Chapter 1

System Features, Dynamics, and Resilience – Some Introductory Remarks

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1. Complex Systems

The interest in “complex systems” has grown over the last few decades. The focus is on the “involvement of many parts, aspects, details, notions, and necessitating earnest study of examination to understand or cope with” (Webster´s Third New International Dictionary, as quoted in Klir, in UNU 1985). It thus deals with the interplay of many elements in a varied fashion due to many variables and structural constrains. However, the word “complex”, as it may be applied to many different systems, could have many meanings. Briefly, it can be said that the degree of complexity can be measured in terms of information: “the more information that is needed to describe a system, the more complex it is”.

Yet, there is no obvious or pre-eminent definition of complexity, “although all world agree that the brain is complex and a bicycle simple, one has also to remember that to a butcher the brain of a sheep is simple while a bicycle, if studied exhaustively (as the only clue to a crime) may present a very great quantity of significant detail” (Klir, in UNU 1985). In this sense, “the complexity of a system is in the eye of the beholder. It is measured by how well we understand causes, expect behaviours and, in praxis, achieve purposes. Hence, large numbers of variables, non-linear relations among them, and the open nature of a system are important only to the degree they present barriers to understanding” (Holling, in UNU 1985).

Characteristic features of complex systems have to do with the web of frequently non-linear interrelations between variables. This setting introduces thresholds, lags and discontinuities. The feedbacks and feed forwards opens up for surprises and non-intuitive behaviours of the systems. Sometimes the uncertainties found in the analysis of the systems calls for reflections about deeper indeterministic behaviours. The nature of the causal webs push the need to address multicausal phenomena in frames that may not even be clearly defined, as systems may be more or less open.

Although complex systems could be very simple, such as a double pendulum, or a chemical reaction with three substances, they often consist of a large number of components, such as in the case of a biological cell, a brain, or an ecosystem. Other characteristics of complex systems include non-linearities, self-organization and emergence. Complex *global* patterns can be generated by repeatedly applying simple *local* procedures or rules. Above a certain threshold of complexity, new qualities may arise (emerge).

Complex systems are often, due to their non-linear nature with feedback loops and time delays, prone to (deterministic) chaotic behaviour. We will not here elaborate much on this, but just mention some of the characteristics of such behaviour. These include sensitivity to "initial conditions", and unpredictability at a longer time scale, while the behaviour may be predictable at a shorter time scale. Thus, this irregular, or random behaviour is more structured than "pure noise", which is unpredictable at all scales. Examples of systems, which have been described as chaotic include turbulence (e.g. smoke, cream in coffee), the weather, brain-waves, certain ecosystems, and the stock market. Actually, many systems with three or more coupled components can display chaotic behaviour under certain circumstances (with a certain set of parameters).

It is already at this point clear that we are speaking of complexity at different levels, both in time and space. Thus, the discussion on micro-meso-macro scales apply equally well to the temporal as to the spatial scale. In fact, often the temporal and spatial scales are correlated, so that spatially "microscopic" systems and structures are characterised by a "microscopic" time scale, i.e. "the smaller the system, the faster it moves". Similarly, larger systems are typically characterised by longer time scales (slower motions). For example, the characteristic time scale of molecules is at fractions of seconds, whereas that of macroscopic systems, such as "touchable bodies", is much longer. This is also important to keep in mind, when we are talking about shocks and resilience, relative to processes with time scales that are either relatively "microscopic", or "macroscopic" in time.

In general, a shock is a relatively fast process, whereas a possible resilience "defence" process may not only be able to absorb the shocks in real time, but may also have to reorganise the system over an extended time frame. The connectedness in time frames between the "shock" and the "resilience" part of the process is of course much closer when it concerns phenomena that could be regarded as mere "elasticity", as in a young tree trunk or a mast which is subject to a sudden blow of wind, and quickly recovers to almost the identical initial state. The resilient recovery process is in this case of roughly the same order of magnitude in time as the shock, although of course somewhat slower. Another case concerns a forest fire of three days of high impact, which will require a prolonged period of ecosystem recovery of several decades and in some cases centuries when the resilient characteristics of the ecosystem may show its capacities to bring the ecosystem back to something which is at least somewhat similar to the state before the fire started. It is also important to see that the problem of complexity concerns structure, its connected functions, as well as dynamics. However, a simple structure, such as a double pendulum can, despite the "simplicity", give rise to a complex and unpredictable behaviour ("chaos"). Likewise, a large system consisting of millions of particles, such as a gas or liquid, can have a rather simple and predictable behaviour, for example as moving waves (sound or sea waves). Under certain conditions, though, the same system of particles may behave chaotically, as in turbulence.

