling, and the pace of life in cities', *Proceedings of the National Academy of Sciences of the United States of America*, **104** (17), 7301–6, doi:10.1073/pnas.0610172104.
- Buchanan, R. (1992), 'Wicked problems in design thinking', *Design Issues*, **8** (2), 5–21.
- Buckner, R., J. Andrews-Hanna and D. Schacter (2008), 'The brain's default network: anatomy, function and relevance to disease', *Annals of the New York Academy of Sciences*, **1124** (March), 1–38.
- Cantor, G. (1883), 'On infinite, linear point-manifolds (sets), part 5' (in German), *Mathematische Annalen*, **21**, 545–91.
- Castells, M. (1996), *The Rise of the Network Society*, Oxford: Wiley-Blackwell.
- Chomsky, N. (1986), *Knowledge of Language*, New York: Praeger.
- Christaller, W. (1933 [1966]), *Central Places in Southern Germany*, Englewood Cliffs, NJ: Prentice Hall.
- Cottineau, C., E. Hatna, E. Arcaute and M. Batty (2015), 'Paradoxical interpretations of urban scaling laws', July, *ArXiv*, 1507.07878.
- De Dijn, A. (2020), *Freedom: An Unruly History*, Cambridge, MA: Harvard University Press.
- Dekel, E. and D.G. Gurley (2013), 'How the Golem came to Prague', *Jewish Quarterly Review*, **103** (2), 241–58.

- Faddegon, K., D. Scheepers and N. Ellemers (2008), 'If we have the will, there will be a way: regulatory focus as a group identity', *European Journal of Social Psychology*, **38** (5), 880–95, doi:10.1002/ejsp.483.
- Feigenbaum, M.J. (1983), 'Universal behavior in nonlinear systems', *Physica*, **7D** (1–3), 16–39.
- Florida, R. (2002), *The Rise of the Creative Class: And How It's Transforming Work, Leisure, Community and Everyday Life*, New York: Perseus Book Group.
- Gardner, H. (1987), *The Mind's New Science*, New York: Basic Books.
- Gell-Mann, M. (1994a), *The Quark and the Jaguar: Adventures in the Simple and the Complex*, New York: Freeman.
- Gell-Mann, M. (1994b), 'Complex adaptive systems', in G. Cowan, D. Pines and D. Meltzer (eds), *Complexity: Metaphors, Models, and Reality*, Reading, MA: Addison-Wesley, pp. 17–45.
- Gibson, J.J. (1979), *The Ecological Approach to Visual Perception*, Boston, MA: Houghton-Mifflin.
- Gregory, D. (1978), *Ideology, Science and Human Geography*, London: Hutchinson.
- Guilluy, C. (2014), *La France périphérique: Comment on a sacrifié les classes populaires*, Paris: Groupe Flammarion.
- Haken, H. (1983), *Advanced Synergetics*, Berlin, Heidelberg and New York: Springer.
- Haken, H. and J. Portugali (1996), 'Synergetics, inter-representation networks and cognitive maps', in J. Portugali (ed.), *The Construction of Cognitive Maps*, Dordrecht: Kluwer Academic, pp. 45–67.
- Haken, H. and J. Portugali (2015), *Information Adaptation: The Interplay between Shannon and Semantic Information in Cognition*, Berlin and Heidelberg: Springer.
- Haken, H. and J. Portugali (2019), 'A synergetic perspective on urban scaling, urban regulatory focus and their interrelations', *Royal Society Open Science*, **6**, 191087, doi:10.1098/rsos.191087.
- Haken, H. and J. Portugali (2021), *Synergetic Cities: Information, Steady State and Phase Transition. Implications to Urban Scaling, Smart Cities and Planning*, Cham: Springer.
- Harvey, D. (1973), *Social Justice and the City*, London: Edward Arnold.
- Hatna, E. and I. Benenson (2007), 'Building a city in vitro: the experiment and the simulation model', *Environment and Planning B: Planning and Design*, **34** (4), pp. 687–707.
- Healey, P. (2007), *Urban Complexity and Spatial Strategies: Towards a Relational Planning for Our Times*, London: Routledge.
