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Gianfranco Minati
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From Collective Beings to Quasi-Systems

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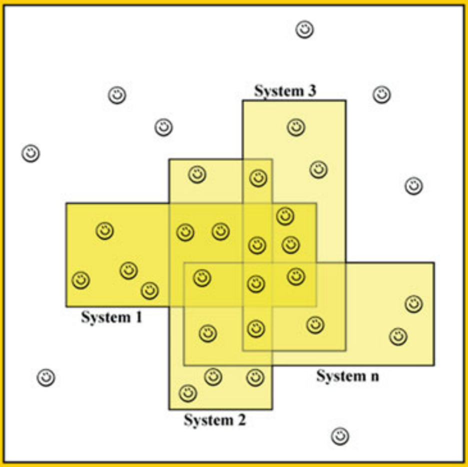
CONTEMPORARY SYSTEMS THINKING

Collective Beings



By
Gianfranco Minati
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Springer

Foreword

The development of modern science is dominated by an ever-increasing specialization of its various disciplines leading to more and more sub- and sub-sub-sections. It is, to use a parable of my late friend Yuri Klimontovich, like working in different mines, where each worker digs deeper and deeper and does not know what happens in other mines. On the other hand, as is witnessed by many important examples, say from medicine or space science, the cooperation of many, seemingly quite different disciplines is mandatory for the solution of basic problems. The same holds true for pure science. So for instance, we observe the penetration of mathematics, conventionally only used in ‘hard science’, e.g. physics, into what was traditionally called ‘soft science’, such as sociology, linguistics and so on. So quite obviously, there is a need for some overarching science that fosters the exchange of concepts, ideas and methods between different disciplines.

A first important step had been done by Ludwig von Bertalanffy with his general systems theory, where he searched for *analogies* between the individual *parts* of systems. I looked for analogies at the level of collective variables, the ‘order parameters’ within a field of research I called ‘Synergetics’ — science of cooperation that in particular aimed at shedding light on the ‘emergence’ of new properties at the system’s level.

Since quite a number of years, the authors of the present book, Gianfranco Minati and Eliano Pessa, have carried system’s science considerably further in a variety of ways. As the list of contents show, this book covers a wide range of topics. Incidentally, the authors carefully — and critically — discuss previous theories, e.g. the limitations of AI based on the concept of processing symbols or the applications of dynamical systems theory (not to be mixed up with general systems theory). The present authors go far beyond their approaches by opening new vistas by means of new concepts such as ‘quasi-systems’ with a clear distinction between analogy and metaphor, a careful definition of quasiness and its implications and so on.

In the domain of physics, this book includes even important aspects of the quantum world. I am particularly intrigued by the book’s topics of social culture

— including the ‘ontology of management’ and ‘architecture and city planning’, topics I am familiar with from numerous discussions with my friend Juval Portugali.

I am sure that this book will become a highly inspiring source for further studies in this both fascinating and important scientific endeavour.

Stuttgart, Germany Hermann Haken
February 2016

Preface

The general purpose of this book is to outline a possible future theoretical perspective for systemics and its conceptual morphology and landscape, while the Good Old-Fashioned Systemics (GOFS) era is still under way. The change from GOFS to future systemics can be represented, as shown in the book title, by the conceptual change from Collective Beings to quasi-systems.

The 'Good Old-Fashioned' attribute comes from the experience of artificial intelligence (AI). In that context the acronym GOFAI (Good Old-Fashioned Artificial Intelligence) denoted the oldest original approach to AI, based only on endowing computers with logical reasoning and problem-solving abilities. GOFAI was the dominant paradigm of AI until the late 1980s. This approach was based on the assumption that intelligence consisted almost completely of high-level manipulation of symbols. Therefore the main purpose of GOFAI was to endow a machine with intelligence, in particular of a general and human-like nature.

The severe limitations of this conceptual paradigm were subsequently realised, and new approaches were introduced, such as the sub-symbolic one (using tools such as artificial neural networks and cellular automata) and the dynamicist one (typically using dynamical systems theory). We recall here that the acronym 'GOFAI' was introduced by *John Haugeland* (1945–2010) in a celebrated book (Haugeland, 1985), exploring the philosophical implications of AI research, when GOFAI was already on Sunset Boulevard.

In an analogous way, GOFS can be identified with the first phase of systemics, full of enthusiasm and new theoretical proposals, overcoming the more classical mechanistic views. At that time complexity was not yet lying in ambush, and people were confident of the possibility of changing the world simply by adopting the new conceptual framework offered by systemics. Unfortunately, the presence of inherent complexity in many systems showed that the old conceptual tools (typically of mechanistic origin) were insufficient for making the systemic framework to work in practice. This circumstance marked the end of the golden era of GOFS, even though it is still alive.

For this reason in part A of the book, devoted to theoretical issues, we first of all try to identify the fundamental aspects of GOFS, often including *post-reductionistic* approaches able to contain systemic concepts but having local, functional and disciplinary applications within a classical framework. Examples are given by systemic properties such as self-regulation, feedback and functionalities. Such properties can be easily used and manipulated in a non-systemic conceptual framework and adopted to describe new *states* reached by systems. They are considered when dealing with reproducible phenomena obeying classical evolutionary *dynamics*, intended as a description of changes occurring in entities conserving their structures in space and time (a typical case is, e.g., motion in mechanics and even in organizations).

This *reduced* application of systemics is unable to deal with complex phenomena such as the properties acquired by collective systems with *changing structures*. In these cases new conceptual problems, such as that of *coherence*, arise, and it becomes impossible to deal with them using GOFS except in particular cases. However, GOFS is suitable to deal with processes of acquiring and maintaining the *same* or only a few, fixed systemic properties. On the contrary complex systems continuously acquire new (often delocalized) and sometimes coherent sequences of properties.

The authors, relying on previous studies, introduced (Minati and Pessa, 2006) the concepts of Multiple Systems, Collective Beings and the DYnamic uSAge of Models (DYSAM) to deal with these phenomena, focusing, in particular, on collective behaviours such as those characterizing swarms, flocks, herds, traffic, crowds and industrial districts. A wide variety of approaches on these themes have been published in the scientific literature. An overview of this subject is available (Vicsek and Zafeiris, 2012). However, all these approaches are plagued by some form of incompleteness. Namely, as the latter authors pointed out (Vicsek and Zafeiris, 2012, p. 134):

> ...
>
> *(iii) The problem of a coherently moving, self-organized flock of unmanned aerial vehicles is still unsolved in spite of its very important potential applications.*
>
> *(iv) And last, but far from being the least, the question about the existence of some simple underlying laws of nature (such as the principles of thermodynamics) that produce the whole variety of the observed phenomena we discussed is still to be uncovered.*

Moreover, besides these quoted remarks, other aspects and problems which are still waiting for effective approaches for their emergence, particularly in collective phenomena, should be mentioned. Among them is the fact that we are still unable to suitably model and:

(a) *Recognise* a phenomenon as emergent.
(b) *Induce* the emergence of collective behaviours in populations of elements collectively interacting.
(c) *Act* on collective emergent phenomena with the purpose of *changing*, *regulating* and *maintaining* acquired properties.
(d) *Merge* different collective emergent phenomena.

Simple extensions of GOFS are not sufficient, primarily because of the novel *nature* of problems often formulated in classical or in GOFS terms, but which require different and more suitable representations and approaches. These problems include those related to dynamical multiplicity and transformation, the latter being viewed as a continuous acquisition of even simultaneous but non-equivalent properties, where the study and modelling of the *transient* is the central aspect.

We then try to outline and, where possible, identify new conceptual categories, suggested even by actual advances in disciplinary domains such as theoretical physics, biology, neuroscience, experimental economics, network science and many others. The purpose is to establish novel, coherent conceptual frameworks and technical tools to support the development of a fully trans-disciplinary general theory of change. A *new systemics* should be the place where the *objects* under study are the systemic properties themselves, their emergence, the dynamics of their dynamics, their correspondence, their coherence and their possibly non-homogeneous occurrence.

Such changes towards a new systemics will be represented, in particular, by the conceptual shift from Multiple Systems (MS) and Collective Beings (CB) to *quasi-systems* (QSs). The latter are entities in which systemic properties are partial, sometimes regular, but in other cases partially lost. On this point, we introduce the concept of *pre-property*. QSs are useful for studying changes in, and the recurrence of, properties at various levels of emergence and inter-level dynamics.

In part B of this book, devoted to the translation (not transposition) into social culture of the new concepts, we revisit the classical systemic concepts of inter- and trans-disciplinarity, by resorting to specific disciplinary examples.

Two appendices deal with some crucial issues and questions and may be of help to the reader.

In order to give the reader a preliminary idea of the contents of the book, as well as its perspective, here we provide a bird's-eye view of the topics dealt with in the individual chapters.

Starting with Chap. 1, we outline some of the concepts, principia and assumptions of GOFS having a double nature. These contributed to the structure of such systemics, allowing emphasis of the differences between systemic and non-systemic properties. However, they also replicated, although in a different way, some of the crucial aspects of non-systemic thinking, since they tended to lead one to conceive systemic properties merely as characterizing more complex *states*. Thus it handled properties in a non-systemic way, by considering systems only as special phenomena to be dealt with by using classical non-systemic culture. In this way systemics was diluted and absorbed into classical approaches, declining it only in particular and non-interconnected specific disciplinary cases.

Chapter 2 introduces and discusses aspects of a new systemics, including coherence and multiple coherences; irreversibility-uniqueness; non-separability; the *world* between macro and micro, true and false and open and closed; uncertainty; and the nature of phenomena occurring *within* degrees of freedom.

Chapter 3 is devoted to the concept of dynamics. After a short history of the classical concept, we deal with the nature of dynamical single or multiple coherences in processes of emergence as characterizing the ontological dynamics of system identity (given by the coherence of sequences of properties and by the nature of the sequences themselves and of their emergent behaviour). Equivalence/non-equivalence between system models, classical and non-classical, is also covered. We introduce the approach based on modelling emergence through the coherence of sequences of structures, i.e. meta-structural properties, focusing on the transient.

Chapter 4 introduces key issues related to the conceptual change from Collective Beings to quasi-systems. The concept of quasi-system is counterposed to the classical one of system and considered as a paradigmatic variation of those of Multiple Systems and Collective Beings. This paradigmatic shift requires the introduction of novel concepts such as pre-properties, quasi properties, system propagation and dynamic coherences.

Chapter 5 introduces new approaches for dealing with the need to formalize. In particular, following a discussion on the need to go beyond *non-explicit* models (ideal-non ideal?), we introduce aspects to be considered in the new systemics, such as non-invasiveness as a characteristic of approaches and tools used to induce and orient processes of emergence, intended as non-prescribable within the framework of non-causality, low energy and soft actions. The latter must be suitably used and graduated by the collective intelligence of a coherent multiplicity.

Chapter 6 focuses upon the principia and approaches of quantum field theory (QFT), viewed as a general theoretical framework incorporating systemic principles. QFT can be used to deal with the quantum aspects of a new systemics or even a quantum systemics *tout court*. Various aspects are considered including equivalence and non-equivalence in an eventual quantum systemics based on concepts such as entanglement (no classical interactions are required as the latter is given by the properties of the vacuum), long-range correlations and quantum decoherence, collapse, interaction, emergence, information and macroscopic and microscopic quantum effects.

Chapter 7 outlines the landscape of a new systemics by dealing with topics such as modelling phenomena occurring *between* levels of emergence (are they classical or non-classical?) and particularly the coexistence of classical and non-classical representations recalling wave-particle duality.

In the new systemics, we should consider not only a single transient when acquiring a system property, as for phase transitions, but even *transience* between multiple systemic properties and validity regimes of structures and representations. Within this framework, the recurrence of properties is considered at different levels, and the context demands that the properties be studied with regard to their partiality, instability, uncertainty and incompleteness. This leads to consider multiple dynamics and coherences of emergence. Phenomena of multiple emergences are then considered where the dynamics relate to changes of levels or of the kind of emergence.

Chapter 8 discusses the possibility of considering network science as a suitable conceptual framework for post-GOFS. After outlining its brief history, we present its basic concepts and related specific disciplinary applications. We present the detailed trans-disciplinary content of topological behaviours adopted by networks when considering, for instance, *critical phenomena in complex networks* and *topological phase transitions of random networks* determining possible behavioural scenarios. Network properties can be reasonably considered as trans-disciplinary properties. This chapter also considers correspondences with aspects and properties previously introduced for characterizing post-GOFS, such as multiplicity, coherence and emergence.

Chapter 9 deals with the problem of *translating* the novel concepts presented here into social culture. This translation requires a multiple understanding, generating a comprehensive cultural proposal and not merely a simplified popularization. In this context we stress the importance of the new inter- and trans-disciplinarity fundamental to establish knowledge, or better, meta-knowledge, for the knowledge society by acting upon language and adopting constructivism as a general framework.

Chapter 10 lists some specific disciplinary cases where it is possible to see the new systemics *at work* and generating related culture. In particular, we consider cases related to experimental approaches under study, such as in architecture, city planning and design, medicine, economics and management, safety at work, cognitive science, education and embodied cognition.

