Understanding Complex Systems

Springer : COMPLEXITY

Christian Walloth

Emergent Nested Systems

A Theory of Understanding and Influencing Complex Systems as well as Case Studies in Urban Systems

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About the Author

Christian Walloth was born in 1979. In 2011, he joined the Advanced Research in Urban Systems (ARUS) program at the University of Duisburg-Essen, Germany. One of his research interests is complex systems, in particular the emergence of real novelty (new qualities) in complex systems. Another interest is pursuing the possibilities of influencing emergent systems, specifically possibilities of applying methods of effectuation to urban development.

Christian is the chair of the biannual symposium of Urban Systems Research at the European Meetings on Cybernetics and Systems Research (EMCSR). He is also the editor of the book series on Understanding Complex Urban Systems. Before joining the ARUS program, he worked as a strategy and management consultant for five years, primarily advising clients in the hightechnology, energy, and financial industries. He holds a degree in electrical engineering.

Chapter 1
Complex Systems and Man's Desire to Understand and Influence Them

> *How can we have any security or plan anything if everything changes all the time?*
>
> Rand 1957, p. 10

Why does some purposive planning fail, while some unplanned developments prosper? Why is one city lucky to develop a culture of cozy coffee shops, while another city becomes a tourist attraction, and yet another city doesn't seem to develop new, decisive qualities? Why do neighborhoods or entire regions also fail to develop the latter? What gives rise to urbanity in a city, and how is it possible to introduce urbanity into an assembly of buildings and streets?

All these exemplary questions concern the city as a whole—the city as urban *system*. System and complexity theories have been developed and applied to explain urban systems. But what can researchers and practitioners learn from these existing theories about the success or failure of planning in systems like cities? What could they learn about the development of *qualities*, such as urbanity, that may have a significant impact on the course of events?

It is, thus, no surprise that system and complexity theories have long been applied in urban and regional studies. Before system studies had become popular, Christaller (1933) had already described how smaller and larger towns form an interdependent network in his theory of central places (Fig. 1.1a). Jane Jacobs concluded her famous analysis of the *The Death and Life of Great American Cities* by recognizing that cities are what Weaver (1948) called systems of organized complexities. "The Kind of Problem a City Is," Jacobs states, is one of "organized complexity, 'in which a half-dozen or even several dozen quantities are all varying simultaneously and in subtly interconnected ways' " (Jacobs 1961, p. 433). Such interconnectedness may be visualized by Kauffmann's button model (Fig. 1.1b).

More recently, system approaches applied to understanding and influencing complex urban systems are flourishing with the research of Juval Portugali (e.g., Portugali 2008, 2011), publications edited by De Roo et al. (2012) and Walloth et al. (2014), and the dedication of research groups, such as Advanced Research in Urban Systems (UDE 2015), urban systems symposia (e.g., EMCSR 2014) and researcher's work

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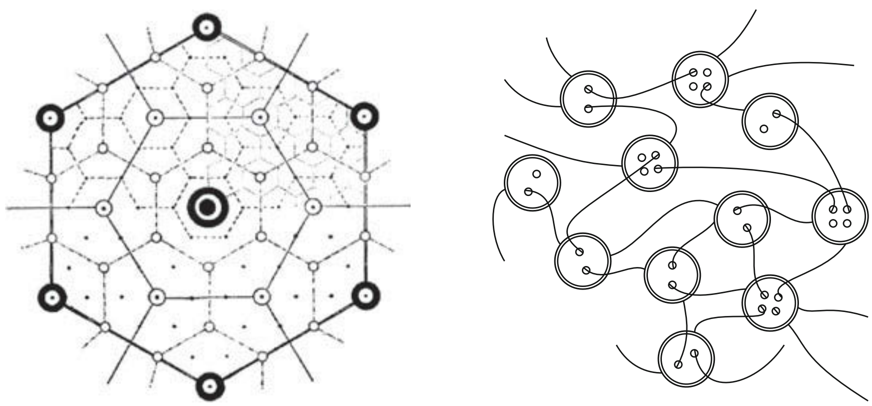
groups (e.g., AESOP 2015). And this is mentioning only a few of the latest activities. A brief overview of branches of system sciences and their application in urban studies is provided in Gurr and Walloth (2014, pp. 4–5).

The aim of applying complex-system concepts to cities is often related to the support of decision-making in the context of urban development. For example, system-dynamics models may reveal hidden interrelations and allow for the simulation of various scenarios—assuming the structure of the system and the dependencies remain the same over time. The system-dynamics method was pioneered for cities by Forrester (1969).

Later, system theories were likewise demonstrated to help with decision-making, such as theories of self-organization. Both Nicolis and Prigogine (1977) and Haken (1977) have developed theories of self-organizing systems, i.e., of dissipative systems and of synergetics, respectively. In the context of urban systems, the first theory was applied by Allen and Sanglier (1981), the second by Weidlich (1987). Today, agent-based models that simulate individuals' activities have gained considerable ground in supporting decision-making processes (e.g., Batty 2003 and Gebetsroither-Geringer 2014).

It isn't often asked why plans don't work out—despite all our theories and models of complex systems. Why could all the chains of causes and effects—or the activities of individuals—considered in our system-dynamics—or agent-based models—not come up with a scenario of a new coffee shop culture or the attraction of love locks?[1]



(a) Levels of central places (Christaller 1933, Fig. 2)

(b) Kauffmann's button model (after Kauffman 1996, Fig. 3.3)

Fig. 1.1 Systems as networks of interdependent elements: **a** Christaller's model of central places and **b** Kauffman's button model (own illustration). Kauffman's model illustrates the interconnectedness in complex systems, as well as the interdependence in case of local variation: If one button is pulled into one direction (or even removed), the change propagates through the entire network (see also Atun 2014, p. 53)

[1]Love locks are padlocks, which are usually engraved with the names of lovers. The lovers then fasten the locks onto the balustrade of a bridge and throw the key into the water. The love-lock

What are our theories and models good for if forecasting the real game changers lies outside their capabilities? By investigating the reasons why some plans do not work out, I will offer an alternative route to understanding complex systems, as well as understanding how purposive planning could become more effective.

In this work about complex systems, I will often draw on examples from cities, i.e., complex *urban* systems. Urban systems are complex in the way complexity is understood in this work (see below, Sect. 1.1). Urban systems are complex, in that interactions in urban systems can be very many and of various kinds. These interactions may be among many parts of the system, and both parts and interactions may be changing over time. For example, Christaller (1933, p. 26) suggests that central places gain their significance from the intensity of (economic) interactions of individuals.

These interactions may change with time and by the activities of individuals:

> Every birth and every death, every change of profession by an individual, every change in fashion, every change in individual wants for certain goods, every invention, every price fluctuation, every new tax, etc., influences the size of the range of the central goods, even if only to a small degree (Christaller 1933, p. 113).

This, in turn, "might well lead to changes in the overall system of central places" (Ibid., p. 113).[2]

With this work, my aim is to contribute to a branch of science that Ludwig von Bertalanffy (1968/2006) termed "General System Theory." General system theory seeks to identify principles common to a variety of, if not all, complex systems. General principles, so-called isomorphisms, are valid for, e.g., both the physical and the social realms. In choosing urban systems to exemplify my theory of studying complex systems, as well as my corresponding case-study methods, I will be able to apply this theory and these methods in a way that transcends disciplinary approaches. Other than urban systems, not many systems could be studied from a variety of disciplinary perspectives. These varied perspectives include politics, the physics of the present materials, the biology and ecology of the living beings, the psychology and social habits of citizens, and so on. In urban systems, very different things come together; e.g., technical artifacts meet cultural codes. This will allow me to demonstrate general system principles on a study object that is one and the same.

Structure of This Chapter

In this first chapter, I will introduce basic ideas, concepts, assumptions, and conjectures related to complex systems. I will take up the idea behind complex systems, as opposed to mechanical (analytical) and random (stochastic) systems (Sect. 1.1). Then I will come back to the problem of prone-to-failure planning, from which I will

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(Footnote 1 continued)
trend has changed urban places, including their attraction to locals and tourists, in an unforeseen way. For example, it had a major impact on the image and tourist attraction of the Hungarian city of Pécs (cf. Hammond 2010).

[2] My translations.

deduce my working hypotheses, as well as questions to be answered in the course of this work (Sect. 1.2).

In this context, it is important to understand that, despite the risk of failures of any purposive activities such as urban planning, there is a point in searching to influence the course of events. This understanding requires a concept of development that is different from both the concepts of deterministic planning and random evolution (Sect. 1.3). The empirical focus of this work is on urban systems. From these systems, many examples could be provided from failed planning and unplanned developments, and they also make good case studies to exemplify theories of complex systems (Sect. 1.4). This introduction concludes with an overview of the structure of the subsequent parts of this book (Sect. 1.5).

1.1 Complex Systems

Any attempt to understand a system faces the first challenge of its description—creating a model, i.e., a representation of the system. Three types of models of a system can be distinguished since the work of Weaver (1948):

1. Models of systems in which all (relevant) cause-and-effect relations can be analyzed and in which said systems can be understood from the understanding of all of these cause-and-effect relations.
2. Models of systems that can be built on the likelihoods of effects the systems produce with and/or without external stimuli.
3. Models of systems that seem to be 'more complex' and that cannot be achieved by either of the first two methods.

For some systems, analyses of their parts and activities, i.e., the systems' cause-and-effect relations, may lead to their descriptions. This is possible in cases where the parts to be modeled are few, and the activities, e.g., the interactions to be modeled, are either few, or structured enough as to be easily understood (Fig. 1.2, region A). In urban systems, one could, e.g., select a good or service an individual regularly purchases. Knowing the distance that individuals would go to purchase the good or service, the population distribution, and the minimum purchases of a good or service justifying a sales location, one could then model the development of a system of central places (central with respect to having a sales location for that good or service). The difficulty of such explicit cause-and-effect models arises from mutual influences among central places: a demand satisfied in one center will leave profit there, increasing the center's relative significance. Over time, the system's development—growth or decline of central and peripheral places—follows profit shifts among centers (White 1974, p. 220).

For other systems, the analysis of average effects may lead to a system's description. This is possible in cases where the parts are very many and/or the activities are randomly distributed (Fig. 1.2, region B). In urban systems, one could, e.g., consider the median household income. Knowing the number of households in each town and the average annual household expenditures on goods and services, one could then determine the centrality of a place by the expenditures it additionally attracts from outside sources (Preston 1971, pp. 139–140). Such a statistical model could help to predict how central places develop if incomes and/or expenditures grow or decline, if products and/or services are replaced by new ones offered in different centers, or if a central place from just outside the considered region grows stronger. However, such a statistical model cannot predict the impact of a single activity on the growth or decline of a center's relative significance, as it develops under the mutual influences among all central places.