Related to these issues is the so-called "stability-sensitivity dilemma", i.e. how can the system maintain a stability to external (and internal) fluctuations, while at the same time being able to respond to weak signals? It is essential that the system is stable to short-term fluctuations, or common insignificant events, while it should also be able to react to rare important events, as well as adapting to long-term changes. Ideally, the system should be able to regulate its sensitivity, depending on the circumstances, so that it can be stable and non-reactive to insignificant fluctuations, and sensitive and reactive when the situation demands it. Biological systems have evolved such adaptive mechanisms and can change rapidly its sensitivity, as for example an eye, which can, under certain circumstances (darkness) sense a single photon, while it can also function quite well under intense sunlight.

We will return later to the problem of how systems can deal with fluctuations, noise or chaos, but we will first discuss the kind of (complex) systems, which this book primarily deals with, namely biological and combined socio-natural, as well as socio-technical systems. These kinds of systems express many features of what we refer to as "complex systems". They often can be described in terms of network structures, or various hierarchies, opening up for all sorts of interactions, typically with both feedback and feed forward loops, enabling amplification, as well as attenuation and control. Such systems are also often characterised by a high degree of redundancy, which make them less vulnerable to disturbances and malfunctions of the parts. These systems are often self-organizing and adaptive. There could emerge spatio-temporal order out of disorder. The systems typically operate far from any equilibrium, and they could be intrinsically unpredictable. (See Århem, Liljenström & Svedin, 1997)

As an example, the human brain, often described as the most complex system known, has all the characteristics above. There are feedback loops in the neural networks, which seem to be responsible for the oscillations and chaoticlike behaviour that is found in, for example, EEG (electroencephalography) recordings of the cortical neurodynamics (Freeman, 2000). Complex spatio-temporal activity patterns are also apparent in other brain imaging techniques, such as PET (positron emission tomography) and fMRI (functional magnetic resonance imaging). In addition to the network structures of the brain, it is also characterised by a hierarchical organization, as for example in the visual system, from the eye to the higher visual areas in the back of the head. The structural organization of the brain and the neural activity that arise in these structures seem intimately linked to the functions of the neural (sub)systems. Vision, for example, is a result of an amplification of the retinal response to photons, and the amplified signals are then subject to adaptive control and self-organised neural activity in the subsequent brain structures, until the activity eventually become conscious experience. How the neural activity is related to conscious experience is, however, still a mystery.

2. The micro-macro span

As we have discussed above, there are many features of complex systems. One of them deals with the "layering" structures: i.e. different phenomena appear at different levels of aggregation and spatial scale, while at the same time there could be an interplay between the system as a whole and other systems which also may by "layered". In many cases, this means that new and unpredictable qualities emerge at every level, qualities that cannot be reduced to the properties of the components at the underlying level. In some cases, you could find a hierarchical structure of a simple kind, where "higher" levels "control" lower ones (c.f. the so-called enslaving principle, Haken, 1983). To a certain extent this happens in food webs, where higher level predators could be seen to "control" the outcomes of existence at lower levels. But there could also be a more "bottom-up" interpretation of systems, where indeed the micro phenomena, through various mechanisms, set the frame for phenomena at higher structural levels. This interplay between micro and macro levels is part of what frames the dynamics of systems.

It also contributes to the vulnerability and evolutionary characteristics of them.

Often, analytical approaches to such structural phenomena has either been devoted to the macro level, or to the micro level. The interest in probing the complexity nature of systems calls for an increased attention to the interplay between the levels, including a special focus on the "meso-level", i.e. the level in between the micro and the macro, as that is the domain where bottom-up meets top-down (Freeman, 2000).

One can thus as an example approach complex systems in the biological world at different organizational levels: 1) the microscopic, (e.g. at a molecular level), 2) the mesoscopic, (e.g. at a cellular level, and 3) the macroscopic level (e.g. at the organ level). These levels are of course linked to each other in various ways, bottom-up and top-down, and the functionally significant couplings are found both for processes (temporally) at the different levels, as well as structurally (spatially). In general, a large number of components at any one level are necessary to make any impact at the next higher level. This is, however, not always true, and a single "individual" component or event can have effects also at a higher, "population" level.