The book also includes two appendices. Appendix 1 lists syntheses of some issues specific to the new systemics described in this book. Appendix 2 presents some questions and answers in order to illustrate some of the concepts introduced for the new systemics.

For the reader's convenience, we have also included *boxes* containing brief condensed information, sometimes with relevant references, regarding the issues being considered. Such information can, through the use of the references given, lead the reader to a more detailed study of those aspects.

Milan, Italy Gianfranco Minati
Pavia, Italy Eliano Pessa

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Chapter 1
The Background of Good Old-Fashioned Systemics

Contents

This chapter is devoted to an overview of the basic concepts defining Good Old-Fashioned Systemics (GOFS). The list and comments about such concepts is to be viewed as an introduction to Chap. 2, where we consider new conceptual categories, elaborated upon later when outlining the landscape of a new systemics. The reflections contained within these chapters have been made keeping in mind the current status of the discipline, the advancements, problems and approaches of contemporary science. We also review a partial list of unanswered questions raised by the original von Bertalanffy proposal of a General System Theory. In the last section, dedicated to further remarks, we briefly discuss the concept of matter, which is the basic framework itself of GOFS. This concept will be updated according to the conceptual basis for a new systemics outlined in Chap. 2 and in the rest of the book.

G. Minati, E. Pessa, *From Collective Beings to Quasi-Systems*, Contemporary Systems Thinking, https://doi.org/10.1007/978-1-4939-7581-5_1

1.1 The Epoch of Good Old-Fashioned Systemics (GOFS)

The epoch of GOFS is related to a number of approaches based on disciplines such as, for instance, dynamical systems theory, automata theory, control theory, cybernetics, games theory, catastrophe theory, chaos theory, network theory, economic dynamics, mathematical ecology and sociobiology. The ‘General System Theory’, introduced by Ludwig von Bertalanffy (1901–1972) in his most famous works (Von Bertalanffy, 1950, 1968), had the purpose of generalizing a number of findings obtained by these disciplines through the use of key concepts such as interaction, general interdependence, openness and closeness, organization and homeostasis within the general framework of the isomorphism between sciences while looking for the unity of science. The subject has already been introduced and discussed (Minati & Pessa, 2006, pp. 3–38).

These pioneering ideas were the precursors of many developments in various disciplinary fields so that today the concept of system is used in almost every discipline. However, the concepts were introduced by inevitably using the language available, i.e. the disciplinary representations. For instance, the formalization of some systemic concepts introduced by Von Bertalanffy was based on the language used in the theory of systems of ordinary differential equations, which, at that time, was already characterized by a well-established and stable corpus of knowledge.

We can thus say that in some way GOFS tried to build systemics by relying on disciplines which were already in a mature state of development. Systemic approaches, models, recommendations and theoretical efforts to unify and globalize were made by resorting to traditional conceptual tools whose further development was already out of the question. On the contrary, current advances in domains such as theoretical physics, mathematics, software engineering, biology, medicine, neuroscience, chemistry and many others offer a variety of new conceptual frameworks, approaches and technical tools enabling the building of a fully transdisciplinary general theory of change, upon which a new systemics dealing with spaces of systemic properties, such as multiple emergence, self-organization, coherence and transience, can be based.

Below we list some of the old key concepts used by GOFS to be substituted by the novel concepts introduced in the second part of the book. Part B shows how the knowledge to be used and developed to introduce a new systemics, interestingly, corresponds to the knowledge to be used and developed to manage knowledge societies (also called post-industrial societies where the main resource is knowledge). Knowledge societies are still largely managed by using the same knowledge they are supposed to manage, without resorting to more powerful, abstract and generalized meta-knowledge.

1.2 The Challenge of Multiplicity and Transition

The issue of multiplicity has its own history. This began in the times of Newton when classical physics, mostly for reasons of mathematical convenience, started by focussing on the study of properties and behaviour of single entities (such as a planet revolving around the sun or a cannonball following a ballistic trajectory). Only in special cases were pairs of interacting entities taken into consideration. In any case, it was initially taken for granted that the study of multiplicities constituted by many entities could be made by using suitable generalizations of the methods used for dealing with single entities. This belief, for instance, supported the popular mechanistic view held by Laplace.

Unfortunately, early developments of classical mechanics showed that on increasing the number of entities, the mathematical nature of the game changed radically. Within this context a typical example is given by the so-called three-body problem (Barrow-Green, 1997), consisting of determining the general behaviour of a system of three bodies and their reciprocal gravitational interactions. The problem was tackled by mathematicians including Leonhard Euler (1707–1783), Joseph-Louis Lagrange (1736–1813), Carl Gustav Jacob Jacobi (1804–1851) and Jules Henri Poincaré (1854–1912). But at the end of the nineteenth century, it was definitively shown that such a problem can never be solved in terms of algebraic functions. Moreover, the analytical solution in terms of infinite power series, discovered in 1912 by Karl Sundman (1873–1949), had such a slow convergence rate as to make it useless for any practical purpose.

The failure of classical mechanics in solving the three-body problem can be considered as one of the reasons which undermined faith in the mechanistic view and induced Poincaré to introduce the so-called ‘qualitative theory’ of differential equations, which is the basis of modern dynamical systems theory (see, on this aspect, Aubin & Dalmedico, 2002). These developments lie at the origin, for instance, of Mathematical Ecology, through the pioneering Lotka-Volterra model (Volterra, 1926; a simple analysis is contained in Davis, 1962; modern treatises include Murray, 2007; Pastor, 2008). And even more recent findings on chaotic behaviour (Lorenz, 1963) have some ancestry in these theories. It is, moreover, to be recalled that the birth of the new approach fostered by Poincaré was more or less contemporary with the work of Gibbs and Boltzmann, which led to the foundation of statistical mechanics. Despite the limitations of the latter, it undoubtedly introduced a new way for dealing with multiplicities and, by relying on probabilistic methods, showed the inadequacy of determinism, which is so characteristic of traditional classical mechanics. On the issue of multiplicity, GOFS adopted a phenomenological approach, inspired by the methods of Mathematical Ecology and of economic dynamics. Chiefly in the latter, the macroeconomic models of business cycle (Gabisch & Lorenz, 1989; a more comprehensive reference is Gandolfo, 2010) were formulated in terms of macroscopic aggregate variables fulfilling not too complex evolutionary laws, without a connection with the microscopic variables describing single individuals. Generally people were confident that the methods of statistical mechanics could relate to microscopic and macroscopic aspects, as occurs in some physical systems. However, such confidence has never been vindicated through specific modelling activities.

In any case, already during the era of GOFS, the issue of multiplicity had been dealt with in biology and physics. Unfortunately, the advances achieved in these fields, besides the fact of being known only to a small group of scientists, were ignored by the practitioners of systemics. These acquisitions became popular only recently, owing to the growing interest within disciplines such as sociobiology (Wilson, 1975) and by the practical applications of physical phenomena such as superconductivity and the laser effect. Quoting a phrase written by two prominent physicists of condensed matter, it can be said that 'Physics was able to delay serious consideration of collective effects for nearly 300 years, and only in the last 30 years or so has it confronted complex collective phenomena involving multiple scales of space and time, unpredictable dynamics and large fluctuations' (Goldenfeld & Woese, 2011). Among the physicists who reintroduced the subject of collective behaviours, with a general theoretical competence and a rigorous approach, we must cite Philip Warren Anderson, Nobel Prize for Physics in 1977 (Anderson, 1972). On the question of transition, since the times of the ancient Eleatic philosophers, this issue is strongly related to that of multiplicity (more information can be gained from standard textbooks such as Palmer, 2010). And this is precisely what happens in modern physics where the transitions are understood as macroscopic changes produced by the behaviours of a multiplicity of microscopic particles. In fact, modern atomism is strongly grounded on the old Eleatic ideas (a very interesting paper on the unexpected role of these ancient views on modern physics and mathematics is Silagadze, 2005). This led physicists to build successful models of transitions, which have been used by the modern theory of phase transitions. Within the latter, a macroscopic change is understood as a transition between two different kinds of coherence, i.e. phases. The main conceptual tools are based on modelling radical emergence as given by a spontaneous symmetry breaking (SSB) mechanism in quantum field theory (QFT). Concrete examples are given by transitions from paramagnetic to ferromagnetic phases, the occurrence of superconductivity and superfluidity and order-disorder transitions in some kinds of crystals. In these cases there are very complicated transient dynamics where classical and quantum aspects mix (Parisi, 1992; Sewell, 2002).

Unfortunately, during the GOFS era, most contributions from physics were neglected, and this prevented them having a sound theoretical foundation for studying transition processes occurring in many different systemic concepts. As already mentioned, the phenomenological approach adopted within GOFS induced most people to model transitions through macroscopic system dynamics. Within this context, however, the only available tools are based on the theory of bifurcation for differential equations (see, for an introduction, Glendinning, 1994; Scott, 2003). While the models making use of the latter are very attractive and seem to account for a number of processes of morphogenesis (e.g. the popularity enjoyed by the models of *dissipative structures*, introduced by Prigogine and co-workers; Belintsev, 1983; Beloussov, 1998; Nicolis & Prigogine, 1977), they are, however, plagued by a number of shortcomings. The latter include the instability of the new emerging structures with respect to perturbations (Fernández, 1985), the critical dependence of the emergence processes on specific initial and boundary conditions (a simple example can be found in Schöll, 1986) and the impossibility, in a number of cases, of viewing the structures themselves as macroscopic counterparts of a suitable microscopic dynamics (Nitzan & Ortoleva, 1980; Stein, 1980).

1.3 Classical Approaches

In this section we comment upon a partial list of concepts, each denoted by a single word, assumed, singularly and together, as being representative of a way of representing and thinking used by classical disciplines and having a dialectical relationship with GOFS. In the same way, as emergent phenomena and their properties must emerge from something and higher-level properties maintain a non-linear heritage of lower levels, analogously GOFS maintains heritages from specific disciplines and their approaches. Here we use the adjective 'classical' when referring to the nature of both disciplinary concepts and approaches of GOFS as well (as listed below), in order to characterize the fact that they are unable to deal with phenomena of complexity such as emergence, self-organization and acquisition of coherence.

We need to identify previous concepts, which still belong to the conceptual framework of current thinking, not so much to update and extend them but rather to radically change them by interpreting new effects and phenomena. This process should also be considered from a constructivist view and occurs whenever a sort of Gestalt continuity, extensions or replications of conceptual categories previously adopted is preserved to deal with unexpected phenomena, such as emergence. It can be hypothesized that it is analogous to the clustering of cognitive states minimizing the energy of the neuronal phase space of the observer (Edelman & Tononi, 2000).

Before discussing the following partial list, we stress that the process is similar to that encountered when managing knowledge, or post-industrial, societies using only existing knowledge (Minati, 2012).

1.3.1 Defining

Here we refer to the approach which starts every investigation by defining, in a rigorous way, its subject. Generally this approach is based on the assumption of absolute precision, lack of ambiguity, time independence and observer independence or at least presumes that it would be possible to produce definitions endowed with these properties. This view has a platonic nature, and it is generally assumed that one can suitably apply it to abstract contexts, typically to that of mathematics. We may comment that its alleged generality is mainly due to a simplification, i.e. working not so much with representations but with properties of the representations themselves, assumed to be applicable to the represented entities. This approach has been very effective for dealing with single, well-identifiable, conceptually separable in classical space and time, stable and replicable phenomena, typically those usually considered by classical physics.

Already in the twentieth century, new and different approaches were introduced allowing the introduction of definitions associated with a suitable level of precision. For instance, uncertainty principles in science (Minati & Pessa, 2006, pp. 55–63) have undermined the traditional approach to definitions, by taking into account both the unavoidable interfering role of the act itself of observing and the occurrence of pairs of variables which cannot be simultaneously measured with unlimited precision (the most celebrated example is given by the Heisenberg Uncertainty Principle, concerning the position and momentum of a particle; see Heisenberg, 1971).

Another approach was based on the introduction of fuzzy sets, fuzzy logic and fuzzy systems (Klir & Yuan, 1996). Fuzzy sets are sets whose elements have membership degrees within the continuous interval between 0 and 1 and not, as in classical set theory, only 0 or 1. The membership function characterizes the fuzzy set being considered. The related fuzzy set theory is used in several disciplinary fields such as engineering, information theory and bioinformatics in order to deal with problems in which information is incomplete or imprecise.

In mathematics, the end of the so-called Bourbaki programme (1935–1998) aiming at a completely self-contained treatment of the core areas of modern mathematics based on set theory was a manifestation of the decreasing effectiveness and role of classical mathematics relying on abstract definitions and axioms.

In a more general way, we may conclude this subsection by mentioning how formal, symbolic rigour becomes a particular, local case of constructivism (Von Glasersfeld, 1991, 1995). In a brief and expressive manner, we can say that the approach of looking for defining with absolute precision, independently of the observer, is replaced instead by the cognitive reality introduced by constructivism when (a) scientific experiments are viewed as questions about reality which is intended to respond by making them happen, as there are no answers without questions, and (b) events may become answers if we abductively invent the proper question. The shortcut of simplifying and designing symbolic machines coexisted and still coexists with GOFS. New updated approaches, taking into account the conceptual improvements so far, will avoid the application of systemics to cases defined in the old way.