In many additional systems, parts and their activities are too manifold and/or unstructured to be modeled analytically. At the same time, single activities can have too significant an impact for the systems to be modeled statistically (Fig. 1.2, region C). In those cases, when a system cannot be adequately modeled analytically or statistically, the system may be called complex.[3] It is both too complex to be reduced to an analytical model and too complex to be modeled in terms of statistical averages (cf. von Bertalanffy 1968/2006, pp. 35, 93 and Weaver 1948, p. 583).[4]

A complex system, according to this classification, is made of many different parts that act in a nontrivial way. In order to be a complex system, these parts and their activities must be dynamically changing over time (after Simon 1962, p. 468).

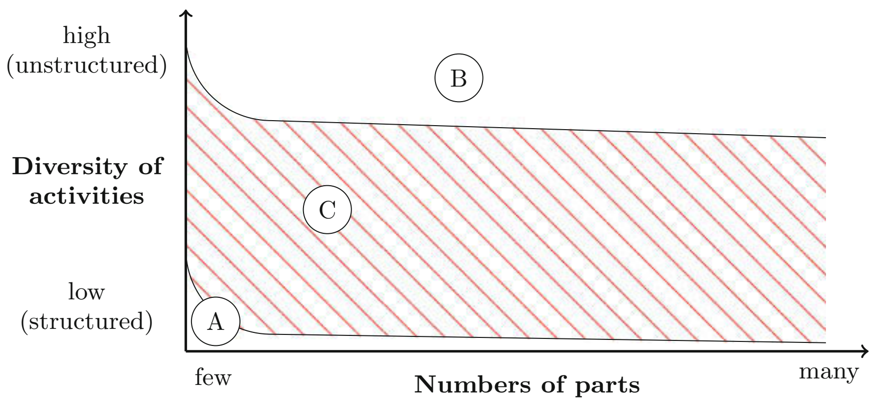

Fig. 1.2 Analytical (A), statistical (B), and complex (C) systems can be defined by the number of parts and diversity of these parts' activities each (after Weinberg 1975, p. 18)

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[3]Weaver (1948) originally called this 'organized complexity', as opposed to what he called 'disorganized complexity' and to what would later be referred to as statistically describable systems. However, in this work, complex systems are those which cannot be adequately modeled analytically or statistically.

[4]Weaver's distinction between three types of systems may not point to ontologically different systems, but only *epistemologically* different systems. If so, then all systems are in fact complex systems. However, at some aggregate levels, we can observe them as mechanical artifacts, such as a tramway, or as statistical "systems," such as a population.

1.2 The Limits of Planning Complex Systems

Where systems are complex—where interactions and parts are changing all the time—how then is it possible to devise effective plans? Where systems are too complex to be reduced to an analytical model and too complex to be modeled in terms of statistical averages, how can results of purposive activities be foreseen?

Indeed, plans often don't work out as intended. Examples of this are provided in the case studies discussed in Chap. 6. Thus, I would like to state the following …

problem definition: Planning in complex systems is prone to failure.

But why might plans not work out in complex systems? My conjecture is that some plans don't work out due to the types of system properties that are able to stabilize or break up systems without men's purposive activities. These properties must be influencing the complex system in such a way that purposive development plans might not succeed. Referring again to Christaller's central place theory, how could urban planning change the order of economic significance in an established central place system, or even change it in a case where a central place system is just developing on its own? Which kinds of properties in a system establish and maintain such a central place system, in which each smaller or larger town has its particular significance?

I suggest that it is worth looking at how complex systems come into existence, in order to possibly find ways to influence their development, i.e., methods which are less prone to failure—and thus more effective—than planning methods that consider cities as either mechanical or statistical systems. This leads to my …

working hypotheses: Properties of complex systems may void purposive development plans. However, purposive development might become more effective if these properties could be understood.

In brief, I claim that the (deduced) fact that complex systems develop on the basis of their own, inherent properties is at the core of (at least some) planning failures and, thus, that this requires investigation. Henceforth, I set out to discover these properties, to understand how purposive activities are influenced by these forces, and to find out how this influence of the complex system can itself be influenced effectively by man's purposive activities. Thus, these are my …

research questions: Of which type are the inherent properties of complex systems? How do they influence purposively planned developments? How can purposive planning, in turn, influence these system-inherent properties?

1.3 Purposive Planning and Untargeted Evolution

Even though, or perhaps because, planning, as it is understood and performed today, is prone to failure, there is a point in searching for ways to better influence the development of the complex system. This might require a different approach to understanding complex systems. Besides the understanding that rests on analytical cause-effect relations or statistical correlations, a complex system could be understood as an evolutionary system that shows results of mutations and various types of 'natural' selection. In addition to or instead of this understanding, it could be seen as a system in which purposive and creative human activity complements the evolutionary development.

Much planning rests on the idea that (at least partly) deterministic cause-effect relations can be discerned—either by analytical (discrete cause-effect relations) or statistical (overall cause-effect relations) methods and reproduced. E.g., urban planning assumes that "design and regulation of the uses of space … involving goal setting, data collection and analysis, forecasting, design, strategic thinking, and public consultation" (Encyclopaedia Britannica 2012) is effective.

However, as explained above, there are limits to the analytical understanding of complex systems (cf. Sect. 1.1), as well as limits of planning in complex systems in general (cf. Sect. 1.2). Above all, our daily experience tells us that the future cannot be determined.

The theory of evolution introduces mutation and selection into concepts of development. Evolution follows no strategy; it "has no foresight or memory: it can't aim at future targets, and can't learn from models of past successes" (Marshall 2009, p. 268). But understanding complex systems purely in analogy to biological systems would mean giving no consideration to man's ability to make foresighted decisions and/or regarding man's decision-making as either just a series of noises leading to mutations or a selection of developments which have already appeared.

In fact, planning involves purposive decision-making, though that does not stand alone in a complex system. On one hand, there is untargeted evolutionary development that can be understood as "unthinking trial and unforgiving error," with selection determined "by the environment, which itself has no purpose" (Ibid., p. 269). On the other hand, in contrast to biological evolution, man is able to "evaluate the end state of the imagined behavior" (Popper 1978, p. 354). Man's ability to anticipate, his (imperfect) "foresight and memory" (Marshall 2009, p. 269) "may lead to useful actions in the physical world" (Popper 1978, p. 350), as well as to creative, targeted "macro-mutations" (Marshall 2009, p. 269). However, purposive decision-making by one person may interfere with the (unrelated) decisions of other individuals. Development is, at first, evolutionary, and, in cases of purposive decisions and activities of men, it is influenced—but not determined—by these decisions and activities.

Whether by mutation or design, development happens in a complex system. There are, in complex systems, mutation and purposive introduction of change, as well as purposive and purposeless selection. This "implies that … we can do better than having no planning at all [and] that we can somehow have an … outcome that is better than … evolution left on its own" (Ibid., p. 254).

In order to make purposive activities more effective in influencing complex systems, I suggest looking into how the interplay of complex systems and purposive activities works. From this endeavor, an understanding of complex systems shall arise that enables man to consider and employ a system's inherent properties, which is a significant contrast to what traditional (urban) planning does. The subsequent chapters aim to make a contribution to understanding and influencing complex systems in this sense.

1.4 Evidence Supporting the Theory

Evidence is required to test a theory that is being developed. More generally, case studies are required to illustrate a theoretical understanding of complex systems. Case studies may show the system-inherent properties, as well as the game-changing influence of particular activities or developments. In addition, such studies show how particular activities and developments can be traced back to man's purposive decisions—implemented as, e.g., urban interventions.

The following questions, raised implicitly and explicitly throughout this introduction, were helpful in choosing insightful case studies: How does urbanity come back into a city which had been deprived of it? Under which circumstances may a culture of cozy coffee shops develop? Why don't some places thrive? Does planning fail because there are systems-inherent properties in place that will not let the plan prosper? How do complex systems develop in a city over time? How can knowledge about a complex system be used to make development targets more effective? How can a deadlock situation in a stable system be broken up to allow for innovation?

Hence, studies of urban systems should deliver two types of evidence. The first evidence should support the hypothesis of the existence and influence of system-inherent properties. The second evidence should show that case studies—that do not assume that the city is understandable as either an analytical or statistical entity—can provide an insight into approaches to urban development. Thus, case studies should reveal how complex systems develop from the interplay between system-inherent properties and man's purposive activities.

1.5 The Structure of This Work: Theory, Evidence, Conclusion

Some fundamental ideas have been introduced in this chapter. It should be clear by now that complex systems develop through an interplay of purposeless evolution and of purposive activities, and that I assume that men's purposive activities might become more effective if complex systems' inherent properties are understood.

Subsequently, an initial question to be answered is exactly how complex systems come into existence. This question will be dealt with in Part I of this book, in which I am going to make a contribution to the general theory of complex systems. In Part II, I will develop an approach to understanding complex systems, and I will present three case studies from an urban system, the city of Lviv, that support this theoretical contribution. Finally, in Part III of this work, I will draw a number of conclusions concerning the understanding and influencing of complex systems.

> But people who are interested only in how a city "ought" to look, and are uninterested in how it works, will be disappointed by this book. It is futile to plan a city without knowing what sort of innate, functioning order it has
>
> Jacobs 1961, p. 14

Part I
A Theory of Emergent Nested Systems

Chapter 2
Emergent Systems: Nested, Fast, and Slow

> *What matters is that the movement and fate of the parts from that time onward, once a new whole is formed, are thereafter governed by entirely new macro-properties and laws that previously did not exist, because they are properties of the new configuration ...*
>
> Sperry 1986, p. 267

Where do these game-changing qualities, such as a new coffee shop culture or the attraction of engraved padlocks, come from? As indicated above, I suspect that such qualities are due to properties that can only be found in complex systems, but not in analytical or statistical ones. These properties are not (yet) usually considered when decisions are made in complex systems. I claim that the available approaches cannot predict *new* qualities, which, I argue, are the true game changers in complex systems. It is the core concern of this chapter to uncover this property of complex systems.

Is it, in principle, possible to know what the future may bring for complex systems, i.e., what may interfere with our plans? Or do we simply have to deal with novelty that is, in principle, unpredictable? Would such novelty arrive out of the blue, or could it at least be anticipated as the result of contemplation—or even of a subtle feeling? Considering the often seemingly stable order of urban or other complex systems, how may novelty exert any significant influence at all?