There is yet another – but similar – approach to the organization in micro-meso-macro aspects, which apply, for example, to ecological or social structures. That approach could be appropriate when discussing the relation between an individual ("microscopic") and the group or population ("mesoscopic"), within which it is a part, and to the entire ecological system ("macroscopic").

As briefly mentioned above, there are also interesting and important relations between *processes* at micro- and macroscopic levels, often describable in terms of "microscopic" and "macroscopic" time scales. Environmental changes occur at several time scales relevant to life, but it is impossible to make any exact separation of these scales matching the different life processes. One attempt is to crudely relate to the average life span of an individual organism. In particular, this can be applied to the animal brain, which we will return to in the next section.

In a social system, e.g. dealing with the structure of decisions, the multilayered structures play more and more important roles role (Rolén, Sjöberg & Svedin, 1997). Globalisation phenomena (macro) meet phenomena at a local level (micro). It is very difficult to deduce the effects at one level to those at another. Of course, the ensemble of micro events build up global tendencies. But what are the mechanisms of shaping coherence on the way up the ladder? And to which extent do globalisation phenomena really frame local events, more than just preconditioning them in certain fairly vague directions? Often, the analyses about such layered interdependencies (O´Riordan, 2001) take as a start the observation that no specific actor may claim a full knowledge of the system. Thus, the issue of overview, or the lack of it, holds some of the keys to the understanding of such multilayered phenomena, including the understanding of interdependencies between levels and the actors operating the interplays.

Social phenomena often express themselves in a frame of a natural environment. In this way, there may be two ladders of micro-macro relations that relate to each other: one of socio-economic-cultural character, and one of natural origin. The specificities in these two realms, and the logic running them, may be very different. However, when combined these two systems connect. Then, the issue of the match between them becomes paramount. One example is the watershed management around a river. The natural system of the water flows has to be managed within a socio-economic and cultural context, which comprises the other part of the joint socio-natural system. The interplay between the levels – and the role of the meso-scale – is here of central importance.

3. Dynamics

Features of systems in terms of their development over time are, of course, highly interesting. It was the interest in the time patterns of the planetary movements that once opened up for the development of classical physics. But for most complex systems, e.g. in biology, the time development has to be understood in ways that do not only draw on the experiences from how physical systems behave. This holds true even more for social systems, including the changes in cultural patterns.

In order for living organisms to survive in a complex and changing environment, they need to be able to respond and adapt to environmental events and changes at several time scales. In particular, organisms with a nervous system can adapt to environmental changes at three different time scales: 1) a very long one based on genetic changes (evolution), 2) an intermediate one based on permanent synaptic changes (learning), and 3) a short one based on neuronal activity and transient synaptic changes (perception–action). The latter should be in the order of a few hundred milliseconds, or less. The interaction with the environment, e.g. in terms of behaviour of an animal, depends upon the present (dynamical) state of the organism, as well as on previous experiences stored in its molecular and cellular structures. At a longer time scale, organisms can adapt to slow environmental changes, by storing information in the genetic material (DNA and RNA molecules) that is carried over from generation to generation.

At a shorter time scale, the immediate interaction with the environment is a result of both the genetic information and of learning. Single cell organisms, such as bacteria and amoebas, have a rather direct interaction between the intracellular processes and the extracellular environment, whereas multicellular organisms have differentiated cells with different functions involved in the interaction. In animals, some cells act as sensory cells, whereas other cells function as motor cells and yet other cells connect and distribute information between the sensory and motor cells. Eventually, larger and larger networks of interconnected nerve cells (neurons) between the sensory "input" and motor "output" expand the realm of behaviour of the organism. If the nervous system, in particular the brain, has been optimized during evolution to deal with complex and rapid environmental changes at time scales shorter or comparable to the life span of the individual (including the interaction with other individuals), it should be reflected by a rich "inner" dynamics. Whereas biological systems are complex and driven far away from equilibrium, most systems described mathematically in e.g. physics and chemistry are relatively simple and at equilibrium. In contrast to systems at equilibrium, where "nothing interesting happens" – and in which the future looks roughly the same as the present – complex systems far from equilibrium can exhibit a very rich dynamics. The future is here unpredictable, but with information about present and past states, future states can in some cases be predicted to a satisfactory degree. This is done with the aid of the dynamics of the brain, which also determines the complex behaviour of the organism. The activity of the brain can partly be studied with experimental techniques, such as EEG, PET, and fMRI. It reveals a very complex dynamics, with oscillations in certain frequency bands interspersed with aperiodic, chaotic-like behaviour.