1.3.2 Completeness

The concept of completeness has many different connotations in a number of scientific disciplines, such as logic, mathematics, computation theory, economics and biology. Often it is related to properties of the system under study such as the finiteness, identifiability, stability and the knowledge in advance of the number of the available possibilities. In turn these properties entail the exhaustibility of the possibilities themselves. The simplest implementation of this situation is given by finite-state systems which evolve in such a way as to adopt, over time, a finite number of possible states, eventually exhausting or visiting all those possible. However, even though finite-state systems can become very complex when the number of these states becomes high enough (the typical case is that of Boolean networks; see Gersenshon, 2004; Kauffman, 1993), infinite-state systems are far more interesting. Unfortunately, the latter have rarely been taken into consideration within GOFS. And, as expected, the associated concepts of completeness are far more abstract and difficult to apply in concrete cases. For example, in the case of logical theories, one must distinguish between syntactic completeness and semantic completeness. For theories with a minimum degree of complexity, there are unlimited sets of propositions, and the arguments about the presence or absence of both kinds of completeness require the use of sophisticated technical tools, available only to a small number of expert mathematicians. This rules out any possibility of an immediate and intuitive understanding of the role of completeness in these domains.

Within this context it is natural to mention the two celebrated Gödel syntactic incompleteness theorems, proved in 1931. The meaning of the first theorem is that in any mathematical theory having at least the power of arithmetic, there is a formula such that neither it nor its negation is syntactically provable in such a theory. The meaning of the second theorem is that no coherent system can be used to demonstrate its own syntactic coherence. Both theorems can be interpreted as proving the inexhaustibility in principle of pure mathematics, viewed as a system (Feferman, Parsons, & Simpson, 2010; Franzén, 2005; Raatikainen, 2005). In other words, infinite-state logical theories when sufficiently complex are necessarily incomplete. Whether this result implies a sort of incompleteness of other kinds of theories (for instance, those of physics) is still an open question.

Here we consider incompleteness as not being due to improbable events such as environmental noise or perturbations. The problem of completeness is an abstract one related to the model and its level of representation. The key point is that the only acceptable limits to completeness are ignorance of possible states, limits to the model itself, environmental perturbations and the relativistic role of the observer. Clearly, this approach is unsuitable for dealing with processes able to autonomously produce new configurations. Examples include the processes of evolution, self-organization and emergence even when autonomously established or induced by noise or topological defects. As we shall see in these cases, the better approach is not to search for completeness but, rather, for coherence.

1.3.3 Accuracy and Precision

In science, as in engineering, the accuracy of a measurement is usually defined as the distance of the measured value from the correct one, whereas the precision is related to the distribution of values of repeated measurements of the same quantity.

This definition of precision relates it to the degree of reproducibility or repeatability of the same measurement under constant conditions. For repeated measurements, a commonly used quantification of precision is given by the standard deviation of their average value divided by the square root of their number (the so-called standard error).

However, these two aspects are only at first sight related to measurement. More in general they are also related to other aspects such as the exhaustiveness and lack of ambiguity of reasoning. Within this context they are assumed to be an important aspect of rigour if not coincident with rigour *tout court*. On this point, it should be noted that accuracy and precision can be introduced only when dealing with systems in which it makes sense to speak of the correct values of the variables characterizing the systems themselves. For instance, deterministic dynamical systems with a very small number of state variables are systems of this kind, and, as already stressed, most models used within GOFS belong to this category. However, a number of other systems must be dealt with from a different perspective. These include, for example, stochastic systems, fuzzy systems and quantum systems, that is, almost all systems encountered when studying complex behaviours in physics, biology, economics, sociology and psychology. Within these contexts the traditional definitions of accuracy and precision are devoid of any sense, even when continuing to use the tools of probability theory.

The simplicity of the mechanistic approach, as well as within GOFS, is equivalent to stating that life, i.e. reasoning and behaving, should occur in a sort of monodimensional world allowing very few degrees of freedom, whose values are assumed to be respected as the main goal of actions and thoughts. In such a mechanistic world, deviations are just errors to be corrected. However, in the cases with which we are concerned possessing opposite qualities such as inaccuracy, imprecision, ambiguity and non-exhaustiveness, different assumptions and strategies are often required. These qualities may be understood as aspects of processes possibly converging towards different levels of accuracy, precision, exhaustiveness and lack of ambiguity, which characterize arrival points, attractors or temporary points of stability. Moreover, in the systems supporting these processes, the dynamics of their levels may be symptoms of the establishment of novel equilibriums and pre-properties. Further interesting symptoms are the ways in which the degrees of freedom are respected and used during the process. Violations of the degrees of freedom may be precious sources of information about the ongoing process in order to discover whether it might be induced and not just forced towards a unique, i.e. ‘correct’, evolution.

Within these contexts it is convenient to make use of diversity, rather than of homogeneity, by resorting to suitable strategies. Examples of the latter include multiple modelling through logical openness, dealt with in Sect. 2.7, and DYSAM (Minati & Pessa, 2006, 64–75). In these cases the goal is not to find the ‘best’ and ‘unique’ approach but to use different approaches together, in such a way as to reproduce the coherent evolutionary multiplicity of real processes. This is a step towards understanding the multiple and dynamical unity of science glimpsed by von Bertalanffy. Such unity should be dynamical and contextual rather than based on static isomorphisms.

1.3.4 Hard Versus Soft Computing

One heritage of GOFS has been the tendency to build models relying on so-called ‘hard computing’ tools. This expression denotes a conventional form of computing, based on a precise formulation of analytical models and on binary logic. These models must be studied by resorting either (in some favourable cases) to abstract mathematical methods or (more often) to computer simulations. The latter require the writing of suitable software programmes, implementing complex techniques of numerical analysis. Moreover, this software works in a reliable way (i.e. without producing artefacts) only in the presence of accurate input data, giving rise to a precise output. Again, the traditional deterministic models of simple dynamical systems, written in terms of differential equations, constitute a prototype of models requiring hard computing approaches.

In more recent times, however, a number of ‘soft computing’ tools have been introduced to deal with complex systems being characterized by imprecision, uncertainty and stochasticity. The description of these systems is often approximate and allows only a partial knowledge of what actually occurs. These soft computing tools include neural networks, cellular automata, genetic algorithms, artificial life models, ensemble-learning algorithms, multi-agent modelling, swarm intelligence models, fuzzy systems and quantum computing (for reviews see textbooks such as Tettamanzi & Tomassini, 2010). Within the context of hard computing, the models can describe only very abstract and idealized situations, whereas soft computing tools, able to deal with ambiguous and noisy data by using multivalued or fuzzy logics, are more suited for realistic cases. That is, they are characterized by low computational cost, self-evolving software, easy tractability and high tolerance for imprecision. In a sense, their operation is more akin to that used by the human mind, as underlined, for instance, in the seminal paper of Zadeh (Zadeh, 1994).

Unfortunately, in a number of cases, such novel approaches are used only as technical tools without replacing the old approaches. Thus the general reasoning is still based on the combination and use of the new tools in an antiquated conceptual framework. This is a kind of *second-order reductionism* characterizing GOFS. In this way it is possible to ignore the theoretical impossibility of resorting to models based on hard computing when dealing with families of problems and phenomena requiring the adoption of multiple and possibly nonequivalent approaches. This need is particularly acute when studying environmental relationships, emergence (possibly radical) and self-organization. It should also be recalled that soft computing tools nowadays are currently used within domains such as operational research, automata theory, control theory, cybernetics, games theory and system dynamics. These domains, often basically relying on hard computational tools, have been very popular within GOFS and, undoubtedly, their achievements are useful for managing a number of mechanistic systems requiring, for instance, some kind of automatic control. Such systems are widespread in many technological domains and pervade even our daily life. Unfortunately, such achievements are often scarcely applicable to the study of complex systems and, more importantly, of biological and human systems. Thus, the applications of soft computing in these domains can often be viewed as an apparent use of nonclassical tools without changing the inherently classical reasoning framework adopted (Kaliszewski, 2010).

1.3.5 Computability

This problem is dealt with by computability theory or recursion theory, a branch of mathematical logic and computer science. Its main achievements, starting from the thirties, are due to contributions from scientists such as Kurt Gödel, Alonzo Church, Alan Turing, Stephen Kleene and Emil Post. Within this context the central problem was to reach a definition of effective computation. The efforts made in this direction produced the first proofs that in mathematics there are decision problems which cannot effectively be solved. As it is well known, the Turing machine became the main prototypical system to define effective computability as studied in recursion theory (Turing, 1937).

Within GOFS the problem of computability was never explicitly dealt with. However, some aspects of recursion theory (maybe not the most important ones) underlie implicitly the role played by computational activities during the GOFS era. Among these aspects there is the fact that computability has often been understood, in short, as resolvability through algorithms, i.e. by a computer programme. This concept of computability was inevitably connected with that of treatability related to, for example, computational cost and the number of variables used. The assessment of non-treatability of a problem has sometimes been solved by reformulating the problem in different but equivalent way.

As mentioned above another concept inevitably linked with computability was that of decidability. Within computability theory the existence of undecidable problems, i.e. problems that, in principle, do not admit an algorithmic solution, has been proven. Examples of undecidable problems by using an algorithm are (a) the computation of the Kolmogorov complexity of a string of symbols and (b) the so-called Turing halting problem. In short, the Kolmogorov complexity of a string is given by the length of the shortest possible symbolic description of the string itself in a suitable fixed universal description language (see also Li & Vitányi, 2008). As regards the halting problem, this consists in determining whether a programme, processing as input the instructions of another programme, can decide whether the operation of the programme under examination will reach an end or will continue indefinitely.

While these results of undecidability (which constitute the true core of computation theory) do not seem to have been taken into consideration within GOFS, the identification of computation with the existence of an algorithm has been combined with other assumptions such as that everything is measurable, quantifiable and numerable, producing another second-order level of reductionism embedded into GOFS as a disciplinary heritage.

1.3.6 Optimization

An optimization problem in mathematics, operational research, engineering and computer science consists in finding the best solution to a given problem among all possible ones. Often people distinguish between two different kinds of optimization problems: those in which the variables are continuous and the other in which they are discrete. In the case of discrete variables, an optimization problem becomes equivalent to a combinatorial problem. Usually these problems are formulated, by convention, in terms of the minimization (or maximization) of a suitable function, sometimes called 'objective function', related to the goals which gave rise to the problem itself. In general, the convexity features of the objective function provide some indication about the possibility of the existence of several local minima. In particular, if we have a strictly convex function on an open set, we know in advance that it cannot have more than one single minimum.

Both operational research (see, e.g. Jensen & Bard, 2003) and its application to the world of business, so-called *management science* (Easterby-Smith, Thorpe, & Jackson, 2012), have been very popular within GOFS. In this context optimization has been understood, in general, as the search for an optimal use of resources, i.e. maximization of results against the use of limited resources. The general assumption was that optimization should always be an effective approach. Accordingly, and in a typically reductionist way, systems governed by optimized processes should, in their turn, be optimized. While this approach can work and produce useful results in specific cases of systems very close to a stable equilibrium state, it is unfeasible in the presence of processes of emergence and profound structural change. In the latter case, we need to study the crucial effects of non-probable events and the selection processes between equivalent possibilities which occur owing to fluctuations of various kinds. On the contrary, the assumptions behind the concepts of minimization and maximization, considered as opposites in a space where only A and non-A exist and transients cannot be taken into account, are that minimization and maximization always identify single exclusive solutions and not multiple ones, having various degrees of equivalence. This is another case of the second-order level of reductionism embedded into GOFS as a disciplinary heritage.

1.3.7 Solving

Here the word 'solving' is used to denote a general approach to problems based on the implicit assumption that solvable problems have a unique and computable solution. As is well known from logic and mathematics, this assumption is often incorrect, as there are many problems where such solutions may not exist or may even be multiple. Namely, we know that there are many unsolvable problems and there is a long list of unsolved problems, for which we still lack a proof of solvability or unsolvability. The latter circumstance, however, has not been taken into consideration in the GOFS era, in which the tools of systemics were just used to find a unique solution to a number of problems in domains such as management or conflict resolution.

We focus now upon the process of solving when it is assumed to be applicable, even in the presence of a multiplicity of different solutions. In the latter case, solving may be understood as equivalent to finding the best solution among several available possibilities. It is intended as a process of selection, and the more available solutions there are, the better it is. It is like entering a supermarket of possible solutions. An abundance of possible solutions is supposedly provided by research and technology. Another possibility consists of computing the solution. In such cases suitable algorithms and approaches allow one to find the proper solution or even the proof of its non-existence. As the process occurs through algorithms, this ensures that an end is always reached. This approach, typical of the GOFS era, works in a number of situations, but others require recourse to different strategies.

For instance, a strategy could consist of carrying out or inventing solutions, rather than finding them. In this case one would search for 'semantic' solutions reached by formulating and representing the problem in a virtually undefined number of ways, to be dealt with by any suitable approach. A typical situation is where one reformulates a problem so as to make it more treatable. In theoretical physics examples include statistical and macroscopic representations of microscopic problems.