In this chapter, I aim to provide a first understanding of complex systems as *Emergent Nested Systems*. In brief, I will claim that complex systems are emergent and that a relatively faster system is always enclosed by a relatively slower one. This chapter and the following two chapters will present a largely theoretical contribution; however, here and there, I will exemplify some points by referencing urban systems, or systems that can be found in cities. I will exemplify the applicability of my theoretical contribution in Chap. 6.

Developing this contribution would not have been possible for me without the ground prepared by prior works of many remarkable scholars. Among the works cited throughout this chapter, I would like to highlight the first chapter in *The Self And Its Brain* by Popper (1977), and "The Architecture of Complexity," an article by Simon (1962); these are very fruitful resources concerning "the admittedly vague idea of emergent evolution" (Popper 1977, p. 16).

C. Walloth, *Emergent Nested Systems*, Understanding Complex Systems,
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In the former mentioned work, Karl Popper introduced his propensity theory (first published in Popper 1959) on the probabilities of *single cases* into the wider context of emergence, e.g., the emergence of life, consciousness, and "creativity…which…we find in man" (Popper 1977, pp. 15ff.). In the same chapter, he also introduces levels of emergence in nature, and furthermore, he suggests that there is both outward and inward influence acting between the levels. "Each level is open to causal influences coming from lower and from higher levels" (Ibid., p. 35). The blend of propensity theory with notions of emergence is what makes Popper's ideas the point of departure for my work. Also, his merely-sketched theory presents the possibility to re-conceptualize—in light of the recent developments in system and complexity sciences—a theory of emergence.

In the latter mentioned work, Herbert Simon attributed high-frequency dynamics to enclosed systems and low-frequency dynamics to enclosing systems. However, Simon did not, at least to my knowledge, suggest any relation between emergence, nestedness, and fast and slow systems.

Many other scientists, who have influenced the development of my theoretical contribution, have been working along the same, or complementary, lines. These scientists notably—but certainly not exclusively—include Herman Haken (e. g.1977, 1981, and 2012), Christopher Alexander (2002a, 2002b, 2004, and 2005), and Christian Fuchs and Wolfgang Hofkirchner (e.g., 2005).[1] It should not go unmentioned that many other scholars have worked on theories of emergence over the past 100 years—from the British emergentists (e.g., Samuel Alexander, Charles Dunbar Broad, and Conway Lloyd Morgan, cf. Stephan 1999) to more modern proponents, such as Roger Walcott Sperry and Donald Thomas Campbell (cited in, e.g., Popper 1977) and the contemporary American emergentists, such as Sawyer (2005) and Deacon (2011).

However, none of the scientists mentioned in the last paragraph seem to have been aware of the high- versus low-frequency dynamics mentioned by Simon—an idea which plays a key role in my work.

Structure of This Chapter

The structure of this chapter can be understood along three key themes: unknown unknowns, propensities and emergent qualities, and properties of nested systems, especially the relation between relatively fast and relatively slow systems.

At first, I will suggest that *nested* systems emerge out of propensities, i.e., inherent dispositions of *unique situations*. This means that the emergence of a system is not under the control of anyone, and that it cannot be predicted before it starts to exist (Sects. 2.1 and 2.2). This, of course, has consequences for the value of *comparative* case studies; more about this in Chap. 5.

The notion of *emergence* is certainly the most intriguing one here. I will argue that emergence always involves a *qualitative leap*, i.e., a new quality beyond what could have been imagined, based on known qualities and the knowledge of the situation

[1] Although Alexander is approaching complex systems from a slightly different point of view, I'm convinced that he is working on elucidating the very same quality. What he calls life, the quality that creates and is bound by centers, is what I describe here as emergent quality—being enclosed as a center and enclosing other centers.

it appeared from. There are qualities which we have no ability to know, predict, or imagine until they start existing in this world. I.e., how could life have been imagined in a world without life, and how could a city have been imagined in a world with only scattered farmhouses?

In Sect. 2.2, I will argue that the ever-new emergence of systems actually leads to a *nested* arrangement (Sect. 2.3.1). In nested arrangements, the emerged systems are guiding the systems that previously existed by means of *new rules* (Sect. 2.3). I will explain in Sect. 2.4 how the nested systems always exhibit faster *dynamics* than the nesting ones. In a nested arrangement, the emerged slower systems guide the fast systems' activities, while the fast systems might, in turn, indirectly change the guiding rules—a relation that I consider to be most crucial for the understanding of complex systems.

The bottom line with regard to decision-making in complex systems might appear as trivial as this: Plans don't work because situations change. The entire story, however, is not as simple as this sounds.

2.1 What Do We Not Know that We Don't Know?

Man is continuously making decisions based on limited, imperfect knowledge. On one hand, this is due to individual limitations of knowledge, since "knowledge…[is] not given to anyone in its totality" (Hayek 1945, p. 520).[2] On the other hand, there is,

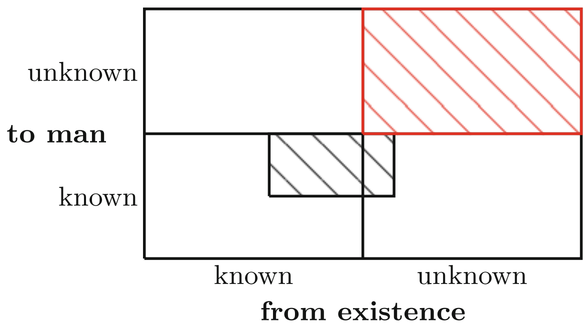

Fig. 2.1 The four realms of (un)knowledge. The knowledge of the individual (*dark hatched area*) excludes unknown knowns. It is furthermore limited to the individual's subset of known knowns, i.e., the knowledge about what exists in the world, and known unknowns, i.e., the knowledge that some situations in the future cannot be known, e.g., the time and strength of the next earthquake. Like known unknowns, which may not be known by anything in the universe except man, unknown unknowns do not yet exist in the universe. Unknown unknowns involve objective novelty and, hence, they cannot be known by man (*red hatched area*)

[2]Hayek draws on the problem of complex situations. To Hayek, complex situations depend on such a large amount of mutually dependent variables that it is practically impossible for man to find out how a situation came into existence (see, e.g., Hayek 1964, pp. 343ff. and pp. 348ff.).

at any given time, knowledge which cannot be possessed by anybody—knowledge of the future.

Everything outside of what is known to the individual can be considered as the individual's "unknowledge" (Shackle 1974, p. 4). This individual unknowledge can be reduced by gathering other individuals with complementary knowledge (known knowns) and by acquiring knowledge through research (making known knowns from unknown knowns). For example, bacteria were unknown knowns—known to the universe (they existed in), but unknown to men—before they were *discovered* by van Leeuwenhoek in 1676 and, hence, became known knowns. The areas of individual knowledge, unknowledge, and knowns and unknowns are depicted in Fig. 2.1.

Yet man may still know that some future situations may, in principle, come into existence, e.g., the decline or renewal of an urban neighborhood. Other future situations, however, will be fundamentally different, compared to anything that existed before.

Known Unknowns

Possible future situations include those that are mere reconfigurations of known situations, e.g., the renewal of an urban neighborhood in (almost) the same manner as had been observed somewhere else. Man knows that something like this may

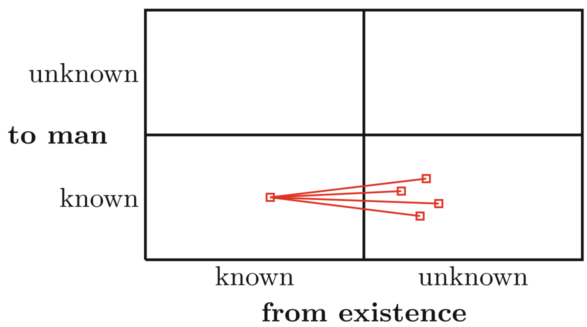

Fig. 2.2 Models, forecasts, and scenarios are built on known unknowns, i.e., future situations that man can imagine (*red strokes*)

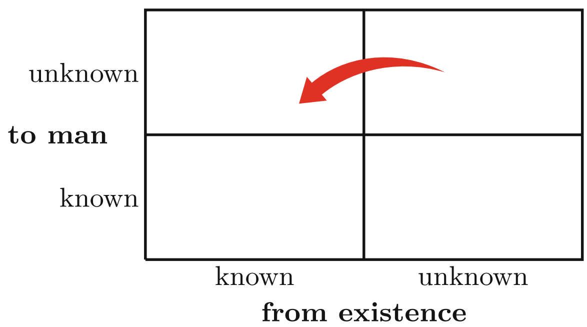

Fig. 2.3 Whenever an unknown unknown comes into existence, it may or may not become known to man

(Footnote 2 continued)
He does not see the limitation in ontological novelty that is, in principle, unpredictable (an argument which is independent of human ignorance). Rather, he sees our capabilities as being too limited to disentangle the continuous succession of situations, and internal and environmental factors, that may lead to ever-new situations.

happen and may even try to influence the development (cf. Chap. 4). However, until it actually comes into existence, the particularities of the situation remain unknown.

The imagination or simulation of possible, future situations produces known unknowns (Fig. 2.2). Models are built, based on known knowns; by any means of imagination or simulation, situations that are not yet existent, i.e., unknown to the universe, are forecast. The known knowns in models include, e.g., a time series of past demographic developments, activities of real estate developers, or correlations among car traffic, citizens’ healthiness, and economic productivity.

The consideration of known unknowns cannot afford the existence of novelty. Simulations or imaginations of future situations, based on known knowns and their variations, yield possible configurations of known situations—known unknowns. If there were something new, it could not be predicted, based on known situations.

Unknown Unknowns

No knowledge of novelty can be possessed by man, or by the universe, until it comes into existence somewhere first—whether it be by man’s creative invention or not. Until it comes into existence, such novelty remains an unknown. Unknown unknowns cannot simply be imagined or simulated as configurations of known situations. As mentioned earlier, man could not have known what a city would be like before it first came into existence.

Yet novelty—the coming into existence of unknown unknowns (Fig. 2.3)—plays an eminent role in the course of events. And while it can only be in vain to seek to foresee when, and which, unknown unknowns could come into existence, it might be useful to understand *how* they come into existence. What—if anything—gives rise to unknown unknowns, to something new emerging out of existing situations?

The expectation is that through understanding more about unknown unknowns coming into existence, novelty can be identified, and the ground may be prepared on which (desired) novelty grows. In other words, what are the catalysts required for novelty to come into existence, and how can those catalysts be influenced?

A further conjecture is that there is a connection between the coming into existence of unknown unknowns and of nested systems. If, as hypothesized in Sect. 1.2, a better understanding of the forces underlying nested systems could make, e.g., urban development more effective, it is worth studying how novelty comes into existence.