The dynamics of neural systems, the neural activity of the brain at its different spatio-temporal scales, can be analyzed mathematically and computationally. At the *microscopic* level, mathematical analysis is used to understand, for example, ion channel activity. At the *mesoscopic*, or cellular level, a mathematical description could concern nerve impulse activity, both in terms of interval and amplitude variability. At the *macroscopic* level, there can be a mathematical treatment and computer simulations of extra cellular recordings of brain activity, such as different.

There are three major types of dynamics that can be mathematically described: 1) steady-state, (fixed-point dynamics; equilibrium), 2) oscillations (limit-cycle attractor dynamics), and 3) deterministic chaos (strange attractor dynamics). In addition, the dynamics of a system can be totally irregular, without any structure, as a result of uncorrelated, stochastic events. Such dynamics can only be described mathematically in terms of probabilities and distributions.

The rich dynamics of the brain can be well exemplified by the olfactory system (primarily bulb and cortex), which has been extensively studied by Freeman and co-workers (2000). This system processes odour information, determining the quality and quantity of odour objects in a fluctuating environment. An essential feature of its dynamics is spatio-temporal patterns of activity, which do not seem to depend critically on the detailed functioning of individual neurons. Self-organization of patterns appears at the collective level of a very large number of neurons. Oscillations occur at various frequencies, in particular around 5 Hz (theta rhythm) and 40 Hz (gamma rhythm). There are also waves of activity moving across the surface of the olfactory cortex. In EEG studies of bulb and cortex Freeman has also found evidence for chaos, or at least aperiodic behaviour different from noise and with some degree of order.

What is the significance of this dynamics? How is it related to computation and information processing in the brain, and in particular, to cognitive functions? As pointed out before, cognition requires a rich dynamics, but the relationship is far from clear. In some way, the dynamics of the brain, as “the inner world”, seems to be able to reflect the dynamics of the environment, “the external world”. Although oscillations and “chaos” could be mere epiphenomena, as an inevitable consequence of the neural circuitry and without any specific biological role, these phenomena have been suggested to have functional significance.

Oscillatory or complex dynamics provides a means for fast response to an external input, such as a sensory signal. If sensitivity to small changes in the input is desired, a chaotic – like dynamics should be optimal, but a too high sensitivity should be avoided. Oscillations can also be used for enhancing weak signals, and by “resonance” large populations of neurons can be activated for any input. In addition, such “recruitment” of neurons in oscillatory activity can eliminate the negative effects of noise in the input, by cancelling out the fluctuations of individual neurons. As discussed above, noise can, however, also have a positive effect, which we will return to shortly. Finally, from an energy point of view, oscillations in the neuronal activity should be much more efficient than if a static neuronal output (from large populations of neurons) was required. In engineering, great efforts are made to eliminate oscillations in the system, but if the system can perform as well (or better) with oscillations, energy can be saved.

In order for the system to make use of the various dynamical states, there has to be some kind of regulatory or control mechanisms. Many factors influence the dynamical state of brain structures, for example the excitability of neurons and the synaptic strengths in the connections between them. A number of chemical agents act on these neural properties. Such agents, e.g. acetylcholine (ACh) and serotonin (5-HT), can change the excitability of a large number of neurons simultaneously, or the synaptic transmission between them. (They can thus be regarded as "order parameters", in the sense Haken (1983) uses the term for synergetic systems). The concentration of these "neuromodulators" is directly related to the arousal or motivation (or mood) of the individual, and can have profound effects on the neural dynamics and on memory functions. For example, ACh increases the oscillatory activity in the olfactory cortex and in brain slices of hippocampus.

At a general level, learning features in systems provide early warning capacities. Capabilities to transform such signals to adaptive changes of the system make them more robust and increase their resilience.

4. Fluctuations and shocks

We usually address the development of a system under "normal conditions" (which often means slowly varying conditions), and those which are due to unexpected external shocks, such as a meteorite plunging the surface of the earth. We could also have to face internal accumulations within a system of disruptive factors, e.g. the aging of a glass window causing a gradual "brittleness" to develop. This could, in turn make the system extremely fragile to "normally" small perturbations that otherwise would not cause drastic changes (e.g. in terms of irreversible cracks of the glass). In this sense, sudden drastic changes to systems may have several origins, both at the level of the "resilience" of the system, as well as being due to the character of the impact or the time development of the triggering event.