How does this relate to systemics? We may, in short, say that this strategy may be convenient when the problem to be dealt with is related to profoundly systemic properties. The objective may be how to allow a system to function with a given property, or induce a system to vary a property, or allow a system to keep a property, or induce a system to lose a property while preserving others, or induce a system to acquire a new property while preserving others. In a first instance we may say that approaches based on principia such as induce, orientate, insert the buds of new properties such as pre-properties, make different systems interact, make a system become multiple or a quasi-system and go beyond GOFS. In these cases the identity of a system is fixed rather than given by the structural dynamics of its changing. Metaphorically speaking in the new systemics, we should be able to theoretically introduce structural changes in the very nature of systems.

1.3.8 External-Internal

One of the general assumptions made in many disciplines, in the disciplinary heritage of GOFS, is the 'obvious' and general possibility of distinguishing and separating 'between': distinguishing, for example, between components, both in homogeneous (when components are identical) and in nonhomogeneous cases (where components are different from one another), or distinguishing between the system and the environment.

In reality, the act of distinguishing is a kind of simplification assumed to work at certain suitable levels of representation. This simplification, however, neglects that which occurs at the boundary between the two entities being distinguished. ‘Between’ introduces a reference to the problem of transience, negligible at suitable levels of representation when what happens between two entities does not matter. In temporal terms, this is equivalent to considering two states, the initial one and the final one, and possibly to deal with what happens in between. At some levels of representation, the problem can be disregarded, and what matters are the two states. This typically occurs when we describe the operation of some kinds of machines. In other contexts, however, this approach appears to be useless.

In this regard, we recall that for a long time physicists and engineers have dealt with the problem of transience in electrical and electronic systems (for the case of electric power systems, see Das, 2010; Greenwood, 1991). Recent advances in theoretical physics have now renewed interest in transient phenomena, considered the most important ones for complex open systems in non-equilibrium situations (Kamenev, 2011; Klages, Just, & Jarzynski, 2013; Lai & Tél, 2011; Stefanucci & Van Leeuwen, 2013; Tél & Lai, 2008). Unfortunately, these developments are, so far, known only to a small group of specialists and are not being utilized in the building of a new form of systemics. The latter is, of course, necessary as the study of complex systems forces one to consider multiple dynamics, transients, non-equilibrium states and undefinable or moving boundaries.

Within these domains the study of ‘between’ requires models based on various combinations of both classical and nonclassical approaches. That is, the ability to differentiate ‘between’ is conceptually substituted by an undefined number of possible approaches where the ability to distinguish is a particular case to be used for macroscopic and mono-structural regimes of processes. Regarding the separability of systems from the environment, a simple example of the inapplicability of this assumption is given by ecosystems where the differentiation between external and internal is unsuitable. In these cases the environment pervades the elements which produce, in their turn, an active environment. This environment, if we can still call it such, is active and not an amorphous, abstract space hosting processes. It is interesting to consider eventual conceptual correspondences with the quantum vacuum pervading everything.

This view impacts on the concept of identity. The new assumption is not to have single identities but, rather, different, eventually coherent, dynamics, intended as identities. Such dynamics may be multiple, superimposed and possessing multiple, hanging coherences. Coherence and the related acquired property is the identity, just as flocks and biological living bodies keep their identity while their structures or materiality changes over time. The focus is no longer on the states but rather on the dynamics of processes and on their nature, i.e. classical or nonclassical, even when occurring in non-separated ways. These aspects can be taken as characterizing the new systemics.

1.3.9 Uncertainty: Certain Uncertainty

As mentioned above the conceptual framework of GOFS is unsuitable for dealing with processes of emergence. Furthermore such concepts are intertwined with others such as ‘uncertainty’ and ‘probability’. The latter are in turn related to the concept of ‘lack of certainty’. Often the lack of certainty is considered as objective, measurable and computable in such a way as to give a result which is certain. In short, uncertainty is intended as a property possessed by phenomena and processes. The problem is to compute it. The common approach requires finding and using appropriate formulae, usually obtained from probability theory. An event is assumed to be characterized by an intrinsic probability of happening. Once the problem of finding the algorithm is solved, the computation itself, in any case, is performed in a deterministic way.

On the other hand, if we take into account the new framework introduced by Bruno De Finetti (1906–1985), according to which probability does not exist in an objective sense (see, among the many books devoted to a discussion of De Finetti approach, the chapters contained in Gillies, 2000), the certainty attributed to the computation of uncertainty vanishes. Namely, within the *Subjective Theory of Probability* (on this subject see textbooks such as Jeffrey, 2004; Mellor, 2005; an interesting practical application of subjective probability can be found in Vick, 2002), probability is intended to exist only subjectively within the minds of observers, depending on their expectancies and the configuration of the situation taken into consideration (De Finetti, 1974). The past does not matter since configurations have no memory of the past. Any attempt is a new one and probabilistic values are resettled.

The subjective probability approach appears to be better suited when dealing with processes of emergence. Namely, the latter imply the occurrence of multiple, subsequent and superimposed configurations, and the problem is to model such processes and their coherences rather than focussing on single, possibly non-distinguishable configurations. We may say in these contexts that uncertainty may be uncertain, that is, non-computable. Therefore, we can also say that probability becomes a property continuously acquired by emerging, coherent systems. This should not be intended as a kind of surrender of the objectivist approach to the subjective one, but understood as an aspect of the embedded undecidability, incompleteness and uncertainty of the dynamics of processes of emergence. Of course, the introduction of these conceptual dimensions within the old framework would give rise to a sort of ‘agnosticism’. It is another failure of GOFS to be unable to represent and model the observer and the observed in terms of each other.

1.3.10 True or False

These concepts can be related to the frameworks typically used in many domains of science and often adopted within GOFS. The dichotomous representation of events, processes, questions and answers is very popular and strictly related to the use of binary digital devices, such as those operating in real computers. Generally, people assume that this representation is induced by the logic used in making deductions. However, this assumption is not entirely correct. Namely, the terms 'true' and 'false' are nothing but technical expressions used in a specific part of logic, that is, the *model theory* (Chang & Keisler, 2012; Marker, 2010). Here, formal logical theories can receive an interpretation within a given Universe (i.e. a set of facts and relations between them), in turn dependent on the particular kind of semantics adopted, giving a virtually unlimited number of different possibilities, whose choice is based on extra-logical considerations. Outside the specific domain of model theory, formal logic theories never deal with the problem of truth or falsity but with other problems, such as the proof of deducibility of a formal symbolic expression from the axioms of the theory taken into consideration.

It is, of course, true that, in the history of logic, some specific formal theories received special interest, their models being so simple and natural as to become popular and induce people to identify these models with the whole body of logic. We refer here, in particular, to first-order two-valued predicate logic and to its model based on Tarski's semantics. This kind of theory is plagued by a number of conceptual problems, highlighted by scientists such as Kurt Gödel or Abraham Robinson, but widely used in a whole range of domains, from computation theory to logical network design. Thus, it is not surprising that it has often been used, sometimes in an incorrect way, to support the conceptual frameworks sustaining many different disciplines. Regarding the researchers in logic, their attitude consists of considering the first-order theory nothing but as a convenient tool, devoid of any sacredness. The mappings found, for instance, between many-valued logics and first-order theory (Ansótegui & Maryà, 2005; Hänle, 1994) induce one to be prudent when attributing to the latter – and whence to truth and falsity – a special role.

In any case, it is evident that resorting to binary logic is a kind of simplification. This may be effective depending on the problem and interests of the observer. This approach is suitable *tout court*, i.e. without any simplifications, for problems such as those of elementary games theory. However, even there, multiple solutions are possible as in the case of the so-called prisoner's dilemma. GOFS has been compatible with such a view and has had difficulties in adopting a generalized alternative approach. This was understandable, at most, as being required by exceptions and peculiarities which could occur in disciplinary phenomena to be dealt with by appropriated methods.

Instead, in the case of processes such as emergence, the logical aspects should be modelled in a suitable way and, in their turn, not even be explicitly formalizable, possibly noncausal and dynamical, i.e. with classical and nonclassical aspects and with diverse structural regimes of validity. The new systemics should not be fully compatible with a binary framework but, at most, must be considered as useful only in particular and non-generalizable cases.

1.4 Unanswered General Aspects

This chapter presents a partial list of outstanding issues and questions left unanswered by GOFS and related to General System Theory as intended by its founder von Bertalanffy and subsequently elaborated, for instance, by the approaches mentioned in Sect. 1.1. This list can be formulated as follows:

(a) Relations between systemic properties in the same or different contexts.
(b) Transformation of systemic properties into other systemic properties.
(c) Relations among systemic properties and their materiality: can properties exist without materiality?
(d) Systemics not only of elements but of processes and fields.
(e) Homogeneity and non-homogeneity.
(f) Continuum and discrete.
(g) Transience: birth and transformation of systems.
(h) The environment.
(i) Active-passive.
(j) Induction of systemic properties.
(k) Scale invariance and systems.
(l) Equivalence and non-equivalence: multiple modelling and behavioural choices.
(m) Ability to recognize systemic properties.

A further important issue concerns the observer and the observed in terms of each other. This is related to the fact that emergence and the Dynamic Usage of Models (DYSAM) assign a crucial role to the observer producing and using models. A complete theory of emergence may develop as one being able to model processes and observer as one unique entity. In the same way, a complete theory of openness and of the dynamical usage of models might be proposed as a theorization of processes, models and user in an integrated manner. The very first step should be the definition and adoption of a language able to express such an integration. We still use descriptions and languages based on dividing, considering as separated the process and the observer.

Our insistence on the role of the observer calls for a clarification of the role of scientific method in studying open systems and in managing a logical openness even in the construction of scientific models. On this point, we recall that the scientific method is based on (1) the observer, his knowledge and purposes; (2) the model adopted, carried out by the observer on the basis of his/her knowledge and goals and characterized by its ability to explain and foresee; and (3) experimental data, answers to questions on the nature of experiments, obtained from the context using the model and the observer's language.

By applying a suitable operator $R1$ (representing the fact of performing an experiment) to the observer at moment n, it produces a corresponding model. Such a process may be described in formal terms by the expression:

$$\text{model}(n) = R1(\text{observer }(n)).$$

Another operator $R2$ may then represent the assessment of the correspondence between experimental data (n) obtained during the process of validation of the model (n). This assessment may be described in formal terms by the expression:

$$\text{experimental data }(n) = R2\ (\text{model }(n)).$$

However, the experimental data change the observer's knowledge and may also influence his/her goals. An operator $R3$ can show that the successive state of the observer depends on the experimental data obtained. This may be represented by the expression:

$$\text{observer }(n + 1) = R3\ (\text{experimental data }(n)).$$

By considering the combination of the three circumstances, we obtain:

$$\text{model }(n + 1) = R1\ (\text{observer }(n + 1)) = R1\big(R3(R2\ (\text{model }(n)))$$

By introducing the abbreviation $R = R1\ R2\ R3$, a simpler expression is possible:

$$\text{model }(n) = Rn\ (\text{model }(0)).$$

where Rn indicates the n iterations of the operator R.

This approach, introduced by Minati, Penna, and Pessa (1998), is based on that previously introduced by von Foerster (Von Foerster, 1984) briefly expressed as:

$$\text{Obs } n = \text{COORD } n(\text{obs}\,0)$$

where

- Obs$n$ represents the state of observable variables relative to the action of the observer and objects at step n.
- COORD represents the inferential coordination related to the observer's actions and that between the objects.

Even in the recursive formula, model (n) = Rn (model (0)), it is possible, as proposed by von Foerster in his approach, to consider as eigen-models those defined by:

$$\text{Model }(\infty) = \lim Rn\ (\text{model }(0)\ )$$
$$n \to \infty$$

and considering that ∞ has no practical meaning, we can see how the process, triggered by application of the scientific method, may converge to two different points of arrival:

1. Logically closed models, or having a finite degree of openness.
2. Impossibility of finding a definite eigen-model.

If we were to have a workable definition of the limit and enough knowledge about how it had been reached, we could obtain a unified description both of a model of an open system and of the conceptual processes occurring within the observer to obtain it. Such a sort of 'logically open' modelling would be far better than the current one, in which we take for granted that the properties of the system being studied can be defined in an objective way. The new conceptual approach we propose could be very useful in understanding the different complementarities existing in the study of an open system, such as those between observed and observer, between process and structure, between rate-dependent and rate-independent and between part and whole. A similar conceptual approach could be introduced for other famous dualities such as language and thought, mind and body and entities and environment.

Another important issue to be mentioned is that relating to meta-structures and meta-models. It can be thus formulated: is it possible to have meta-structures and meta-models having general validity? We briefly mention here a topic discussed in more detail in Sects. 2.4 and 3.7. This subject relates to emergent systemic properties as coherent properties continuously acquired, for instance, by collective systems. We thus need to understand the difference between single, specific systemic properties such as self-control, feedback and functionalities when coherence is given by maintaining the same property and sequences, multiple coherent properties establishing the behaviour of complex systems. General validity is not given by the same systemic properties effective within different disciplinary contexts but by operation of the same process of emergence within different disciplinary contexts allowing emergence of coherence regardless of the property being considered.