- Herman, R. and I. Prigogine (1979), 'Two-fluid approach to town traffic', *Science*, **204** (4389), 148–51.
- Higgins, E.T. (1997), 'Beyond pleasure and pain', *American Psychologist*, **52** (12), 1280–300.
- Higgins, E.T. (1998), 'Promotion and prevention: regulatory focus as a motivational principle', in M.P. Zanna (ed.), *Advances in Experimental Social Psychology*, New York: Academic Press, pp. 1–46.
- Innes, J.E. and D.E. Booher (2010), *Planning with Complexity: An Introduction to Collaborative Rationality for Public Policy*, London: Routledge.
- Jacobs, J. (1961), *The Death and Life of Great American Cities*, London: Penguin Books.
- Kandel, E. (2012), *The Age of Insight: The Quest to Understand the Unconscious in Art, Mind, and Brain, from Vienna 1900 to the Present*, New York: Random House.
- Kelso, S.J.A. (2016), 'On the self-organizing origins of agency', *Trends in Cognitive Sciences*, **20** (7), 490–99.
- Killingsworth, M.A. and D.T. Gilbert (2010), 'A wandering mind is an unhappy mind', *Science*, **330** (6006), 932, doi:10.1126/science.1192439.
- Koonin, S. (2013), 'Smart cities will need big data', *Physics Today*, **66** (9), 19.
- Korzybski, A.H.S. (1933), *Science and Sanity: An Introduction to Non-Aristotelian Systems and General Semantics*, Englewood, NJ: International Non-Aristotelian Library, pp. 747–61.
- Levitsky, S. and D. Ziblatt (2018), *How Democracies Die*, New York: Crown.
- Lorenz, E.N. (1972), 'Predictability: does the flap of a butterfly's wings in Brazil set off a tornado in Texas?', paper presented at the 139th meeting of the American Association for the Advancement of Sciences, Washington, DC, 29 December.
- Lösch, A. (1954), *The Economics of Location*, New Haven, CT: Yale University Press.
- Lynch, K. (1960), *The Image of the City*, Cambridge, MA: MIT Press.
- Mandelbrot, B.B. (1983), *The Fractal Geometry of Nature*, San Francisco, CA: Freeman.
- Manson, S.M. (2006), 'Bounded rationality in agent-based models: experiments with evolutionary programs', *International Journal of Geographical Information Science*, **20** (9), 991–1012.
- Maturana, H. and F. Varela (1973), 'Autopoiesis: the organization of the living', repr. 1980 in H. Maturana and F. Varela, *Autopoiesis and Cognition*, Heidelberg: Springer, pp. 63–134.
- McLuhan, M. (1964), *Understanding Media: The Extensions of Man*, New York: Signet Books.
- Meerow, S., J.P. Newell and M. Stults (2016), 'Defining urban resilience: a review', *Landscape and Urban Planning*, **147** (October), 38–49.
- Mounk, Y. (2018), *The People vs Democracy: Why Our Freedom Is in Danger and How to Save It*, Cambridge, MA: Harvard University Press.
- Portugali, J. (1985), 'Parallel currents in the natural and social sciences', *Geoforum*, **16** (2), special issue, 227–38.

- Portugali, J. (1996), 'Inter-representation networks and cognitive maps', in J. Portugali (ed.), *The Construction of Cognitive Maps*, Dordrecht: Kluwer Academic, pp. 11–43.
- Portugali, J. (2000), *Self-Organization and the City*, Berlin, Heidelberg and New York: Springer.
- Portugali, J. (2006), 'Complexity theory as a link between space and place', *Environment and Planning A*, **38** (April), 647–64.
- Portugali, J. (2011), *Complexity, Cognition and the City*, Berlin, Heidelberg and New York: Springer.
- Portugali, J. (2012), 'Complexity theories of cities: achievements, criticism and potentials', in J. Portugali, H. Meyer, E. Stolk and E. Tan (eds), *Complexity Theories of Cities Have Come of Age*, Heidelberg and Berlin: Springer, pp. 47–62.
- Portugali, J. (2013), 'Small data is beautiful', Ninth International Space Syntax Symposium, Seoul, 1 November.