When discussing the long-term development of complex systems, one sometimes deals with catastrophic events in terms of intrinsic and external influences, respectively. Most often, catastrophic events, such as error catastrophes in the cellular protein synthesis system, mass extinctions of species, or breakdown of a technical or social system, are believed to be due to external "forces" acting on the system, such as a drug, an earthquake or a meteorite. However, there is also the possibility that there are intrinsic factors of the system itself, which causes these catastrophic events. It is said that these systems are "at the edge of chaos", i.e. small fluctuations will inevitably, sooner or later, bring the system across the threshold of instability. This phenomenon has been termed "self-organised criticality", and is popularly illustrated by the growth and collapse of a sand pile (Bak, 1998).

It is important to note that what might be regarded as a shock or catastrophe at one level may be an insignificant fluctuation at another level. E.g. the death of a single cell of a multicellular organism, or a wound of moderate size, the death of an individual of a population, or the destruction of a village due to an earthquake. All these events may pass without notice at a higher level of organization, or at a longer time scale. Similarly, the gaps that appear in a rain forest due to tree fall or fires are local "catastrophes", but can be seen as normal fluctuations in the spatio-temporal development of the forest. Indeed, such catastrophes/fluctuations constitute a necessary part of the normal life of the forest: it allows for new individuals of various species to prosper and grow, which otherwise would have been prevented by the previous structures. The same could, as seen from a very general level of observation, be said of mass extinctions of life forms (for example, the dinosaurs), or even of societies and cultures.

An interesting aspect of biological systems in general and of neural systems in particular, is their dependence on noise and errors (See Århem, Blomberg & Liljenström, 2000). Biological systems are normally associated with a high degree of order and organization. However, disorder – in various contexts referred to as fluctuations, noise or chaos – is also a crucial component of many biological processes. For example, in evolution random errors in the reproduction of the genetic material provides a variation that is fundamental for the selection of adaptive organisms. At a molecular level, thermal fluctuations govern the movements and functions of the macromolecules in the cell.

The role of noise, or random events, in biological systems was perhaps first brought to attention by Schrödinger (1944). In his book *What is Life?* Schrödinger asks fundamental questions regarding the stability and sensitivity of our body in general, and of the brain and sensory organs in particular. He argues that our sense organs (and the brain itself) would be useless if they were too sensitive and reacted to single atomic motions. Based on a general statistical law, Schrödinger argues, "that an organism must have a comparatively gross structure in order to enjoy the benefit of fairly accurate laws, both for its internal life and for its interplay with the external world".

The activity of neural systems often seems to depend on non-linear threshold effects, where microscopic fluctuations may cause rapid and large effects at a macroscopic level. The "errors", or inaccuracy, in the neural information processing could in fact be the key to human intelligence. This "fuzziness" in our neural processes, which results in some kind of "indeterminism", or at least unpredictability in our actions, does not need to depend on quantum processes. It also does not need to involve chaotic processes, in a true mathematical sense. Chaos, as it is characterized by mathematical means, requires "infinite" time for its development, whereas the neural processes are very unstable and shift from one state to another within a few hundred milliseconds or less. Yet, there is a dynamical region between order and pure randomness that involves a high degree of complexity and which seems characteristic for neural processes. The complex dynamics of the brain can be regulated e.g. by neuromodulators and perhaps also by noise. By this flexible control the neural system could be put in an appropriate state for the right response-action dependent on the environmental demand.

Internal, system generated fluctuations can create state transitions, break down one kind of order in order to make place for and replacing it with a new kind of order. Externally generated fluctuations can cause increased sensitivity in certain (receptor) cells through the phenomenon of *stochastic resonance*. The typical example of this is when a signal with the addition of noise overcomes a threshold, which results in an increased signal to noise relation.

5. Resilience and vulnerability

When can "microscopic fluctuations" have effects at a macroscopic level, and become shocks to the entire system? The decay of a single uranium atom has normally little macroscopic effect, but the effect can be amplified if a chain reaction occurs in a large number of uranium atoms. Similarly, a single virus or bacterium is not harmful to an organism, but it is the proliferation of the viruses or bacteria that become harmful and maybe even lethal (catastrophic) to the organism. Also, very different types of systems in the socio-economic domain express similar features. It is generally considered that the coordinated action of a large number of stock holders can avalanche into a stock market crash.