The problem in modelling the latter case is faced by using a variety of approaches introduced in the literature. However, here we consider a different, possible and new approach based on meta-structures intended as coherent sequences of structures of interaction (see Chap. 3). The reason for introducing this new approach comes from the inability of various interdisciplinary models introduced in the literature (e.g. physics, biology and economics) to allow approaches suitable to induce and orient processes of emergence. Such a novel approach will allow researchers not only to simulate but to change or maintain acquired emergent systemic properties.

1.5 Further Remarks

Several other aspects should be studied taking into account a number of disciplinary advances, which may become coherent and generalized. On this point, we conclude this chapter by mentioning a transversal topic, which constitutes a necessary condition for systemic elaborations. This topic is considered obvious, even in GOFS. We refer to the concept of matter. The latter is intended as a general platform on which everything is necessarily grounded. However, subsequent emergent properties cannot be intended as reducible to the properties of matter.

The question *what is matter?* Seems to be a philosophical one as matter is intended as the general basis for properties and having itself no or only basic properties, eventually contrasting with a void having no properties, being the lack of matter and as such opposed to the quantum vacuum. Are biological, living, nonliving, physical, neurological, chemical, thinking (mind and matter), inert, fossil, dark phases of matter and so on different or the same matter? Since levels of such matter are assumed to derive from the simplest (see particle physics), inferior one, is matter considered by GOFS a metaphysical entity if the simplest one does not exist? Is it a conceptual scaffold with no actual scientific meaning when a level should be intended as being built upon a lower simpler one? Is such a reductionist understanding of matter the real core of all reductionism? Do these hierarchical levels have an end at the bottom? Does this eventual end the real general matter? This subject is further discussed in Sect. 2.8 when dealing with prospective new conceptual categories. The void, as in quantum field theory, will be considered as a pervasive, unavoidable source of properties such as entanglement.

Box 1.1: The Phase Space

The time evolution of a dynamical system can be represented in a multidimensional space termed *phase space* that is not the graphical representation of the geometric motion of the system. *In it are represented the trajectories in the space whose coordinates are given by its variables.*

In the phase space of a dynamical system, all possible instantaneous states of the system are represented by points in this space.

This concept was developed in the late nineteenth century by Boltzmann, Gibbs and Poincaré and is widely used in the scientific domain.

The phase space is an abstract space where each variable of the system is associated with a coordinate axis. It is possible to graphically represent this n-dimensional space (where n is the number of variables) only in the special cases in which $n = 2, 3$. The time behaviour of the system can be considered represented by the movement of a point along a trajectory in such a space.

For example, the phase space of a pendulum is constituted by two variables: the angular variable p that identifies the position and which moves on a circle and the speed variable v that can vary along a straight line. The phase space thus assumes the shape of a cylinder (Nolte, 2010).

Box 1.2: Approaches in Science: The *Asymptotic Approach*
Henri Poincaré (1854–1912) introduced the asymptotic approach that focuses on the asymptotic states of the system under study, i.e. appearing in extreme conditions such as for:

$t \longrightarrow \infty$ (final destiny).

$N \longrightarrow \infty$ (macroscopic states).

$V \longrightarrow \infty$ (thermodynamic limit).

The great merit of the approach introduced by Poincaré was the invention of methods to determine the final destiny of systems without having to solve the equations that rule their dynamics (Awrejcewicz, Andrianov, & Manevitch, 2012).

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Part I
Theoretical Issues

Chapter 2
Prospective New Conceptual Categories

Contents

This chapter presents an overview of prospective new conceptual categories expected to characterize the new or second-generation systemics. We refuse here to call it *systemics 2.0* (Minati, 2016; Minati, Abram, & Pessa, 2016) even though GOFS, or *systemics 1.0,* had several *releases*, as mentioned in Sect. 1.1, including the theory of dynamical systems, automata theory, control theory, cybernetics, games theory and system dynamics.

As shown in the previous chapter, on the one hand, the disciplinary heritages introduced intrinsic and implicit limitations within GOFS, while on the other some disciplines adopted and elaborated concepts and problems of GOFS by using new approaches. This was, for instance, the case for physics and biology from where most of the concepts considered in this chapter come. However, such disciplinary advances were often *intrinsically* unable to lead to theoretical *generalizations*. Namely, the advances themselves were not only unable to produce applications in the various disciplinary fields but also to introduce approaches, principles, models and assumptions having general validity, in the search for a general, trans-disciplinary understanding from their relationships within different theoretical frameworks. This chapter focuses upon some such new concepts and approaches. These are not meant to be transposed to other disciplines or used as they are but should rather be viewed as *clues* to second-generation systemic properties or as

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pre-systemic properties looking for a new conceptual framework suitable for theoretical generalizations.

One aspect of such new properties is that they are all related, interconnected so that in each one of them we find aspects of the others. This can be understood as a new *conceptual* interaction or entanglement, as introduced below where we show that these properties cannot be considered as separate entities. This building of a new interconnecting and unavoidable conceptual systemic framework is the real challenge facing the new systemics. Within such a conceptual context, it seems natural to suggest some correspondence with the entangling quantum vacuum considered in quantum field theory (QFT). Moreover, other new properties are considered throughout this book. These include *quasiness*, generalizing the concept of *quasi* being applied to quasi-systems and their quasi-properties.

In the last section, dedicated to further remarks, we briefly discuss the concept of *matter*. This topic is dealt with because it is impossible to introduce the scientific developments and even the approaches of second- generation systemics while retaining unaltered the classical metaphysical concept of matter, which continues to be related to almost all everyday issues such as those concerning living and non-living matter, mind and matter, biological matter, dark matter, inert matter, antimatter and so on.

2.1 Coherence

The concept of coherence is related to various disciplinary meanings. We limit ourselves to mentioning only some of these before focusing on that to which this book is dedicated.

In philosophy and logic, the concept of coherence is currently the subject of an intense debate. Namely, although the non-contradictory nature and robustness of reasoning are usually characterized by syntactic and semantic consistency, coherence is a feature related more to the inner relationships within a set of propositions. The nature of these relationships, characterizing the coherence of a proposition with respect to the others belonging to the set, as well as the global coherence of the whole set, is strongly dependent upon the philosophical position adopted. The various approaches include, for instance, *coherentism* and *foundationalism* (Bonjour, 2010, Chap. 9; Audi, 2011, Chaps. 9, 10, 11; briefer, but conceptually intense, contributions include Bouchard, 2007).

The concept of coherence is introduced in a very different way in physics, mainly owing to the fact that most physical systems allow a description based in an essential way on spatio-temporal variables. The concept itself was introduced when classical physics began to study wave phenomena, such as interference (see, for instance, Wolf, 2007). The latter can be more easily observed when we use two waves whose relative phase difference is constant. Thus a natural definition of (relative) coherence identifies it with the constancy of a phase relationship. Such a definition can be further generalized when, instead of limiting ourselves to phase relationships, all kinds of correlation are considered, being quantified through suitable correlation functions (based on suitable averages of individual correlation values). The latter may depend upon spatial delays (*spatial* coherence) or on time delays (*temporal* coherence). In many cases, the correlations are not studied between two different waves but between one and the same wave at different times or positions. This leads one to consider *self-correlation*, sometimes called *self-coherence*, measured by the autocorrelation function, one of the main tools in signal analysis. In the case of temporal coherence, the value of the autocorrelation function depends on the time delay τ and, for most physical systems, shows a decreasing trend with increasing values of τ. The value of τ where the value of the autocorrelation function falls below a given threshold, becoming negligible, defines the so-called coherence time τ_c. The distance travelled by the wave in time τ_c is called the *coherence length*. In most situations, these concepts must be suitably extended because usual wave-like phenomena are rarely produced by single monochromatic waves but instead involve wave packets, made by superposing many waves of different frequencies. In these cases, we must introduce the concept of *bandwidth* Δf, specifying the amplitude of the frequency interval containing all the frequencies of the waves constituting the wave packet being considered. A fundamental theorem of signal analysis states that coherence time and bandwidth are related through a relationship having the form $\tau_c \ \Delta f \approx 1$. The latter is quoted here because it is very similar to the celebrated relationship in quantum mechanics (the Heisenberg uncertainty relationship). In fact, if we treat particles as waves (as is possible in quantum theory), one can derive the uncertainty relationships by resorting only to normal (classical) signal analysis.

Most wave-like physical systems are characterized by very small values of coherence time and coherence length. There are, however, notable exceptions, the most well-known being lasers (light amplification by stimulated emission of radiation), devices which emit light with high degrees of spatial and temporal coherence. The study of coherence in lasers contributed to the introduction and study of complexity (see, for instance, Arecchi & Meucci, 2009).

The concept of coherence becomes more complicated for physical systems described by quantum theories. At first sight, it would seem very easy to translate the classical coherence concept to the quantum case, because in the latter context the particles are also endowed with a wave-like nature (De Broglie). Unfortunately, the nature of quantum waves is profoundly different from that of classical waves, owing to their probabilistic role and to the presence of uncertainty relationships. This forces one to resort to a description of the systems based on the kinds of quantum states which may characterize them. As a consequence, the definition of coherence must be based on a preliminary definition of what is meant by the expression *coherent state*. In this regard, the work done in the 1960s by Roy Glauber (extending previous work by Erwin Schrödinger) showed that a coherent quantum state can be identified with an autostate of the particle annihilation operator used in the number occupation representation of many-particle quantum systems. Physically this means that a quantum coherent state is to be identified with a state which remains unchanged if we annihilate one particle belonging to it. Further Glauber, who won the Nobel Prize for his work, showed that a coherent state as defined above is the quantum state of a quantum harmonic oscillator whose dynamics most closely resemble that of a classical harmonic oscillator. This entails that in a quantum coherent state, the uncertainty resulting from its quantum nature is the *minimum* possible (for more detailed descriptions, see Gazeau, 2009; Glauber, 2007; Klauder & Skagerstam, 1985).

The work of Glauber opened the way for the introduction of *macroscopic* quantum coherent states (see, e.g. Preparata, 1995), which describe a number of experimentally detected physical states, such as those occurring in superconductivity, superfluidity and some kinds of classical electromagnetic waves. These states constitute a prime example of *macroscopic emergence* from the interaction between microscopic constituents. Their nature shows that they can occur only within a quantum context, a circumstance supporting the hypothesis that all emergent phenomena have to be described by quantum models (see Anderson, 1981; Anderson & Stein, 1985; Stein, 1980).

Actually the coherent states introduced by Glauber are called *canonical coherent states*, to distinguish them from other kinds of coherent states which generalize in some way the conditions proposed by Glauber himself. These *generalized coherent states* will probably be very useful when dealing with more complex quantum systems (for an introduction, see Perelomov, 2012).

When trying to extend the physical concept of coherence to other systems in which a spatio-temporal description is impossible or only partly useful, considerable difficulties are encountered. Here, one of the most important contributions came from the philosopher Paul Thagard, who introduced a general definition of coherence within a set of propositions, by identifying the degree of coherence with the amount of constraint satisfaction (see, among many other papers on this subject, Thagard, 1989, 2000, 2012; Thagard & Verbeurgt, 1998). In short, within a domain whose elements are propositions, Thagard replaces the network of spatio-temporal relationships with a network of constraints, each consisting of a relationship of mutual coherence (positive constraint) or of mutual incoherence (negative constraint) between two propositions. As each constraint is associated with the numerical value of its *weight*, we can introduce a connectionist-like neural network description of the dynamical evolution of the system of relationships between the propositions belonging to the set under consideration. Within such a framework, it is possible to introduce (in a number of different ways) a numerical measure of the coherence both of a proposition and of the whole set of propositions (or of a particular subset). In principle the network of relationships can be compared with the network of interactions between the particles belonging to a physical system, in order to find a correspondence between physical definitions of coherence and the more general one introduced by Thagard.

The particular kinds of artificial neural networks introduced by Thagard in order to implement his ideas are characterized by a very slow operation. Namely, they have been designed in order to maximize the coherence of a set of propositions through a learning process based on a modification of weight values produced by the spreading of network unit activations. While this approach is useful to describe the reasoning made by a human mind when searching for the best theory able to explain a given set of facts, it cannot be used to account, for instance, for the very fast detection of coherence within a visual pattern. In the latter context, the neuroscientists use the expression *binding problem* to denote the problem of understanding how diverse features are integrated within the global perception of a whole pattern. It is generally accepted that this integration is due to the detection of a specific kind of coherence, but which? And how does the brain perform such detection in such a very short time, despite the huge information content even of a simple visual pattern?