2.2 The Emergence of New Qualities

From logical concepts, such as the one shown in Fig. 2.1 and described above, it can be expected that the future bears unknown unknowns that must involve novelty, i.e., something not yet existent that cannot be known by any means before it first comes into existence. Thus, situations out of which unknown unknowns, i.e., novelty, can come into existence, are required. Furthermore, such novelty must be more than a mere reconfiguration of existing parts.

Propensities in Complex Systems

The concept of propensities—possibilities of developments, i.e., dispositions inherent in each particular situation—offers an explanation for the manifold possibilities for unknown unknowns to come into existence in complex systems (Popper 1959, p. 34 and Ulanowicz 1996, p. 219). It allows man to understand that the continuous change of situations may generate propensities, out of which novelty may come into existence.

In complex systems, as defined in Sect. 1.1, every small change in a situation might lead to great overall changes. Out of the number of parts, and the diversity of their interrelations, there arises, at every point in time, a number of potential futures. These futures immediately change themselves upon the realization of any purposive decision, mutation, or 'natural' selection (cf. Sect. 1.3). In complex systems, individual choices might thus have a significant impact on the development of the complex system. This is what Christaller (1933, p. 113) pointed out regarding urban systems, as quoted at the beginning of Chap. 1.

Every situation comes with its own propensities, and choices are made instantaneously from within unique situations. Every single one of a succession of choices, or other changes in a complex system, generates *its own* set of propensities (Fig. 2.4), i.e., a new range of possible futures. The probability of a particular choice or change is then a disposition or property of the particular situation itself (Popper 1959, p. 34). Thus, in every situation, i.e., configuration of a complex system's parts and relations, lies "propensities, [which,] when realized, can change those situations so that new propensities appear, then new situations, and so on" (Simkin 1993, pp. 74–75).

This sequel of propensities—realized by choices of nature, i.e., without foresight, or of men, i.e., with purpose and foresight—opens the door to an ever-changing universe and, hence, to the possibility for novelty to come into existence. Although

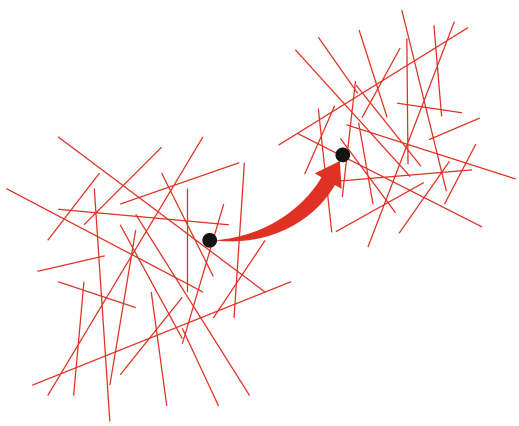

Fig. 2.4 Every situation (indicated by *black dots*) comes with its own propensities—possibilities for future situations. The propensities are visualized as *red lines* in space, and a situation at a given time in a given place meets these lines of propensities. If a propensity is realized, the space of propensities is changed. Thus, in a sense, a first situation (*black dot on left*) *generates* the very next propensities (*red lines on right*)

not a necessity of the concept of propensities, novelty may come into existence out of changing situations and ever-new propensities.

Emergent, Not Resultant

Complementary to such logical constructions as depicted in Fig. 2.1, there is evidence for novelty at several stages of the coming into existence of both natural and artificial systems (Fig. 2.5). This evidence ranges from the development of life out of inanimate matter to the development of consciousness in living beings and the coming into existence of economies or urban cultures. These, and many more novelties, are more than the sum of their (material) parts, i.e., more than what existed before they came into existence.

The coming into existence of an unknown unknown cannot be foreseen by what is known to man and/or the universe. Novelty is not explainable by reduction to its

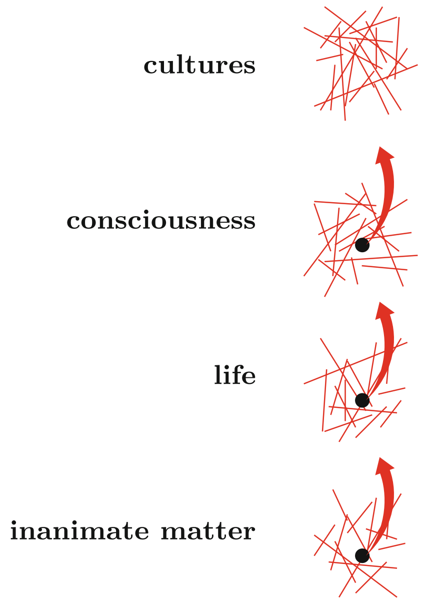

Fig. 2.5 Some selected stages of the emergence (indicated by *red arrows*) of ever-new novelty since the beginning of the world

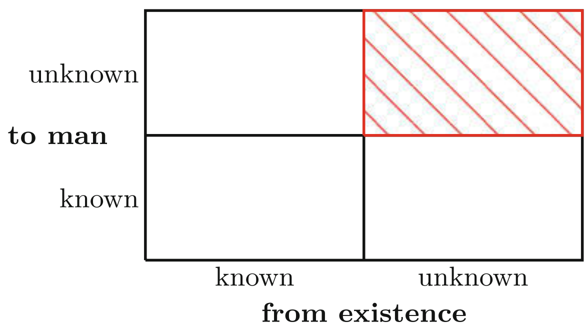

Fig. 2.6 Real novelty cannot be reduced to previously existing qualities: Novelty comes into existence from the realm of unknown unknowns (indicated by *red hatched areas*)

parts, e.g., to atoms, molecules, or pre-urban cultures. Novelty cannot be *resultant*; it must be *emergent* (Hofkirchner 2011, p. 191).[3,4]

More than the Sum of Its Parts

Whatever kind of leap leads to something beginning so that more exists than it had prior to the moment that it began, i.e., more than could be chosen from knowns, it must involve the coming into existence of something emergent, not resultant. This concept of novelty requires the bold conjecture that *emergent qualities* cannot be reduced to previously existing qualities; otherwise, they could have been imagined as known unknowns. Likewise, they cannot be explained by cause-and-effect situations operating within these existing qualities.

> The meaning of the somewhat mystical expression, 'the whole is more than the sum of [its] parts' is simply that the constitutive characteristics are not explainable from the characteristics of isolated parts. The characteristics of the complex, therefore, compared to those of the elements, appear as 'new' or 'emergent.' (von Bertalanffy 1968/2006, p. 55)

Emergence requires new quality to come into existence (Fig. 2.6). The new quality, which is emergent, can be distinguished by its being more than the sum of its parts. The new quality cannot be explained by the qualities of its parts because there are no precursors of the emergent quality in its parts:

> Once there was no poetry in the universe; once there was no music. But then, later, it was there. Obviously, it would be no sort of explanation to attribute to atoms, or to molecules, or even to lower animals, the ability to create (or perhaps to pro-create) a forerunner of poetry, called proto-poetry. (Popper 1978, p. 352)

2.3 General Properties of Emergent Systems

Just postulating that emergent novelty cannot be explained by the parts alone—such as life or consciousness—explains, in fact, nothing. However, a further-developed theory of emergence, embedding the notion of emergence into a more comprehensive concept built around this notion, might add some explanatory value.

Subsequently, I will largely follow and extend the argument of Popper (1977), who conjectures that ever-new emergence leads to a *nested* arrangement of systems (Sect. 2.3.1), and that there is both *outward and inward influence* among the

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[3]Hofkirchner refers to Blitz (1992).

[4]The genesis of this line of argument about emergence is generally attributed to J.S. Mill and G.H. Lewes. John Stuart Mill, in the sixth chapter (titled *On the Composition of Causes*) of the third volume of his 1843 *A System of Logic*, distinguishes 'mechanical' (homopathic) and 'chemical' (heteropathic) effects. For homopathic effects,"the composition of causes correspondent[s] to additive properties, while heteropathic laws give rise to constitutive properties" (excerpt from a lecture by Lloyd Morgan on *Scientific Thought*, 1912, quoted in Stephan 1999, pp. 75–76). The effects of heteropathic laws were termed 'emergent' in G.H. Lewes's 1875 *Problems of Life and Mind* (cf. Sawyer 2005, p. 32).

nested systems (Sects. 2.3.2 and 2.3.3).[5] On one hand, outward influence generates the propensities, out of which a new quality may emerge. On the other hand, rules of, and selection by, an emergent quality influences inward. I suggest that together, the enclosed and the enclosing systems in a nested arrangement form a *whole* (Sect. 2.3.4).

2.3.1 Nestedness

With every emergent quality, new situations become possible. With every one of these new situations, further new propensities are generated, out of which even further novelty may come into existence. Hence, out of new, formerly impossible situations, it may become possible for new qualities to emerge.

What follows is a succession of *ever-new emergent qualities*, made possible by *ever-new propensities* (cf. Popper 1977, pp. 30–31). These nested systems exist without being designed as such by purposive human activities. And yet, nesting and nested systems potentially interfere with purposive human activities, e.g., in the field of urban planning. Urban systems are also nested, in that they are enclosed by other systems, e.g., regional systems, and in that they enclose other systems, e.g., urban districts.

Furthermore, the emergence of urbanity only becomes possible where a city exists already.[6] After the emergence of consciousness, cultural and social qualities emerged, among them economies and cultural codes, which, in turn and in combination with other qualities, made it possible for cities to generate further new propensities, out of which, e.g., urbanity could emerge.

In such a succession of emergent qualities, previously existing qualities become parts of newly emerged qualities; qualities become *enclosed* or "encapsulated" (Fuchs and Hofkirchner 2005, p. 29) by one another. This "leads…to a…theory of the universe, in which the world is composed of stacked layers of emergence" (Miller and Page 2007, p. 45).

From the succession of emergent qualities, one of the most universal features of natural and artificial systems follows: their arrangement into nested systems (e.g., von Bertalanffy 1968/2006, p. 27). Nested systems are like onions: one system inside another system, the outer system enclosing the inner one. For example, metropolitan

[5]Popper, as other authors, writes of upward and downward causation. I refrain from following this terminology for two reasons. First, given the potential of emergence of novelty, there may be no such thing as repeatable causation—but repeatability is key to the idea and usefulness of (rather mechanistic) cause and effect; I prefer to use 'influence' instead (which does not exclude causation). Second, upward and downward may imply a hierarchical relation, just as bottom-up and top-down do; I prefer to express the idea in line with the image of nested systems, where one system is nested *inside*, and not below, another.