Also neural systems are subject to non-linear threshold effects, where microscopic fluctuations may cause rapid and large effects at a macroscopic level. Single ion channels are found to be capable of eliciting action potentials in small hippocampal interneurons. Computer simulations show that spontaneous neuronal activity can induce global oscillations in networks of neurons. For a small change in some parameter values, the global activity instead becomes chaotic-like. However, a more typical example of shock-resilience in the context of neural systems, is the case of a stroke or a blow to the head. In the first case, the recovery involves the reorganization and re-establishment of the damaged neural structures, a process which demands a relatively long time. In the second case – the blow to a head (which might cause a fainting) – the recovery is usually much faster, and only seems to involve the re-establishment of normal brain activities. In this case there is no long-term damage to the structures.

Shock effects at a global level often have little or no effect at lower levels. An earthquake is a good example of a shock, which may have many, and different, effects, depending on differences in e.g. technical (building) constructions and system resilience. First, there is a scaling problem: the shock wave may cause irreversible damage to single buildings, while the society as a whole is rather little affected, or easily and swiftly recovered. There may also be little or no effect on "microscopic" structures, such as a clock or a piece of furniture in the damaged building. Secondly, there is a structural problem. Under other circumstances than those above, in another part of the world, a shock wave of the same amplitude (energy) may be disastrous to the entire city or society. The difference could be ascribed both to the construction of the buildings (shock absorbing materials and structures etc.), and to the organization of the society (fire brigades, hospitals, reconstruction facilities etc.).

Often, physical structures have parts, which are more or less vulnerable to shocks, which is evident, for example, when trying to deliberately tear down an old building, by dynamite or by other means. The "resilience" in this case, could be the construction of a new building, replacing the old one. In this case, it is quite apparent that the first part of the process, the tearing down of the old building, is a much more rapid process than the rebuilding part of the process, illustrating the general temporal relationship between shock and resilience discussed above.

Are there general features of resilient systems which can recover smoothly after shock treatments? What is required by a system to be resilient? It is very difficult to provide a list of such general features, but some properties that make systems less vulnerable to shocks include the following: network structure, redundancy, large numbers, a high interconnectivity with multiple connections to and from essential parts, heterogeneity, self-organised regulatory mechanisms (negative feedback), and elasticity.

The reduction of resilience creates an increased vulnerability to societies. For example fresh water systems may have their vulnerability increased to flood events, but also to toxic algal blooms, which has at its origin intensified fertilizer use, higher densities of animals and poor other agricultural practices (Carpenter *et al.*, 1998; discussed in Folke *et al.*, 2002).

At a very general level (Hägerstrand, in UNU 1985) trace some of the dangers to the combined natural and social systems, which make up our planetary predicament, to the split of what is going on in "the external world" and what is mapped as "projects" inside the human mind. "It is as if our welldeveloped capacity to store and hold together systems of ideas makes us unable intuitively to feel the limitations of the external world to accommodate our projects". Indeed, this is an expression of a severe vulnerability at a profound level in our civilization.

6. This book

In this book, a number of authors address the issues discussed above from different aspects and with examples from different intellectual domains: systems analysis, neuroscience, environmental science, physics and chemistry, computer science, social science (including economics), and the humanities.

Some of the issues that we reflect further upon in this book include, that:

- there are common features between complex systems of very different kinds, and from different areas of application;
- in order to better understand and describe complexity features, a cross-comparative analysis of systems and their behaviours is essential, requiring an interdisciplinary approach;
- level couplings in complex systems are increasingly important;
- the meso-scale level as a junction between the rationalities of the micro and macro levels is seen to be increasingly interesting;
- addressing systems behaviour is often motivated by a need to understand the dynamics, especially connected to robustness under pressure and shocks. Resilience features are in this regard of high concern.

The book is divided into three general parts, reflecting different angles of approaches to complex systems and their dynamics. The first part focuses on the "vertical" system structure and meso-level characteristics, whereas the second part deals primarily with inner and outer dynamics. The third part is particularly concerned with the interplay between structure and dynamical stress: the issue of resilience and shocks. As in real life, these aspects are tightly interconnected, and any grouping of the chapters is thus rather subjective and unavoidably overlapping. Nevertheless, we have chosen to group the different chapters in this way, especially, in order to highlight different angles in addressing the multidimensionality of the problems.