When trying to solve this problem by resorting to artificial neural network models, neuroscientists were faced with the problem that these models cannot learn from experience alone to correctly bind a number of different local features into a unique, holistic and global entity (Hummel & Biederman, 1992; Pessa, 2005; Thiele & Stoner, 2003). In turn, this particular problem is related to a more general conceptual problem, stemming from the fact that we often observe, at a macroscopic level, a number of entities which, in one way or another, appear to manifest properties which, intuitively, recall some form of ‘coherence’ without being able to understand the latter in terms of the behaviour of suitable ‘elementary components’. This gave rise in systemics to a number of different approaches and definitions of coherence. These include definitions of coherence as given by ergodicity, rather than periodicity or quasi-periodicity, and by dynamical clustering rather than synchronization. All these definitions are related, in one way or another, to suitable proposals for quantitative evaluation of macroscopic coherence, including, for instance, those related to pattern formation by dissipative structures or those in hydrodynamics. When dealing with biological or social and economic phenomena, there are tentative generalizations of these conceptual proposals which define coherence, for instance, as:

(i) A possibly dynamical *proportionality* between aspects of different processes. Elementary examples are given by growth processes of biological systems (balance between organs of the body) and in corporations (balance between different divisions). This also applies to the case of *development*, in general intended as a sequence of *proportional* processes of growth; this subject has a long history, starting with the discovery of *allometric* relationships in biology (see for a historical account Gayon, 2000); scaling laws were then also discovered in cognitive and social systems (see, for instance, Bettencourt, 2013; Chater & Brown, 2008; Kello et al., 2010); theoretical models accounting for these forms of coherence include those of Demetrius, Harremöes, and Legendrec (2009) and West, Brown, and Enquist (1997).

(ii) The dynamic establishment and maintenance of subsequent, non-equivalent (where change should be understood as a sequence of phase transitions) properties, *continuously* produced and maintained by suitable interacting components. Such sequences of properties are identified as being coherent through *coherence detectors* available to the observer (Bonabeau & Dessalles, 1997). Examples are given by properties which identify, over time, the establishment and maintaining of collective behaviours such as those of swarms, flocks, traffic (road vehicles or telecommunications), industrial districts, cell growth, markets, crowd movement (evacuation) and networks (Motter & Albert, 2012). Coherence is intended as maintaining the *same* property in the face of structural changes occurring within the system such as those, for instance, related to number, position or speed of components, or to system topology or shape, as occurs in swarms or flocks. Some cues of a general nature exist, such as topological distance (Ballerini et al., 2008) or scale invariance (Cavagna et al., 2010). Research is currently exploring the possibility of finding a generalized approach to describe coherence (see, for an overview, Vicsek & Zafeiris, 2012). In the following chapter, we introduce an approach under study which has the purpose of detecting such general cues at a mesoscopic level. Such an approach is based on identifying *coherence with some sort of dynamical regularity*. However, the definition of dynamical regularity must be tailored to suit the kind of system considered, as the traditional definition of dynamical regularity, borrowed from dynamical systems theory (see, for instance, Milani, 2006), is too restricted for identifying coherence in complex non-linear systems. Namely, if we were to adopt this definition, the overwhelming majority of systems, including many of which are devoid of any coherence (such as a Lorenz system), would give rise to behaviours possessing regularities (for a detailed discussion on this point, see Holt & Holt, 1993). Of course, once suitable generalizations of the concept of dynamical regularity are introduced, as discussed in the following chapters, it is possible to have multiple and even superimposed regularities. As a matter of fact, in these cases, coherence may be considered as being related to the fact that the parameters used to model regularity *vary in their turn with regularity* (Minati, 2008).

(iii) Recent developments within quantum field theory (QFT) (see, for a synthesis, Del Giudice, Pulselli, & Tiezzi, 2009) showed that the mechanisms accounting for the occurrence of macroscopic coherence of a quantum nature could, in principle, be used to explain all other kinds of coherence described above. This leads to the idea that perhaps it would be possible to introduce a *universal theory of coherence*, based entirely on quantum-like arguments. In this case, QFT would become a fundamental basis for a new general systems theory.

Before ending this section, it must be recalled that beyond coherence, its acquisition and preservation, there are processes of *transition* between coherence and incoherence which may be considered, on the one hand, as degenerative and, on the other, as seeding, an *occasion* to establish new coherences, i.e. to make coherent what is incoherent at a given level of representation. There is the profound musical meaning of this understanding of coherence, for instance, when dealing with dissonances establishing dialectical dynamics of coherences, their degeneration, superimpositions and formation (Phon-Amnuaisuk, 2010). In these cases, incoherence is the core of structural dynamics, which *depart* towards new coherences, designated in their turn to degenerate and then dialectically opening up to new coherences. *What comes first, the incoherence or the coherence?*

2.2 Irreversibility

As is well known, the second law of classical thermodynamics states that it *is not possible to design a thermal machine integrally transforming heat into work*, as introduced by William Thomson (Lord Kelvin) in 1852 in a publication in the journal *Philosophical Magazine* entitled 'On the universal tendency in nature to the dissipation of mechanical energy'. Then, in 1854, Rudolf Clausius, while introducing the concept of entropy, showed that the formulation of the second law implied the unavoidable occurrence of *irreversible* processes. In classical physics, these processes for a long time were considered for their *degenerative aspects*, i.e. the impossibility to return to previous states or configurations assumed to be lost. Namely, irreversibility was in contrast with the invariance of Newtonian equations of motion with respect to time reversal. This contrast marked the whole history of thermodynamics and statistical physics, and attempts to eliminate it involved the contributions of scientists of the calibre of Boltzmann, Gibbs, Poincaré, Zermelo and Onsager.

After the Second World War, the introduction by *Ilya Prigogine* (1917–2003), Nobel Prize in Chemistry in 1977, of the so-called thermodynamics of irreversible processes (see, for instance, Nicolis & Prigogine, 1977; Prigogine, 1967) allowed the study of open systems in non-equilibrium situations. This circumstance brought about a radical change in the general attitude towards irreversible processes. As illustrated in his book "From being to becoming" (Prigogine, 1980), these processes began to be considered for their constructive aspects of *uniqueness* and for their major role in the evolution of complex systems. In this regard, Prigogine introduced the powerful notion of *dissipative structures* (Nicolis & Prigogine, 1977; Prigogine, 1967; Prigogine & Lefever, 1968; a more recent presentation is that by Mori & Kuramoto, 2001) to denote self-organizing structures in non-linear systems far from equilibrium (e.g. *whirlpools* existing for as long as they are continuously fed by a running fluid).

While avoiding a discussion about the technical soundness of Prigogine's proposal for introducing irreversibility even at the microscopic level (a proposal which is unnecessary, as models exist whose macroscopic behaviour is irreversible even when that of their microscopic components is reversible; an example is given in D'Souza & Margolus, 1999), we underline the richness and creativity of indeterminacy when systems with equivalent choices are driven by fluctuations implying irreversibility. There are a number of references to properties intended as still missing or inaccessible such as *un*defined, *in*accurate, *in*comprehensible and *un*determined, all in contrast with categories favoured by GOFS such as precision, accuracy, completeness, uniqueness and optimality. The transversal invariant common to the older frameworks is the imprecision with which uncertainty is negatively qualified and intended. However, uncertainty and undecidability, to which we referred above, do not always refer to deficiencies but, rather, should also be intended as specifying *spaces of equivalent configurations* (see Sect. 3.6), explored and created by the system to choose a unique and irreversible configuration.

An example is a constraint fixing the number of the degrees of freedom in a system of spatially distributed interacting elements. Assuming, for instance, that the number of degrees of freedom will determine the minimum and maximum allowable distance between two elements, there is a huge variety of system states which meet this constraint. Each state is related to the *ways* in which this constraint is fulfilled (see Sect. 3.8.3.7).

There will be not only cases where the constraint is *respected or not respected*, but even *histories* characterized by the *ways* of implementing, for example, actual distances corresponding to specific percentages of the distance between maximum and minimum allowable distances. It is the *history of use* of these constraints that establishes the uniqueness of the emergent behaviour of the system. It is *inside* of what is *not prescribed* that the system chooses between equivalent (with respect to constraints) configurations and adopts a unique behaviour from infinite possibilities. A number of observations as well as theoretical considerations show that *phenomenological emergence cannot be* ***prescribed****, but only* ***induced****, being environment-sensitive, depending upon initial conditions, eventual adjustments and the assessment of configurations of components as well as their potential learning (if endowed with a cognitive system)***.**

2.3 Non-separability

The phenomenological experience of systems at the macroscopic level leads us to recognize two different categories: systems which, at a first sight, appear as being devoid of constituent parts (such as, for instance, water flowing in a river, a block of marble, an iron bar) and the other of systems in which we can immediately recognize the presence of constituent parts (a car, society, biological organism, a company). For the following considerations, the former systems will be briefly denoted as *wholes* and the latter as *aggregates*. When trying to understand the operation of both kinds of systems, a number of questions immediately arise. For the wholes, the main question is: can we detect, through a suitable process of *decomposition*, the existence of parts or components (possibly hidden at first sight), whose interactions can account for all behavioural features of the system under consideration? This question arises not only for wholes proper but also for aggregates (the human body or society) in which the presence of parts is evident, but the visible parts do not seem able to account for the holistic features of system behaviour. For the aggregates, on the other hand, the main question is: can we better understand the essential features (eventually holistic) of system behaviour by *composing* in a suitable way the observed parts to obtain a whole?

The overall activity of scientific research consists in a continuous and complicated interaction between the two activities of decomposing and composing, and, despite the objections raised against these procedures (contrasted by authors such as Bechtel & Richardson, 2010), they contribute to the enlargement of our knowledge. In this regard, GOFS, while stating the uselessness of decomposition ('the whole is different from the sum of its parts'), rarely tried to prove the validity of this statement. Moreover, GOFS inspired a lot of research, within systems engineering, devoted mainly to formalizing decomposition procedures (the latter, mainly applied to software programming and hardware design, include contributions such as that of Scholl, 2010; Volf, Jóźwiak, & Stevens, 1995).

Admittedly, the problem of assessing the usefulness of decomposition and composition procedures is very difficult. This difficulty stems from the fact that the existence of general procedures of both kinds is lacking, and upon the circumstance that the number of particular procedures so far introduced for specific classes of systems is very small. After all, a complete theory of decomposition and composition procedures would be fully equivalent to a complete theory of emergence. In more recent times, this question has been addressed within the particular domain of physics, stimulated by the renewed interest in the phenomenon of *entanglement*, allowed by quantum physics. This phenomenon can be considered as an example of *non-separability*, and this circumstance has again focussed attention on the old holistic positions (Healey, 2009).

The usual macroscopic experience and assumption is based on separability and substitutability of *composing* units allowing, for instance, *repair*, i.e. restoring functionality or shape. A material entity is assumed *broken* when partitioned in such a way that the original entity cannot be reassembled. This occurs when the separation into parts has destroyed or cancelled *structural information* essential for the process of *composing*. The concept of structure and structural information may be approached in different ways. For instance, George Klir (1969) introduced the following basic definitions:

- *The ST structure (state transition structure)*: 'The complete set of states together with the complete set of transitions between the states of the system'.
- *The UC structure (Universe coupling structure)*: 'A set of elements together with their permanent behaviours and with a UC-characteristic'.

The study of crystals (Varn & Crutchfield, 2015) allowed the introduction of specific definitions such as those of basis and lattice, where:

- The basis is a fundamental structural unit consisting of a single (e.g. copper) atom or a molecule (e.g. protein).
- The lattice is intended as a partially ordered set. In general this term refers to a number of different models having in common the representation of individual agents as moving entities localized within a discretized spatial lattice. The motion of the single agents and, in general, the evolution of the whole system of interacting agents are a consequence of suitable local evolutionary rules, giving the state of a lattice point at a given time instant as a function of the

state of the neighbouring points at the previous time instant. For instance, a set (typically infinite) of *cells*, arranged within a *lattice* in a suitable *n*-dimensional space (well-known examples include cellular automata, consisting of infinite square lattices of cells in one- or two-dimensional Euclidean space) where each cell is, in turn, associated with a finite number of different possible *states*.

A crystal structure is then formed when a basis is attached to each lattice point and each basis has an identical orientation. This allows one to write:

$$\text{Crystal structure} = \text{basis} \times \text{lattice}.$$

However, exact crystal symmetries may not be produced because of the material's degree of disorder. Research is oriented towards a new crystallography, i.e. chaotic crystallography, more appropriate, for instance, when dealing with noisy, partial symmetries and randomness (Varn & Crutchfield, 2015). Such new approaches will *merge* with the study of *general structures,* as when dealing with chaotic phenomena, dissipative structures or collective behaviours. The latter are of paramount importance when considering condensed states such as *liquids* where processes of structuring occur, as in Rayleigh-Bénard rolls or vortex formation.

Another related subject is that of quasicrystals (see, for instance, Janssen, 2007). The structure of a quasicrystal is ordered but not periodic, and its pattern lacks translational symmetry.

We may also consider the case of *superstructures* in solid-state physics where some additional structure is *superimposed* on a crystalline structure. Examples include:

- Ferromagnetic ordering, in which magnetic superstructures occur when a crystalline material is cooled down and the ordering of spins takes place once the thermal energy is reduced thus losing its influence over interactions between nearby spins (Liua, Zhangb, Dub, & Liangd, 2009).
- Defect ordering, occurring when alloys of different elements form, at higher temperatures, a structure where two elements randomly occupy similar positions in the lattice. Ordering may occur at lower temperatures when crystallographic positions are no longer equivalent (Bogicevic, Wolverton, Crosbie, & Stechel, 2001).

These examples can be considered as special cases *of dynamical networks* given by links between nodes (Newman, Barabasi, & Watts, 2006).

In the case of *broken entities*, where the original structure is no longer *active*, the conceptual *glue* may recompose only entities having a very simple structure by resuming their geometrical position. This glue may partially substitute and reconstitute the simple *information* between pieces such as the relationships in a broken crystal.