[6]The material shape of a city is a result of the emerged qualities, e.g., in the form of immaterial ideas and (cultural) images that are guiding the activities of citizens in shaping the city. See also Footnote 7.

regions enclose cities and towns, which enclose districts, which enclose neighborhoods, which enclose micro-neighborhoods. The latter enclose even further systems, e.g., buildings in the physical realm and families in the social domain.

In his theory of central places, Christaller (1933, p. 26) explains spatially nested systems, in which a central place of relatively higher economic significance covers a region, which includes central (and remote) places of relatively lower economic significance (cf. Fig. 1.1a). With emergent quality being at the core of every system, it becomes plausible why an arrangement of nested systems (Fig. 2.7) is "fundamental in the general theory of systems…from elementary particles to…atoms, molecules,…cells…organisms and beyond to supra-individual organizations" (von Bertalanffy 1968/2006, p. 27).

2.3.2 Inward Influence

Every system in the arrangement of nested systems is defined by an emergent quality, reflected by rules that guide and select activities in the enclosed systems. E.g., after the emergence of a new quality such as urbanity—itself emerging out of situations in cultural and material systems—the (unwritten) rules of an urban place guide the activities of individuals in the city. In that way, the emergent system has inward influence (Fig. 2.8) on the (cultural and material) systems from which it emerged.[7]

New rules start to guide activities in enclosed systems, upon the emergence of a new enclosing system. An enclosing system's inward influence toward the enclosed

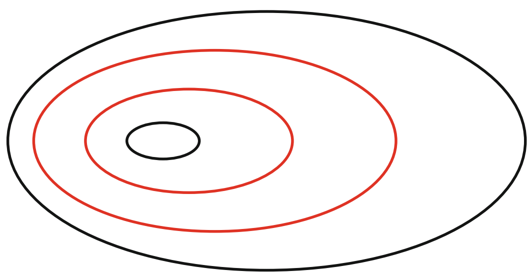

Fig. 2.7 When through the emergence of a new quality the first system becomes enclosed by another system, a nested arrangement of systems comes into existence. Highlighted is a single nested relation, as it will be used in subsequent illustrations

[7] In the case of cities developing a (partly) fractal spatial shape, new rules guide the fractal development after the emergence of, e.g., cultural, esthetic, and social qualities. As a consequence, the fractal shape is not emergent, but the quality of the rules, which guide the fractal shape, is; the fractal shape itself is a resultant. As a further consequence, the concept of self-organization subsides. I.e., despite spontaneous activity—e.g., mutation or creative thought, both subject to selecting rules—which is not organized, there is no such thing as 'bottom-up' self-organization of parts. I hold that patterns that seem to be self-organized are, in fact, resultants guided by the rules of emerged, enclosing systems.

system is restrictive and prescriptive (cf. Fuchs and Hofkirchner 2005, pp. 29 and 31). It is restrictive in that situations that were possible before may not be possible any more, and prescriptive in that situations may become possible that were not possible without the emergent system. By virtue of its guiding rules, every emergent system may act back or even "exert a dominant influence" (Popper 1977, p. 35) upon the enclosed systems.

By restricting the enclosed systems, the enclosing system's inward influence is a selective one that includes choice-making. Whatever (purposive) activity is attempted in the enclosed systems, the enclosing system may or may not let it pass (Popper 1978, p. 348).[8] Either a purposive "choice process may be a selection process" (Ibid., p. 349), or the rules of the enclosing system's emerged quality may accept or reject the activity of the enclosed system. For example, a certain personal activity might not fit within the ethical or moral rules of the actual cultural system, and the activity subsequently might be suppressed.

New rules might as well guide and select such activities in the enclosed systems that support and maintain the emergent quality. The emergent qualities "prescribe the activities of the subsystems", i.e., of the enclosed systems (Haken 1981, p. 17). Thus, there is circular and continuous, autopoietic regeneration of a whole at work (cf., e.g., Maturana and Varela 1980, pp. 78–79 and Luhmann 2004, pp. 78, 108 ff.). For example, a central place system comes along with (unwritten) rules, through which the central place's relatively surplus importance and, hence, the central place quality, can be maintained. The roles of both the enclosed central and less central places are guided by the rules of the emergent system.

2.3.3 *Outward Influence*

Besides inward influence, there is outward influence in complex systems (Popper 1977, p. 35). Outward influence (Fig. 2.9) is *generative*, in that it enables and maintains the emergent quality. However, outward influence may also lead to the breaking up of the emergent quality. Thus, on one hand, emergent systems may only come into existence if changing situations in existing systems generate ever-new propensities,

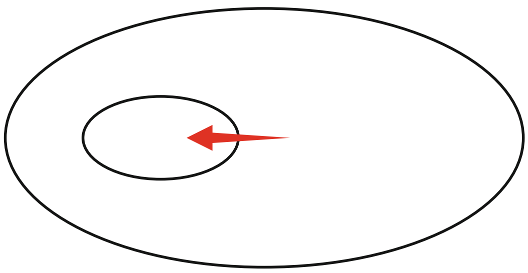

Fig. 2.8 There is inward influence via guiding and selecting rules from the enclosing system

[8]The cited author refers to Cambell (1974), Sperry (1969), and Sperry (1973).

out of which emergence may occur. On the other hand, the continued existence of the emergent system is based on the continued existence of the enclosed systems (Fuchs and Hofkirchner 2005, p. 30).

Activities of outward influence can be either purposive, i.e., with foresight, or untargeted; they can either fit, or be rejected by, the enclosing system's rules of inward influence. The activities of the enclosed systems can also generate propensities, out of which the emerging quality changes. This can be exemplified in social systems where emergent cultural and political systems continuously change. In the most extreme cases, such as a revolution, citizens may break up the political system that encloses them. Similarly, decay of enclosed systems could destroy the enclosing system, i.e., the emergent quality and its rules.

Out of ever-changing propensities in existing systems, eventually an enclosing system will emerge. This could explain why cultural, economic, political, and other systems eventually emerge from the activities of man. Similarly, in natural systems, free elementary particles may form and then get enclosed in atoms; these particles form and get enclosed again, and so on. This leads to an endless realization of ever-new *Emergent Nested Systems.*

2.3.4 Wholes

Together, the enclosing and enclosed systems form a whole. The whole is discernible by the quality of the enclosing system and by its rules that apply to the enclosed system. The enclosed system becomes "sublated" into the whole (cf. Fuchs and

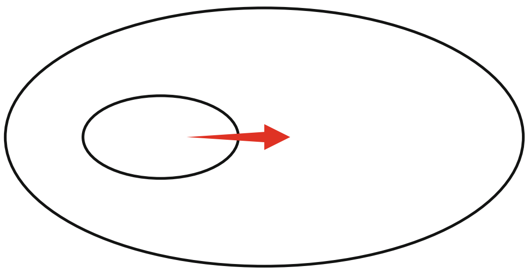

Fig. 2.9 There is outward influence through activities in enclosed systems that generate propensities, out of which the enclosing quality might be changed, or new enclosing quality might emerge

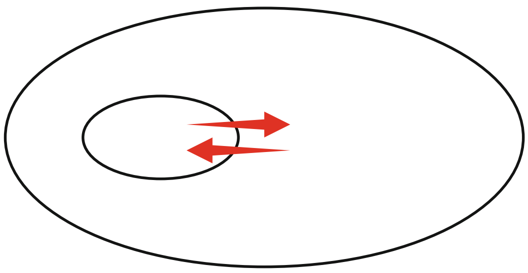

Fig. 2.10 Together, the emerged enclosing system and the generative enclosed system form a whole

Hofkirchner 2005, p. 29). Without an emergent quality, there will be no whole, but only an assembly of parts.

Generative outward influence, and guiding and selecting inward influence, makes the enclosed and enclosing systems an interdependent whole (Fig. 2.10). On one hand, the emergent quality and the enclosed systems are linked by inward influence. On the other hand, the new quality could not even arise without outward influence.

In a whole, neither the enclosed systems nor the enclosing system stand alone. For example, in a system of central places, the whole, i.e., the central place system, and its parts, i.e., the region and the central places, cannot exist independently. There is mutual influence between the enclosing system and the enclosed ones, i.e., between the whole and its parts.

2.4 Fast and Slow Systems

I suggest, building on arguments brought forward by, e.g., Simon (1962), that a further property of ENS is the relatively slower speed of the enclosing systems, as compared to the enclosed ones. Relatively fast outward influence of enclosed systems may generate, change, or even break up the enclosing system. Thus, the enclosing system may be destroyed if it cannot adopt the changes of the enclosed systems.

If this hypothesis holds true, (the relation between) enclosing and enclosed systems could be discerned by measuring the speed of their internal activities, e.g., of their turnover and exchange rates, and/or their rate of change. Also, the slow/fast relation holds explanatory power for outward and inward influence in emergent systems. Generative activities must be able to adapt quickly to changes of rules, just as rules would not be effective if what they governed could not keep up with the changes. In the same way, revolutions breaking up enclosing systems can only work because the enclosing systems cannot adapt quickly enough to the activities of the revolutionists.

The understanding of fast and slow systems provides a means to understand complex systems beyond the hardly useful ‘everything is connected with everything else’ paradigm. In particular, tools and methods developed to effectively influence emergent and nested, i.e., complex, systems, might aim at influencing the relations between relatively faster and slower systems.

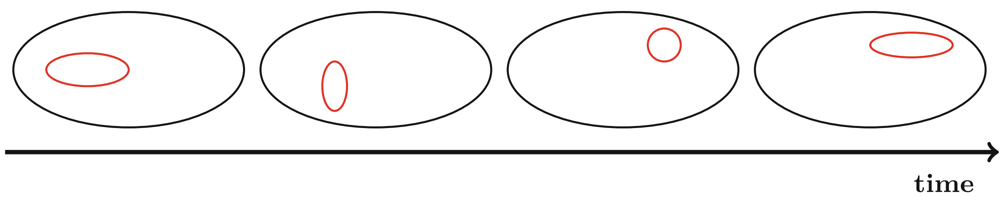

Fig. 2.11 The enclosing system changes slower than the enclosed one

Systems Change Over Time

There is evidence for a link between a system's speed of operation and its position in the arrangement of nested systems. For example, while the individual's habits change relatively fast—every couple of years—the cultural system of a society that guides the individual's habits changes much slower—every couple of decades (cf. Fig. 2.11). Man gives rise to social systems, e.g., political, cultural, or economic systems that constrain a group or society; the social systems have a slower pace of change than the individuals within them. This supports the conjecture that a relatively slower system is enclosing a relatively faster one.