In the first part of the book, there is a discussion on the structural interplay between the micro, meso, and macro levels, with examples from neural to ecological and social systems. Hermann Haken opens up with some general remarks on the importance of considering the mesoscopic level in science, with an emphasis on the brain and its organization. He also sets the stage, by linking structure to dynamics and function, which is a frequently recurrent theme throughout this book. Continuing and expanding on the brain theme, Walter Freeman argues on the necessity of connecting neural activity to brain function at the mesoscopic level. At the same time, he points at the difficulty in conceiving and describing the exchanges between levels, seeing that the measures of time and distance are incommensurate, and that causal inference is far more ambiguous between levels than it is within levels, especially when the gap between levels is wide. Moving from the brain to higher level biological systems, Robert Ulanowicz stresses the "middle kingdom" in ecology, in particular the problem of autocatalysis among mesoscale processes, and the notion of propensity, as a "tendency" between deterministic and stochastic processes. The first part of the book ends with a chapter by Abir Igamberdiev, on self-maintained reflective systems as a dynamic link between micro and macro. It discusses hierarchical space-time structures and their relation to computation. This chapter also links to the issue of the next part, emphasizing the dynamics.

The second part of the book primarily concerns the dynamics of complex systems, in particular the interplay between inner and outer dynamics, and between the dynamics at different levels. The first chapter is by Igor Rojdestvenski and Michael G. Cottam, who discuss time rescaling and generalized entropy in relation to the internal measurement concept. They establish a connection between time rescaling and generalized statistics, which also links to the following chapter, by Leif Gustafsson. He approaches the problem of complex systems in terms of dynamic and stochastic models with the aid of Poisson simulation. The focus in Gustafsson's paper is on the combined dynamic and stochastic aspects, which he claims have to be modelled in one and the same model. A dynamic approach to ecological and social systems is given in the next chapter by Alla Mashanova and Richard Law. They examine the resilience of common-property, ecological systems to human exploitation, as representing a serious shock to these systems. They do this in the context of a formal framework for resource exploitation that spans the boundaries of economics, social science and ecology. The same theme is in focus in the final chapter of this part, where Sjur Flåm gives an account of the dynamics and stability of social interaction, based on deterministic differential equations. He cautiously remarks on the difficulty in drawing conclusions from such theoretical speculations. This is, of course, important to bear in mind for any modelling attempt of real systems. The general problem of system stability is also the main theme of the next part.

In the third and final part of the book, we deal with the interplay between structure and the dynamical stress that is ignited by shocks of various kinds. The connected perspectives of resilience and vulnerability are at the heart, and are applied to a number of different types of systems. Nick Winder starts with a few examples of systems drawn from the realm of chemistry, with implications for the environment. Here, the issues of shocks are treated. A key feature is the buffering of effects before they are released. In the next contribution, Charlotte Borrvall, Maria Christianou, and Bo Ebenman deal with another type of system, i.e. the realm of biodiversity. The topic is the possible collapse in food webs, as a contribution to the long history of the issue about the relationship between biodiversity and stability of ecosystems. Sander van der Leeuw, in collaboration with Christina Aschan-Leygonie, expands the systems realm from the environmental one in isolation, to that of the combined socio-natural one. Here, the focus is on how human institutions may influence the handling of this extremely complex and vast system. The issue about the need to get away with the presumed differences between "cultural" and "natural processes" is at the heart of the argumentation. Roger Seaton moves the target to the technological system. His main question is, "How can the characteristics of resilient technological systems be identified, engendered and efficiently managed?". Also here, the link to the natural systems is part of the analysis although the entry point is from "technos", i.e. the man-made world of artifacts. Seen from the angle of economics, the discussion about shocks and changes with potential catastrophic impacts is developed by Yuri Ermoliev, Tatiana Ermolieva and Vladimir Norkin. A shock is here understood as an event, that removes from the economy a part of the capital without affecting its production function. The issue of growth stabilization strategies is one of the important facets to relate to vulnerabilities of such systems. Finally, Koen Bertels, Jean-Marie Jacques, and Magnus

Boman probe the implications of self-organised criticality, especially with regard to industrial hazards, using an analysis of economic networks as the basis of their approach to crisis management and improved resilience of systems.

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