This approach does not apply when the entity is divided into too many parts, the *glue* becoming *predominant* over the new recomposed entities and, when the interest is in the *uniqueness* of the entity, the latter is irreversibly *lost*.

This predominance affects important aspects such as shape, robustness, functionality and possibly mobility. For instance, although it is possible to glue together the two parts of a broken glass ashtray (the functionality is recovered), it is not possible to glue together a broken violin (functionality is lost even if the shape is restored).

Another case is when structural information is too complex to be restored by a simple mechanical structural rearrangement. For instance, the pieces of a broken magnifying glass cannot be glued together since the glued interfaces will have an influence and may even predominate over optical effects such as magnification.

Such elementary cases could be transposed to more complex situations where the entities considered are, for instance, biological, electronic, informational, social or works of art. The *glue* becomes, respectively, a transplantation, reparatory, semantic, cultural or restoration process. Entities are systems understood by GOFS as composed of interacting elements. In this view, *separability* relates, for instance, to the ability to:

- *Distinguish* both between entities and between interactions.
- Physically *separate* entities, i.e. having, for instance, *metrical* or *topological distance* between them.
- Consider conceptual *independence* between observer and observed. Only explicit, identifiable and interdependence which can be *deactivated* is conceivable.
- Physically *separate* and *conceive* within and outside of boundaries, and separate elements from environment.

General classical assumptions are of the kind that the *same* element cannot be in two different places at the same time, cannot disappear and identically reappear and cannot be disassembled and *immediately after* (granularity of time) be reassembled and that interactions decay over distance and time (exhaustibility) contrasting, for instance, with power laws and *effective* long-range correlations.

Moreover such a conceptual view should consider various possible cases of partitioning, scalarity and interactions enabling different representations of what is assumed to be the *same* system. This deals with the concept of *system identity* discussed in Sect. 3.5. We recall here that this identity is considered *fixed* by GOFS. This does not apply, however, to complex dynamical systems where identity is intended in several ways such as maintaining the same functionality in spite of structural changes or possibly as single coherence maintained in spite of *continuous* structural changes, e.g. non-perturbed collective behaviours, coherent sequences of single successive different coherences, e.g. perturbed collective behaviours and dissipative systems. Furthermore this situation may *even simultaneously* occur at different levels of representations.

Regular or potential ***persistence*** *of possibly different, multiple, superimposed emergent properties, coherences and non-equivalent representations should be considered as the dynamical identity of the system as well as being the property of such persistence*. The presumed effective separability of properties and representations ignores their *dynamical* relationships, interdependence and higher coherence as discussed in Chap. 7 which deals with *systems of levels of emergence*.

The new conceptual environment relates to strategies which have been developed and used, for instance, by quantum physics and biology, and based on:

- Representation of one phenomenon in terms of another so that they cannot be represented as being *separate*. Variables, properties and interactions should be formulated by *generalizing* the traditional *uncertainty principle* of quantum physics. This generalization includes, e.g. (1) the well-known Heisenberg principle, concerning the position and momentum of a particle, as well as time and frequency of signals (from Fourier analysis), and (2) the fact that the observer and the observed are a model-dependent dipolar entity, closely linked to what and how we want to observe (theory of cognitive operators based on theoretical principles introduced by von Foerster).
- Representation of one phenomenon in terms of some of its own properties such as when introducing power laws, e.g. that according to which the frequency of a signal depends upon its intensity. This allows one to consider networked representations as in Chap. 8.
- Finding distance-independent long-range correlations, i.e. violating the assumption that the strength of interaction decays with distance and time.
- Defining the environment through *context*, *space* and *temporal properties*. In the classical view, the environment can be separated when its properties can be considered to have been deactivated *inside* and at best *varied* in areas specified by boundaries. The new approach can consider various properties activated over different space-temporal levels as an *environmental space*. This is indissolubly related to the level of description, modelling and representation adopted by the researcher. We recall here that concepts such as coherence, decoherence and entropy have no *absolute* meaning (Koksma, Prokopec, & Schmidt, 2010; Schlosshauer, 2008). Furthermore, the conceptual selection of the environment allows one to find different descriptions of the *same* phenomena. For instance, the probabilistic features of quantum mechanics (QM) and quantum field theory (QFT), which assume that the main physical entities are fields (of force) and not particles, can be considered a consequence of the fact that the ground state of the Universe is a special kind of noisy state, preventing the existence of truly deterministic phenomena (see Nelson, 1967). This approach, called *statistical field theory*, studies quantum fields by considering them as deterministic entities influenced by noise in a context in which time is imaginary (Chaichian & Demichev, 2001; Itzykson & Drouffe, 1989a, 1989b; Parisi, 1998).

Thus, separability is a matter of simplification, allowing the conceptual possibility of distinction and independence. In contrast, an *unavoidable* space of properties is the place where single and separable properties, elements and interactions may be active *only* at a specific level of representation superimposed upon the entangled ground, ignored for convenience by the researcher. This space may be conceptually intended in all respects as the quantum vacuum.

Formalizations of phenomena are expected to be no longer based on the classical theory of *dynamical systems* introduced on the basis of research implemented by *Jules Henri Poincaré* (1854–1912) where a dynamical system of the generic form $dx(t)/dt = f(x(t))$ is deterministically based on two kinds of information:

1. One given by a representation of the system's state and information about the system itself, i.e. its internal variables $x(t)$ and their growth rate $dx(t)/dt$.
2. The other specifying the dynamics of the system, through a rule describing its evolution over time, i.e. $f(x(t))$.

The first formalization of systems still followed by GOFS and introduced by *Ludwig von Bertalanffy* (1901–1972) was based on this conceptual framework. Bertalanffy considered a system S as characterized by suitable state variables Q_1, Q_2,. .., Q_n, whose instantaneous values specify the state of the system. Examples are the momentum, i.e. product of the mass and velocity, position, volume and pressure. The time evolution of the state variables is considered. In the simplest cases, it is governed by a system of *ordinary differential equations* representing how changes in the values of a given state variable affect all other state variables. Often this analytical assumption represents well the conceptual foundations of GOFS where variables are identifiable, separable, constant during the process and only linked by f_n assumed in their turn to be explicit and identical over time. The mathematical machinery of differential equations represents coherence, and the history of the system is assumed to be identical when starting from the same initial conditions (von Bertalanffy, 1950).

Multiple mathematical systems of the same kind are considered to represent *multiple systems*[1] when the argument (Q_1,Q_2, . . ., Q_n) and f_n change over time. A set of functional constraints, such as ergodicity, can be used to ensure coherence over time (Minati & Pessa, 2006, pp. 116–137).

However, *analytical* dynamics take into consideration only sets of the *same* state variables and the *same* f_n. Structural dynamics (see Chap. 3) consider dynamical couplings and the properties of sequences of multiple rules represented by properties or by properties of networks or meta-structures as introduced below (see Chaps. 3 and 4). Alongside the differential equations and discrete maps (their finite differences counterpart), it is possible to introduce various new approaches, for considering multiple probability features and coherent states rather than sequences of *single* properties of the same system. Among these approaches, we can quote neural networks, cellular automata, genetic algorithms, artificial life systems, multi-agent modelling, swarm intelligence models, neuro-fuzzy systems, crowd

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[1] Multiple systems are simultaneous or successive systems established by the same elements interacting in different ways, i.e. having multiple roles simultaneously or at different times. Component elements take on the same roles at different times and different roles at the same time establishing clusters or behavioural classes. The component elements can migrate from one class to another and simultaneously belong to more than one class. Coherence is considered to be given by the ergodic interchangeability of roles intended as belonging to classes (Minati & Pessa, 2006, pp. 291–313).

computing and quantum computing. Within these contexts, the function *f* conceptually, and continually, *emerges* from the individual cases when considering clusters of variables and their properties as well as properties of sequences of rules as in the case of meta-structures (see Chap. 5).

2.4 Between Macro and Micro

GOFS inherited from various specific disciplines the distinction between the microscopic and the macroscopic level. The concept of ‘microscopic’ relates to the possibility of assuming the existence of a fundamental, indivisible and ultimate level. The underlying idea of matter is that it is formed of final irreducible *bricks*, having stable properties such as structure or position (Sect. 7.1.2.1). This approach is conceptually based upon the assumption of general and definitive validity of *Mendeleev*’*s periodic table* introduced by *Dmitri Ivanovich Mendeleev* (1834–1907). However, non-classical physics studies, for instance, on condensed phases of matter, which can even be produced by Bose-Einstein condensation of photons (Klaers, Schmitt, Vewinger, & Weitz, 2010), take into consideration *quasi-particles* rather than particles (the bricks of the classical dream). As is well known, photons share many features with traditional particles, except localization (Pessa, 2011).

The idea that the current state of nature follows deterministically from its state at the previous instant is attributed to Laplace (1749–1827). If we imagine an intelligence (*Laplace’s Demon*) that at a given instant knows all the relationships between the entities of the Universe, then it could know their positions and their motions, being able to make general predictions about the state of all these entities at any moment of the past and the future. The idea is to consider the Universe as a gigantic *clock*. The problem is that the world *emerges* rather than *functions*.

The previous way of thinking has proved to be ineffective because of the systemic and complex nature of the world where processes are characterized by non-linearities of various kinds as discussed above.

However, the idea of the microscopic as the ultimate, definitive, true and explicative level is still conceptually active and has been useful for introducing some concepts of complexity, when considering, for instance, *Brownian motion*.

In 1827, the biologist Robert Brown considered the irregular, disordered, unpredictable motion of a speck of pollen in water, i.e. so-called Brownian motion (Schilling & Partzsch, 2012). This motion is considered to be caused by collisions between moving water molecules possessing thermal energy. It is the first example of systems where it is impossible to build a deterministic model of their behaviour. Notwithstanding the possibility of directly observing these random fluctuations, this circumstance contributed to the development of the basic concepts of complexity.

According to classical physics, the reason why deterministic models are not applicable is an *incomplete knowledge* of all physical features of the components of the given system (for Laplace's view, see Gillispie, 2000).

Such a concept of microscopic is still *beyond* that of component, part, element and entity assumed to be *inescapably converging* to the microscopic even on various possible scales.

At the microscopic level, it is possible to deal with *single* elements – *multiplicity* is not microscopic – such as molecules, cells and particles, even though they may be indistinguishable because of our limits and inabilities, rather than obeying some intrinsic theoretical principle.

On the other hand, macroscopic features should be intended as indices, related to the general properties of various types of *collections* of microscopic entities considered for their *aggregations* and related properties such as pressure and temperature. These two levels, microscopic and macroscopic, may be considered as two temporary *extreme* hierarchical levels.

First of all, the hierarchical assumption should be considered as a possibility. Secondly, should the hierarchical assumption apply, we may have various hierarchies. They may be superimposed, dynamical and having, in some cases, *dynamical* extremes (see Sect. 7.1.2).

The assumption of the existence of only the microscopic or the macroscopic levels is a matter of simplification.

The point is not only to consider the various hierarchies and their possible extremes but their dynamics as a means of characterizing the systems under study.

We may consider various ***windows*** *for such dynamics adopted as* ***balances*** *between cognitive strategies and physical effects, i.e.* ***philosophically speaking, between constructivism and objectivism***. The study of such windows is a *continuous* systemic trans-disciplinary project, which needs to take into consideration various aspects including neurological, technological, physical (related to classical and quantum physics) and epistemological ones.

Suitable tools and approaches are required for representing and processing such balances when considering not only ***variable levels*** *of microscopic or macroscopic representations at our convenience but possible new levels and representations. Indications and clues may be given by considering approaches such as the so-called non-symbolic computation,mesoscopic variables and network representations as introduced in* Chap. 8. *Let us now consider these three cases.*

The first, non-symbolic computation, is interesting since the processing is not *explicit*, i.e. the result has an emergent nature (Licata & Minati, 2016) since it cannot be recognized or anticipated stepwise. Steps cannot be suitably understood as microscopic computational steps, all sequential parts of a general algorithm playing here the conceptual role of a macroscopic level looking for explicit solutions. The approach was introduced decades ago using connectionist approaches and modelling tools such as cellular automata (CA) and artificial neural networks (ANN). Newer versions of CA such as *multiple cellular automata* (MCA) are used, for instance, when dealing with multiphase systems (Marchisio & Fox, 2013) where the phases of components or areas change not in a fixed way but in such a way as to establish dynamical multiple coherences. In this case, the distance between structures or phases not only varies in order to be coherent but also changes the hierarchy of *ways* to vary (Feng, Ling-Ling, Cheng, & Xin-Bo, 2012). Let us consider, for example, multiple phase systems with subsequent time-varying laws in which not only the phases are multiple, but they vary themselves in different manners, which may depend upon contextual situations (choice function).

The topic of MCA is addressed in the literature by considering, for example, cellular automata in parallel, interactive and networked contexts, and by studying their behaviour from the point of view of *ensemble performance*. A MCA can be considered as being given by the fact that its evolutionary local rule is not fixed but variable and may have only local, temporary validity. There is an available library of limited evolutionary rules applicable to any sequence: either (a) the same identical library of rules for each evolutionary step (sequences of classical cellular automata, applied to the same lattice at its previous state) or (b) different rules for dynamically different areas of the MCA consisting of multiple *partial* cellular automata, coexisting within the same lattice. In the latter case, the inhomogeneous application of the rules can be given by any choice of rule or function, which will also be context sensitive.