- Portugali, J. (2016), 'What makes cities complex?', in J. Portugali and E. Stolk (eds), *Complexity, Cognition, Urban Planning and Design*, Berlin, Heidelberg and New York: Springer, pp. 3–19.
- Portugali, J. (2020), 'Information adaptation as the link between cognitive planning and professional planning', in G. de Roo, C. Yamu and C. Zuidema (eds), *Handbook on Planning and Complexity*, Cheltenham, UK and Northampton, MA, USA: Edward Elgar, pp. 203–19.
- Portugali, J. and H. Haken (2018), 'Movement, cognition and the city', *Built Environment*, **44** (2), special issue, 136–61.
- Portugali, J. and E. Stolk (2014), 'A SIRM view on design thinking – an urban design perspective', *Environment and Planning B: Planning and Design*, **41** (October), 829–46.
- Portugali, J., H. Meyer, E. Stolk and E. Tan (eds) (2012), *Complexity Theories of Cities Have Come of Age*, Heidelberg and Berlin: Springer.
- Prigogine, I. (1977), 'Time, structure and fluctuations', Nobel Lecture, 8 December, accessed 3 June at <https://www.nobelprize.org/prizes/chemistry/1977/prigogine/lecture/>.
- Prigogine, I. and I. Stengers (1985), *Order Out of Chaos*, New York: Bantam.
- Prigogine, I. and I. Stengers (1997), *The End of Certainty: Time, Chaos and the New Laws of Nature*, New York: Free Press.
- Pumain, D. (2009), 'L'espace, médium d'une construction spiralaire de la géographie, entre société et environnement', in B. Walliser (ed.), *La cumulativité des connaissances en sciences sociales*, Paris: EHESS, pp. 163–97.
- Raichle, M.E., A.M. MacLeod, A.Z. Snyder, W.J. Powers, D.A. Gusnard and G.L. Shulman (2001), 'A default mode of brain function', *Proceedings of the National Academy of Sciences of the USA*, **98** (2), 676–82.
- Rittel, H.W.J. and M.M. Webber (1973), 'Dilemmas in a general theory of planning', *Policy Sciences*, **4** (June), 155–69.
- Roo, G. de, C. Yamu and C. Zuidema (eds) (2020), *Handbook on Planning and Complexity – a Synthesis*, Cheltenham, UK and Northampton, MA, USA: Edward Elgar.
- Ross, G.M. and J. Portugali (2018), 'Urban regulatory focus: a new concept linking city size to human behavior', *Royal Society Open Science*, **5**, 171478, doi:10.1098/rsos.171478.
- Schumacher, E.F. (1973), *Small Is Beautiful: A Study of Economics as if People Mattered*, London: Blond & Briggs.
- Shannon, C.E. (1948), 'A mathematical theory of communication', *Bell System Technical Journal*, **27** (July), 379–423, (October), 623–56.
- Shannon, C.E. and W. Weaver (1949), *The Mathematical Theory of Communication*, Urbana, IL: University of Illinois Press.
- Simon, H.A. (1955), 'A behavioral model of rational choice', *Quarterly Journal of Economics*, **69** (1), 99–118, doi:10.2307/1884852.
- Simon, H.A. (1969), *The Sciences of the Artificial*, repr. 1996, Cambridge, MA: MIT Press.
- Snow, C.P. (1964), *The Two Cultures and a Second Look*, Cambridge: Cambridge University Press.
- Thünen, J.H. von (1826), *The Isolated State*, English trans. 1966, P. Hall (ed.), Oxford: Pergamon.
- Tolman, E. (1948), 'Cognitive maps in rats and men', *Psychological Review*, **55** (4), 189–208.
- Tulving, E. (1983), *Elements of Episodic Memory*, New York: Oxford University Press.
- Tversky, A. and D. Kahneman (1974), 'Judgment under uncertainty: heuristics and biases', *Science*, **185** (4157), 1124–31.
- Tversky, A. and D. Kahneman (1981), 'The framing of decision and psychology of choice', *Science*, **211** (4481), 453–8.
- Tversky, B. (1992), 'Distortions in cognitive maps', *Geoforum*, **23** (2), 131–8.