This observation for social systems is in perfect analogy with von Bertalanffy's description of biological systems:

> The living organism is a hierarchical order of open systems. What imposes as an enduring structure at a certain level, in fact, is maintained by continuous exchange of components of the next lower level .... As a general rule, turnover rates are the faster the smaller the components envisaged. (Ibid. 1968/2006, p. 160)

Simon (1962) introduces the concept of "nearly decomposable" systems, i.e., of systems, in which faster subsystems are encapsulated by slower ones[9]:

> It is well known that high-energy, high-frequency vibrations are associated with the smaller physical subsystems and low-frequency vibrations with the larger systems into which the subsystems are assembled. (pp. 475–476)

Similarly, Haken (1977, pp. 191 ff.) and Weidlich (1999, p. 139) observe faster dynamics in subsystems than in the "global conditions" of the environment. In settlement systems, e.g., "fast processes take place on the *local microlevel*" (buildings, traffic infrastructure, etc.), but "slow processes take place on the *regional macrolevel*" (whole settlements) (Ibid., p. 138).

Enclosing Systems Are Slower

The examples above further support the conjecture that enclosing systems are characterized by a slower speed of change than the systems they enclose. E.g., slowly changing social systems guide the relatively fast activity of man, whose overall, relatively slow body guides the relatively fast, biological activities of its organism.

Such relations between slow, enclosing and fast, enclosed systems appear throughout the animate and inanimate world. These relations apply to natural and man-made systems alike, and they interrelate all types of systems through guiding and selecting rules, as well as through generative activities. Simon (1962) notes that:

> "[i]t is probably true that in social and in physical systems, the higher frequency dynamics are associated with the subsystems, the lower frequency dynamics with the larger system. It is generally believed, for example, that the relevant planning horizon of executives is longer the higher their location in the organizational hierarchy" (Ibid., p. 477).

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[9]The term "nearly decomposable" refers to Simon's claim that, when analyzing complex systems, the relatively faster activities within systems may be neglected, and only the slower activities of the enclosing system have to be analyzed together with the few relevant interactions between the faster and the slower systems. Hence, according to Simon, systems can nearly be decomposed—nearly only—because some of these activities in between systems are relevant (see also Sect. 3.3.1).

From the existence of enclosing systems, Simon, like Haken and Weidlich, derives the ability to understand nested systems from the enclosing conditions of the relatively slower system alone (cf. Sect. 3.3.2). Such a conclusion, however, neglects the impact which (individual) activities in the faster system may exert on the slower one.

Enclosed Systems Are Faster

Finally, the relation between slow, enclosing and fast, enclosed systems can explain the important properties of outward influence. It is not only that the slower system emerges from the faster ones, but also that the faster, more dynamic system has the power to change or even break up the slower, enclosing system.

For example, Holling (2001a), following up on Simon (1973)s work, ascribes the role of “triggering a crises,” starting a “revolt,” and invigorating faster systems. To slower systems, he ascribes the role of “constraining, ” setting “the conditions,” guiding, and protecting (Holling 2001a, pp. 397 ff.).[10]

For a “revolt” of a faster system, he provides the example of “local activists succeed[ing] in their efforts to transform regional organizations and institutions, because the latter have become broadly vulnerable” (Ibid., p. 398). If not through revolution, then in a more subtle way,“ideas (generated in the faster system) can become incorporated into slower parts of the panarchy, such as cultural myths, legal constitutions, and laws” (Ibid., p. 401).[11]

Another example of interrelations between fast and slow systems is the interplay between lifeforms and the atmosphere. While the atmosphere has set the conditions under which life can develop, lifeforms themselves have had great impact on the atmosphere, eventually changing it into the oxygen-rich one we know today. However, now it is feared that man may have a similarly tremendous impact on the atmosphere, if released greenhouse gases and other pollutants are able to change the enclosing system.

[10] Holling (2001a) and coworkers (e.g., in Holling 2001b) in particular develop a model for adaptive (eco-)systems that go through cycles of resilience and vulnerability. They claim that layers of such adaptive systems stack up from spatially small to large and from fast to slow.

[11] By the term ‘panarchy,’ the original authors mean a guiding system which encompasses all other adaptive systems in a nested, but not top-down, manner—“a nested set of adaptive cycles” (Holling 2001a, p. 396).

Chapter 3
Emergent Systems: First Implications

Rand persuaded me to look at human beings, their values, how they work, what they do and why they do it, and how they think and why they think. This broadened my horizons far beyond the models of economics I'd learned. I began to study how societies form and how cultures behave, and to realize that economics and forecasting depend on such knowledge—different cultures grow and create material wealth in profoundly different ways.

Greenspan 2007, p. 53

What does it mean that unknown unknowns may come into existence, that new qualities emerge, and that a succession of enclosed and enclosing systems forms a nested arrangement? What does it mean that the enclosing systems guide the enclosed ones, and that the enclosing systems are slower than the ones they enclose?

Below, I will argue that novelty is objective (Sect. 3.2.1), that systems are ontologically real (Sect. 3.2.2), and that novelty is unique, i.e., the exact same novelty is never repeated (Sect. 3.2.3). Thus, forecasting is limited to *types* of emergent qualities, and an a posteriori explanation of emergent qualities makes similar sense, but only for an abstracted type.

Among the direct implications of a theory of ENS lies, on one hand, the potential *influence of the individual* on the course of events (Sect. 3.3.1). On the other hand, there is the emergent system which, by virtue of its own rules, exerts the *influence of the whole* on the (individual) enclosed systems (Sect. 3.3.4). How may emergence itself be influenced?

To begin, I will briefly summarize and rephrase the key elements of the theory presented in the previous Chap. 2.

3.1 Emergent Nested Systems, Fast and Slow

In Chap. 2, I argued that every system that adds a new quality to the world has emerged out of propensities of systems that have existed before. From this argument, a world follows in which systems are arranged in nested systems. I argued further that activities in the enclosed system may change the enclosing system, which, in

C. Walloth, *Emergent Nested Systems*, Understanding Complex Systems,
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Table 3.1 Relations of nested systems

Role in the whole	Enclosed system	Enclosing system
Quality of the system	Generative	Emergent
Type of influence	Generative and triggering	Guiding and selecting
Means of influence	Activities	Rules
Direction of influence	Outward	Inward
Frequency of change	Fast	Slow

turn, by means of its rules, guides and selects activities in the enclosed systems (cf. Sect. 2.3). In such a relation, the enclosed system shows a relatively higher frequency of activity, while the enclosing system shows a relatively slower one (cf. Sect. 2.4).

The relations between enclosed and enclosing systems in a nested arrangement are depicted in the Table 3.1 and are subsequently summarized.

Generative and Emergent Qualities

Every nested system has two qualities. A system is both generative and emergent, in relation to enclosing or enclosed systems, respectively. By a system's generative quality, the systems enclosing it are (re-)generated. Such (re-)generation leads to the (re-)emergence of a particular quality of the enclosing system. As enclosing system, a system is, hence, of the emergent kind, in relation to its enclosed systems.

Generative and Guiding Influence

While the generative role of a system is to (re-)generate enclosing quality, the guiding role of a system is to guide the (re-)generative activities of enclosed systems. Activities in enclosed systems are thus (re-)generative enclosing systems, their qualities, and the rules that come with these qualities—unless the activities are triggering change, which happens when they do not follow the guiding influence of the enclosing system. An enclosing system's influence on the enclosed one occurs through rules that guide the activities of the latter.

Activities and Rules

Thus, an enclosed system's role can be recognized by its activities that influence outward, and the enclosing system's role can be recognized by its rules that influence inward. In relation to enclosing systems, the relevant characteristic of the enclosed one is its activities that continue the (re-)generation of enclosing quality. Vice versa, in relation to the enclosed system, the relevant characteristic of the enclosing system is its rules that guide the (re-)generative activities of the enclosed system. The enclosed system's influence is directed outward; the enclosing system's influence is directed inward.

Outward and Inward Influence

With the complementary roles of a system being both enclosed and enclosing comes the property of a circular, autopoietic regeneration of outward and inward influence in nested systems. The enclosed system's (re-)generative activities influence the enclosing system, while the guiding rules of the latter influence the activities of the former.

This relation may become clear when again considering a central place system. Changing the rules that guide the individuals' activities, e.g., what and where to produce or buy items, may first lead to changes in the enclosed systems through inward influence; changed activities may then change the quality of the central place system through outward influence.

Another example would be when an end to the exploitation of certain natural resources is reached in a region, changing the activities of individuals. This change eventually interrupts the established working mode of the central place system, and may perhaps lead to a vanishing of the quality of a central place (e.g., the Ruhr region in Germany, cf., e.g., Wehling 2014).

Fast and Slow Change

A further characteristic of nested systems is the relation of a relatively fast change of individual's activities in an enclosed system with a relatively slow adaptation of the enclosing system. This relation can be exemplified by a political system that emerges from the activity of men, as well as what then acts back on them. If the political system had a frequency of change faster than the pace of men's activities, how could men ever follow a rule of this political system? Also, if the political system could react and adapt with an internal speed faster than the dynamics of a revolution, revolutions could not occur.

3.2 Objective Novelty in Ontologically Real Systems

Do we only perceive things as complex (epistemological), or are they complex (ontological)? The first and second section below deal with this question and bring up the emergence of novelty, versus a deterministic course of events—as an argument for an ontological reality of complex systems (Sect. 3.2.1). This argument is further supported by the ability to discern complex systems from one another by their relative speed of activity—a measure which does not depend on subjective perceptions (Sect. 3.2.2).

These considerations that involve objective novelty will bring about the question of the predictability of the future. I will argue that indeed, foresighted man may anticipate possible futures of known type, though not the particular characteristics of real novelty (Sect. 3.2.3).

3.2.1 Subjective Novelty?

With regard to the emergence of new quality and its rules, which together make for an enclosing system, one might feel tempted to ascribe the lack of imagining such novelty to limitations of the individual, i.e., to man's subjective processing of knowledge (see also my Footnote 2 in Sect. 2.1). Miller and Page (2007) write that

> Part of the innate appeal of emergence is the surprise it engenders on the part of the observer. Many of our most profound experiences of emergence come from those systems in which the local activity seems to have arisen by magic ... (p. 45)

They go on to wonder if

> It could be that emergent activity is simply reflective of scientific ignorance rather than some deeper underlying phenomenon. (p. 46)

I argue that ascribing the surprise to our subjective limitations implies that once we overcome our subjective limitations, we would be able to avoid such surprise, e.g., by forecasting a priori the emergent quality (Fig. 3.1). This, in turn, would require a universe (or versions of one) that could be foreseen *ad infimum,* a universe of which every future state could be determined.[1]

3.2.2 Ontologically Real Systems

A nested system can be distinguished by it being enclosed by another system, and it enclosing at least one other system. For example, a neighborhood can be recognized by distinguishing it from the enclosing urban district, the enclosed micro-neighborhoods, and the other neighborhoods of the same and adjacent districts. A system, hence, can be defined by *discerning* it from other systems in a nested arrangement of systems.

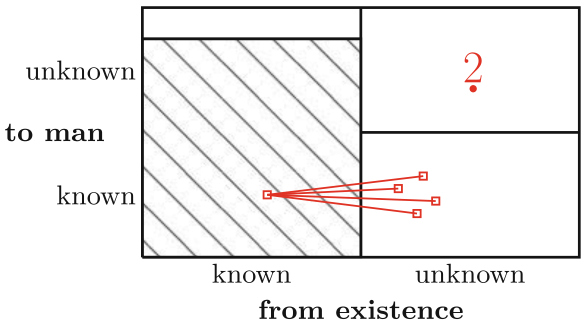

Fig. 3.1 If surprise were only a result of limited, individual knowledge (*dark hatched area*), then increasing, individual knowledge should eventually eliminate surprise. Every potential surprise could be predicted (*red lines* of possible future scenarios) as known unknowns coming into existence. In a world in which, in principle, only predictable, known unknowns can come true, however, no objective novelty—i.e., unknown unknowns—could ever come into existence

[1]The number of possible futures increases exponentially with every change in propensities. There would quickly be more possible futures to be considered than there are atoms in the universe—whatever the implication would be of that (rather materialistic) consideration.

A possible heuristic is suggested here to distinguish systems by their speed of change (cf. Sect. 2.4). A system may be discerned either by its relative frequency of change, as compared to other enclosing and enclosed systems, or by looking at how frequent activities occur within the system. A system's borders with enclosing, enclosed, and neighboring systems are the local minimums of activities (Fig. 3.2).

For example, a neighborhood is often defined by its close-knit, intensely interacting social and economic parts. Or, in a region of central places, the economic functions vary with the centrality of the place. Each central system can be differentiated from the enclosing system by specific economic functions that lead to relatively strong activities *within* the system and relatively few activities beyond it. Hence, an urban system reaches as far into the region as its specific functions lead to activities (cf. Christaller 1933, p. 25).

3.2.3 Forever Indiscernible Causes?

Once a new quality has emerged and surprised us, there might be hope of eventually explaining the emergent quality, based on situations out of which that quality came into existence. Such hope was also expressed by, e.g., Popper (1978): "Life, or living matter, somehow emerged from non-living matter; and it does not seem completely impossible that we shall one day know how this happened" (p. 352).

In the future, it might be possible to know, in more detail, the situation that generated the propensities out of which a *type* of new quality emerged (Fig. 3.3). However, this knowledge can only be gained once the quality has already emerged, not before its first coming into existence. The explanation is only possible *a posteriori*. Hence, man might be able to recreate the situations out of which a known *type* of emergent quality, e.g., life, consciousness, or urbanity, *may* emerge.

However, the *exact* coming into existence of these qualities remains unknown. Newly emerging quality will never spare us surprise, no matter how well we understand generative situations. This occurs because emergence is realized out of the propensities of a *unique* moment in time and space. As a consequence, no two men

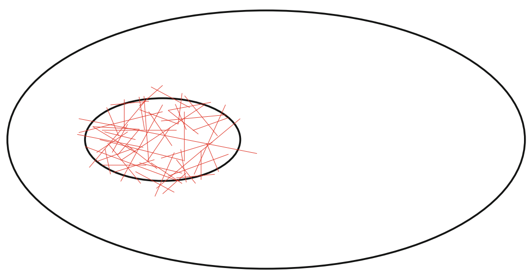

Fig. 3.2 One system enclosed by another (*black circles*) and activities of the enclosed system (*red lines*). The enclosed system's border can be distinguished by the relatively low, cross-border activity, as compared to the activity within the system

possess an identical consciousness, and no two urban places convey the same feeling of urbanity (cf. also below, Sect. 3.3.5). Similarly, no two electrons in a molecule occupy the same orbit (the so-called Pauli principle).[2]

3.3 The Power of the Individual and the Whole

What do such theoretical insights about ENS mean regarding influencing them? I suggested above that explanatory power lies in the concepts of enclosing and enclosed systems, slow and fast systems, and guiding and generative systems. In particular, in every ENS, there are two types of influences: outward influence that may generate the propensities out of which further new systems can emerge, and inward influence that, in turn, guides the activities of outward influence.

Outward and inward influence can be seen as the power of the individual (Sect. 3.3.1) and the power of the whole (Sect. 3.3.4), respectively. Where novelty comes into existence, a third power is at play: the power of emergence (Sect. 3.3.5). Neither novelty nor the significant impact of individual activities, or the guiding rules that lead to changes on such activity, can be understood in terms of statistics (Sects. 3.3.2 and 3.3.3). This section thus puts the use of statistical models into perspective regarding complex systems.

In the words of Hayek (1964):

> …it is necessary to turn aside and consider the method which is often, but erroneously, believed to give us access to the understanding of complex phenomena: statistics. (p. 339)

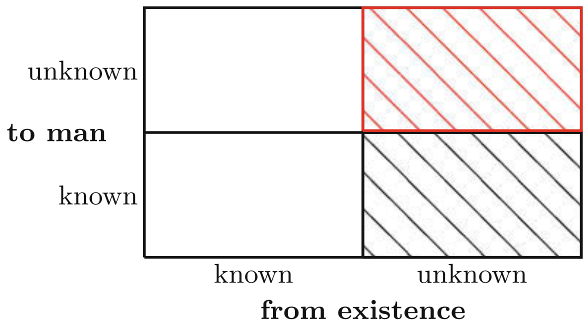

Fig. 3.3 Once quality has emerged, it may be recognized by man, and the same *type* of quality can be imagined for a future situation, i.e., a known unknown (*dark hatched area*). However, the particular instance of any new quality must be the coming into existence of an unknown unknown (*red hatched area*)

[2]The rule may or may not be locally limited. Is it possible that remote systems are completely disconnected? This is a question not only of quantum mechanics, but also beyond the material reality. If the answer is yes, it may be possible that two qualities emerge that are exactly the same.

3.3.1 The Power of the Individual

Activities of outward influence (Fig. 3.4) change situations and, hence, propensities, out of which new quality may emerge as a new enclosing system. On one hand, emergent qualities arise without the activities of conscious minds. In evolutionary processes, purposeless mutation changes situations. Mutation is, thus, the activity that generates the propensities, out of which many emergent qualities come into existence, including life and consciousness (cf. Sect. 1.3).

On the other hand, since the emergence of conscious minds first occurred, some decisions are made with *purpose and foresight.* An individual's decisions, which might well be influenced by an idea that itself has been emergent, can be relevant, or even decisive, regarding the introduction and/or realization of a propensity.

The course of development of a complex system may be changed by an individual's activities. These may not average out with other individual's activities, but rather, they may change situations and propensities, or even realize a propensity by purposive choice. Therefore, the development of an emergent nested system like a city may be decisively influenced by one individual's (purposive) decisions. Man has "the freedom to create" (Popper 1978, p. 350).

3.3.2 Modeling Averages

Any model that is based on averages neglects the influence of individuals' activities on complex systems. Two notable suggestions of modeling complex systems should suffice to exemplify this claim: Simon's theory of near-decomposability and Haken's theory of synergetics. The conclusions of the former are based on weak and strong forces, which hold nuclear particles together. The strong forces are all consumed in the immediate vicinity of the nuclear particles and, hence, can be neglected on any more global level. The latter theory omits outward influence, in favor of inward "enslaving rules" that are bound to determine the whole's activity.

Simon (1962) argues, based on the observation of physical systems, that the higher frequencies in enclosed systems are related to internal activities which, from the

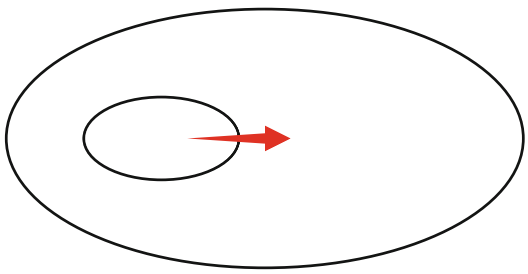

Fig. 3.4 Through outward influence, activities of the individual may generate propensities, out of which the enclosing quality might be changed, or new enclosing quality might emerge

perspective of the enclosing system, average out. Thus, he concludes that the enclosing systems "can be described in terms of the average activity of the subsystems" (Simon 2000, p. 8). Systems are, hence, "nearly decomposable," with the faster activities inside systems being separable from the slower activities that keep the whole together (e.g., Simon 1962, p. 477 and Footnote 9 in Chap. 2).

Such a view of complex systems might be appropriate in steady-state situations, or in situations in which the faster system, after a disturbance, returns to a steady state before new situations can change the slower system (cf. Simon 1993, pp. 3–4). However, if the faster systems' activities—which may change the slower system, or even generate propensities, out of which new quality (i.e., another slower system) can emerge—should be considered, such an approach will not progress further.

Likewise, Haken and Weidlich conclude that it is possible to reduce the complexity of a nested arrangement by looking at the system with only slower dynamics. The theory of synergetics introduces the concept of "order parameters" (e.g., Haken 1977, p. 198), by which the enclosed systems can be considered enslaved (Haken 2012, p. 9). I.e., these systems can be considered "driven and guided by…macrostructure" (Weidlich 1999, p. 138), always adapting to the enclosing system (Ibid., pp. 138–139). Hence, here as well, the fast system may only be considered during its average activity (Ibid., pp. 137 ff.).

Similar to Simon's concept of near-decomposability, synergetics may well describe the enclosing activity of slow systems, and it may fail, in the case of emergence out of situations in the faster systems. Neither Simon nor Haken offer an explanation for the power of the individual, i.e., the influence of activities in enclosed systems. Their theories do not ascribe the timing of the decay of a radioactive nucleus, or the coming into existence of a revolution out of man's purposive decision-making.

3.3.3 The Use of Statistical Models

Complex systems are influenced by *individual* activities that may be purposive. These activities don't allow complex systems to be treated as analytical systems, and neither do these activities always average out, as just discussed. The modeling of statistical systems is, thus, a significant simplification of reality. Statistical systems (and/or models) are not complex.

Nevertheless, since statistical models which work with averages are being applied, they may be useful. Systems can be successfully modeled when based on averages—in special cases. Where systems are actually near-decomposable, i.e., where faster systems strictly follow the guiding and selecting rules (Fig. 3.5), no activities (purposive or not) may change the slower system or generate propensities, out of which new quality may emerge, and a statistical model may be applied. Also, if the individual's activity has no influence on the activity of his fellow man, as is the case in polls, a statistical model works well.

Additionally, models based on averages work—when it can be assumed that individuals only have a few choices and can only follow a few average activities. Thus, statistical models may work, e.g., in forecasting the movements of pedestrians. However, the predicted, overall activity turns out incorrect in cases when an individual makes an unforeseen decision that changes the rules guiding the average, individual activity.

If, however, a model were to simulate suggestions for innovative ideas for urban development, even when knowing the most dominant rules of individual activity, this model could only fail. Rather than activities that are, on average, predictable, e.g., voting results for elections or the movement of pedestrians, innovative ideas are emergent and, thus, unpredictable.

3.3.4 The Power of the Whole

The rules of enclosing systems reflect the power of the whole. This power guides and selects supportive and maintaining activities in the enclosed systems (Fig. 3.6, cf. Sect. 2.3.2). Hence, the enclosing system, through its rules, guides the (purposive) activities for its own well-being, i.e., for its autopoietic survival.

Thus, the above-mentioned power of individuals' activities in the enclosed system can be either extended or limited by the power of the whole. On one hand, the whole may, upon its emergence, make additional activities in the enclosed systems possible.

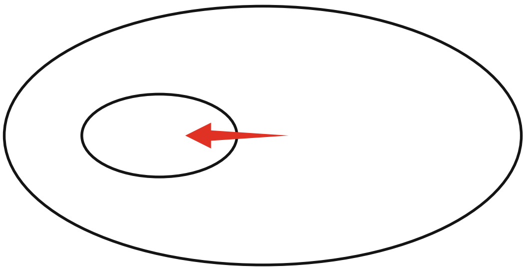

Fig. 3.5 In near-decomposable systems, the enclosed systems follow the guiding and selecting rules of the enclosing system

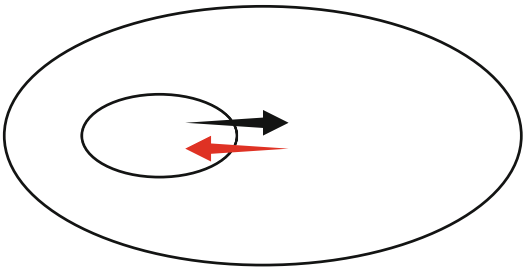

Fig. 3.6 The enclosing system, by means of its rules, guides and selects (*red arrow*) supportive and maintaining activities (*dark arrow*) in the enclosed system and, thus, guides the interrelation that makes the whole

On the other hand, it may restrict formerly allowed activities. For example, after the emergence of a central place system, a central hospital might be built, and it will become the normal activity to go there—and no longer go anywhere else—for treatment.

As discussed above, models based on averages are able to represent the power of a static whole, i.e., a snapshot in time of a whole. As long as there is no change in the enclosing quality or emergence of new quality—and as long as all that matters for the whole's future is that the activities in the enclosed system strictly obey the enclosing system's rules—it might suffice to develop a model of the enclosed system's activities. (E.g., agent-based models rely on this approach, cf. Sect. 7.5.2.)

3.3.5 The Power of Emergence

Emergence is more than the reorganization of known qualities in different patterns. Known qualities in different patterns are predictable, and whether they are a surprise or not depends on subjective knowledge. This is not so with emergent qualities. Emergent qualities are the, in principle, unpredictable coming into existence of unknown unknowns, i.e., realizations of propensities that are generated by *unique* situations of complex systems (Fig. 3.7, cf. Sect. 2.2).

Propensities of situations—not devised design—yield emergent systems. Hence, emergent systems cannot be made directly from human intention. Even if the making or remaking of a type of emergent quality is intended, the desired quality might not emerge.

Though not intently, some emergent systems are clearly man-made. Activities of individuals may generate the propensities out of which enclosing systems emerge. Examples of enclosing systems that emerge through the activities of individuals include cultural systems, economies, and spatial systems, such as central place systems.

An emergent system, even of a known type, e.g., a central place system, always comes with at least some novelty. The novelty of the enclosing system emerges out of *unique* situations. As mentioned above, no two individuals possess the exact same type of consciousness, and no two cities evoke the same feeling of urbanity; each emergent system has its particularities. These particularities of emergent system cannot be foreseen.

If it is not foreseeable, can emergence be influenced? Is it possible for purposive influence to alter systems that have already emerged? Before turning to the answers to these questions in Chap. 4, a note is due regarding the notion of emergence as used in recent literature.

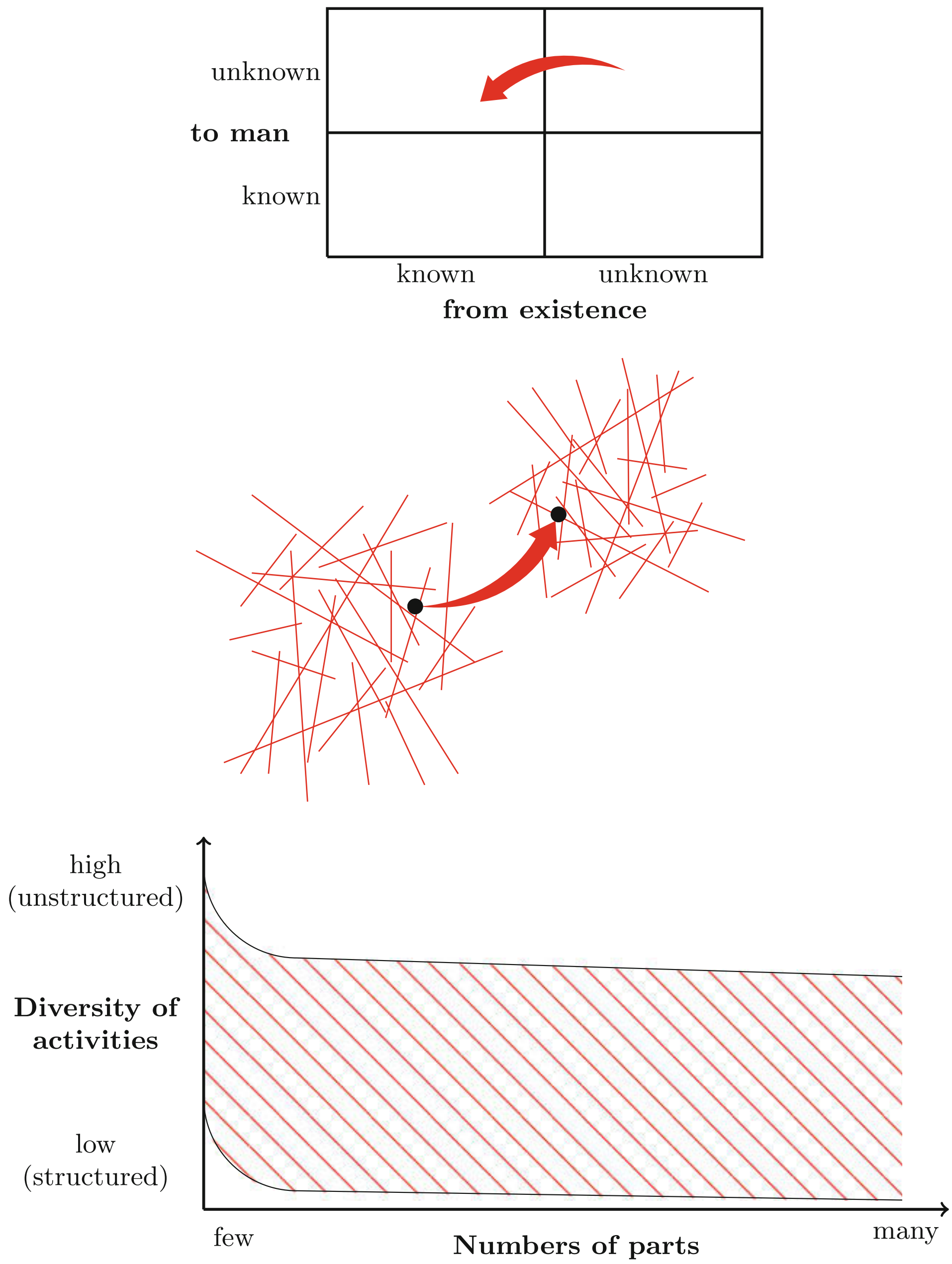

Fig. 3.7 Emergent qualities are the, in principle, unpredictable realizations of *unknown unknowns* (*top*) out of *propensities* (*center*) that are generated by unique situations in *complex systems* (*bottom*, *red hatched area*)

3.4 Emergent, Not Reshuffled

The notion of emergence is used ambiguously in literature, referring either to the coming into existence of an unknown unknown, or to the rearrangement of known qualities. According to the first meaning of emergence (which I adopt in this work), a pattern that involves no new quality, but only forms from known qualities—i.e., that can be described as a compound of previously existing qualities—is not emergent.

The second meaning of emergence is used in, e.g., modeling literature. There, emergence is often used to name a pattern that *results* from the activities of individuals, guided by the enclosing system's rules (cf. my Footnote 7 in Sect. 2.3). I.e., emergence is frequently used to describe the results in relatively fast systems, evoked by (changes of) guiding and selecting rules (Fig. 3.8). For example, Miller and Page (2007) describe emergence as a "phenomenon whereby well-formulated aggregate behavior arises from localized, individual activity" (p. 46).

There is a crucial difference between the rearrangement of existing qualities and emergence that comes into existence as new quality. The "aggregate behavior" of existing qualities describes resulting patterns, e.g., a different distribution of residential and commercial areas, or the way in which people move in a pedestrian zone (cf. the discussion of statistical models above).

In contrast, emergence, as understood in this work, cannot be foreseen and introduces new quality that is more than aggregate behavior. Emergence cannot be modeled in, e.g., life and consciousness; i.e., the political and economic systems could not have been the result of a model before they first came into existence. This difference between the two meanings of emergence is, in literature, commonly understood as a difference between "strong" and "weak" emergence (cf., e.g., Wilson 2012).

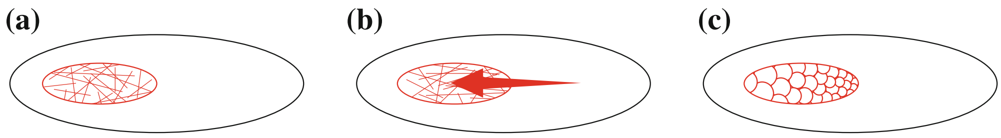

Fig. 3.8 If, in an arrangement of nested systems, the enclosed system (**a**) is subject to rules and to the selection of the enclosing system's inward influence (**b**), the change in the enclosed system is resultant, not emergent—however nice it may look (**c**)