The case is interesting when coherence, i.e. the establishment, maintaining and changing of any property is not simply due to the validity of the *same* CA. This case is considered in the literature on heterogeneous cellular automata (hetCA) (Medernach, Kowaliw, Ryan, & Doursat, 2013; Phon-Amnuaisuk, 2010).

Non-symbolic variables in this case would be the values associated with sequences, e.g. number of sequences, number of repetitions and number of clusters, with configurations which could be suitably parameterized.

The dynamics of MCA are given by its structural change, which is by evolutionary rules of the CA over time.

In the case of neural networks, there are studies and applications of multiple neural networks which can be combined, trained together and employ various models over the same data set. We consider here a *multiple neural network* (MNN) as given by the fact that its connection weights and possibly also its levels are not fixed but variable in conceptual correspondence with cases (a) and (b) considered for MCA.

It is a matter of considering *sequences* of completely or locally different neural networks.

Rules are not explicit as they are for CA, and it will be necessary to consider *structural* variables consisting, for example, of connection weights and levels, their sequences and clusters.

The dynamics of a MNN is given by the sequences of its structural changing, i.e. by sequences of weights and levels over time (Dragoni, Baldassarri, Vallesi, & Mazzieri, 2009; Shields & Casey, 2008).

Similar approaches may be considered, for instance, when dealing with fractality and L-systems (Lindenmayer systems), or with parallel rewriting systems.

The second case is related to mesoscopic variables based on suitable clustering. Mesoscopic variables, when not relating to the quantum level, relate, in several disciplines such as physics, chemistry and biology, to an *intermediate* level between micro and macro where the micro is not completely neglected as usually happens when adopting the *summary statistical* macroscopic levels ignoring details (see, for instance, Freeman, 2000, 2005; Haken, 2005; Imry, 1997; Ingber, 1992; Liljenstrom & Svedin, 2005). This approach is based on the *philosophy of the 'middle way'* (Laughlin, Pines, Schmalian, Stojkovic, & Wolynes, 2000), considering the mesoscopic level of description as an *area of continuous negotiations between micro and macro* and the definition of families of possible observables as a *research strategy*.

The lasers have been intensively studied using mesoscopic variables, later generalized by Synergetics (Haken, 1978, 1983, 1988) using the *slaving principle*. In this context, the amplitude of fluctuations of the unstable mode is called an *order parameter*, as it drives the dynamics of pattern formation.

The meta-structure approach for modelling complex collective behaviours (Licata & Minati, 2010; Minati, 2008, 2012a, 2012b; Minati & Licata, 2012, 2013, 2015; Minati, Licata, & Pessa, 2013) is also based on mesoscopic variables adopted to represent structural dynamics, i.e. changes in the structures of interaction (see Sect. 3.2.4) by considering, for instance, suitable clusterings, their single and cross-correlated properties, the mesoscopic vector and the usage of degrees of freedom.

Furthermore, the properties of clusters corresponding to mesoscopic, including metrical and topological, variables can also be studied. Section 3.7 provides a more extended explanation of meta-structural properties as properties of sets of variables, clusters and their relationships. Clustering may be performed by the observer when adopting a suitable threshold level and assuming *continuity* between the micro and the macro levels even though clustering can occur in various ways: for instance, by minimizing the energy spent by the observer in its neuronal phase space (Bullmore & Sporns, 2012; Edelman & Tononi, 2000; Goni et al., 2014; Sporns, 2013; Van den Heuvel, Kahn, Goni, & Sporns, 2012). In the cases considered in Sect. 3.7, continuity is due to considering the *same* properties for micro and macro levels, that is, speed, direction, altitude and distance, whereas *discontinuity* derives from considering, for instance, properties such as density and scale.

As discussed in Chaps. 3 and 4, meta-structures are considered as coherent sequences of multiple dynamical structures represented by properties of suitable sets of mesoscopic variables and related clusters intended to *transversally intercept* and represent values adopted by aggregates of microscopic variables. Values of mesoscopic variables and related clusters are then considered to suitably represent the effective application of rules of interaction. Suitable properties of sets of such values represent coherence in sequences of configurations, i.e. collective behaviour.

The cases considered above are intended as windows between the micro and the macro.

The third case is related to network representation where systemic properties are considered as properties of suitable networks (see Chap. 8). Network representations may be applied to mesoscopic variables. The mesoscopic and network approaches have been considered previously (Giuliani, 2014).

2.5 Uncertainty: The Richness of *Uncertain Uncertainty*

Some aspects of uncertainty have been discussed above, particularly in Sect. 1.3.9. *This section considers* ***uncertain uncertainty****, i.e.* ***non-computable uncertainty*** *as evidence of true processes of emergence occurring when, for instance,* ***autonomous*** *interacting agents change the rules of interaction due to individual specific cognitive processing leading to* ***decisions*** *and eventual fluctuations.*

This is the case in question, related to how degrees of freedom are *spent* when agents are authorized to select any state respecting the degrees of freedom.

This is the *theoretical freedom* given by non-completeness where equivalence occurs, as when dealing with logical openness (Sect. 2.7). This recalls Turing's halting problem (Sect. 1.3.4). Processes of *radical emergence* (Sect. 1.2) are *unique* (Sect. 2.2) where the final state of the process can be known only at the end. Turing's computations are reproducible as are processes of computational emergence, i.e. simulated, whereas *phenomenological* emergence, as that due to unique phenomena of dissipation, as introduced above, is not. The concept of emergence has been first used as a fundamental theoretical tool by *Conwy Lloyd Morgan* in 1923 (Morgan, 1923) and by the philosopher *Charlie Dunbar Broad*, who introduced *the concept of emergent properties present at certain levels of complexity but not at lower ones* during the same period (Broad, 1925; see also Lovejoy, 1927).

For the reader's benefit, we recall that the concept of emergence refers to processes of various kinds, but all of which are characterized by the fact that, in the case of open systems, there is a *continuous* acquisition of emergent systemic properties.

A well-known process of acquisition of the *same* systemic property, coinciding with preserving that property, is the transition from sets of elements to systems having properties completely different from those *possessed* by those elements. Such continuous acquisition is not a once-and-for-all *result* but occurs, for instance, because of interactions among elements through structures and organization. For instance, electronic and mechanical devices become systems when *powered on*, i.e. when elements interact, the devices are considered as *functioning*. When *powered off*, the system degenerates into a set. Similar understanding may apply to biological systems when acquiring the property of being living.

The emergence of complex systems relates to the continuous acquisition of possibly novel properties (i.e. non-equivalent, non-deducible, requiring various levels of description) compared to those active before the process occurred (see, for instance Johnson, 2002; Kauffman, 2010; Macdonald & Macdonald, 2010; Minati & Pessa, 2006, pp. 89–134) as in the case of collective behaviours (Vicsek & Zafeiris, 2012) of swarms, flocks, bacterial colonies, cells, protein chains, mobile phone networks, industrial districts, markets, morphological properties of cities (Batty, 2013), networks such as the Internet, queues and traffic signals.

See Chap. 7 for bottom-up, top-down emergence and combinations thereof. The difference from *phenomena* intended as *secondary or additional* phenomena, and *byproducts* which result from and accompany primary phenomenon such as secondary symptoms, is given by the *nature* of the processes of acquisition of properties and of the properties themselves.

The understanding of emergent phenomena as epiphenomenal is related to positivist philosophy and reductionism. Epiphenomena are assumed to be completely explainable in terms of relationships between other, more fundamental, phenomena. In medicine, for instance, an epiphenomenon is a secondary symptom apparently unrelated to the dominant one and is only *combined*, eventually aggravating the situation.

However, we know that *everything must happen some way. But the ways they happen are different from what actually happens, and the way they happen may not be due to the causes*. In this case, we need to change our levels of representation when properties become *autonomous*, leaving their causal connections and introducing eventual equivalences with the original system eventually keeping *necessary* relations as for life and autonomous thinking (see Chap. 7 and Hofkirchner & Schafranek, 2011).

If we focus on very complex systems, such as living beings, emergence is like moving among different cardinalities, levels of logical openness, (see Sect. 2.7) and levels of non-linearity and having *strange* feedback loops and attractors in chaotic systems.

Such a kind of emergence is coupled with possibly multiple coherences as a *mechanism* continuously generating and sustaining properties.

On the other hand, emergent properties are unpredictable and not reconstructible from those of the generating phenomena even though their changes are related, as for power laws, topology of networks and swarm intelligence. This is the case for the so-called intrinsic or radical emergence, including examples coming also from very simple systems, as in phase transitions (e.g. from water to ice, from paramagnetic to magnetic phases); *spontaneous symmetry breaking* (e.g. acquisition of superconductivity, superfluidity and protein folding); the constitution, maintaining and evolving of patterns (e.g. the geographical morphology of landscapes, coasts and cities); and the formation and conservation of dissipative structures dynamically *stable*, far from equilibrium and due to the continuous dissipation of matter and energy (as for whirlpools and life).

Classical uncertainty relates to possible changes in the value of a variable. Uncertain uncertainty has structural and *ontological* aspects since it relates to processes of emergence, structural changes and acquisition of unpredictable and not reconstructible properties rather than changes in a given property.

Uncertainty is the other side of the coin of ***uniqueness****, being not arbitrary and not epiphenomenal because, in most cases, due only to multiple coherence(s) and related properties.*

Within the conceptual framework outlined above, we may also consider a kind of *reverse* reasoning, which is *uniqueness and uncertain uncertainty*, i.e. non-computable uncertainty, where *environmental conditions* signal emergence. Questions immediately arise: can emergence and *uniqueness and uncertain uncertainty* be considered independently or are they two sides of the same coin?

We believe there are good examples of phenomena having *uniqueness and uncertain uncertainty*, but it is difficult to prove that they are related to emergence, such as the lines and shapes in the palms of hands, fingerprints, faces and neuroimages. The same holds for chaotic behaviours possessing exponential sensitivity to initial conditions and being unpredictable over the long term, such as weather conditions and smoke diffusion. Similar situations occur for pattern formation by dissipativity like, e.g. in whirlpools.

Similarly, there is also the occurrence of *improbable events*. The importance of such cases is given by the fact that they may *induce* the occurrence of metastable systems (Antman, Ericksen, & Kinderlehrer, 2011) and systems having equivalent evolutionary paths able to produce changes. It can be said that events, even of a *minimal* entity, such as noise or fluctuations, may lead to system *collapse*, and for quantum phenomena to a *selection*, from among various possibilities, implying the reduction of many physical possibilities into a single possibility.

As mentioned above, it is a matter of a suitable balance and combination of determinism and non-determinism. It relates to the suitable configuration of degrees of freedom and to the various uncertain ways of respecting them, which can be considered as being *equivalent* from the point of view of the degrees of freedom. *Between degrees of freedom, there is the world of equivalent paths or behaviours or configurations. Novel approaches are required to recognize, induce, act upon and merge* ***uniqueness***, ***uncertain uncertainty*** *and* ***emergence***. *Some possibilities are presented in the following chapters.*

As considered in more detail below, the approaches should be based on *lightness* as non-invasive, non-prescriptive, non-massive dispensing of, for example, energy or information. They should move from (a) the assumption that dispensing the *maximum* is always the best approach by considering systems as metaphorical communicating vessels which always divide into equal parts to (b) provide non-perturbative, more *moderate amounts*, leaving the system to dose and process them. In the latter case, the system can explore *equivalent* spaces of states and trajectories which can be *selected* on the basis of fluctuations and influences of any kind.

The reference is to the fundamental contributions to *theoretical biology* introduced by Erwin Bauer (Bauer, 1935), considering living systems *unique* in being able to *dose* and not to use up at the maximum rate all the energy dispensed, and life as being inextricably mixed up with the subsequence and preserving of coherence between processes of emergence, passing through various possible equilibrium states based on different, variable usage of the energy available. This is equivalent to provide the system with *suggestions* leaving it to do the dosing and making choices among multiple configurations.

Uncertain uncertainty does not relate to the *results* of a process but, rather, to the *mechanisms of the processes* themselves.

Actions on such uncertain uncertainty cannot be *ideal* nor *explicit* (see Sect. 5.6) due to its *structural dynamics* and DYSAM-like nature.

Modelling should thus be based on sub-symbolic approaches, making use of instruments such as neural networks, cellular automata, meta-structures, perturbative interventions, types, configurations and dynamics of attractors.

2.6 Interfaces as the *Between*

Processes relating to the ***between*** *such as transience, macro and micro, and levels of emergence are considered throughout this book. We introduce here an extended understanding and usage of the concept of* ***interface*** (Hookway, 2014), *already considered in several specific disciplines, for instance, to select, filter and transform signals and energy such as acoustic or thermal. The concept is widely used, for instance, in computer science and telecommunications dealing with human-machine interfaces and engineering* (Artemiadis, 2014).

An interface is given by properties of the time-space *between*, within which interactions occur.

An interface is not a *separation* as for the properties of materials where there is a well-definable one side of the interface, distinguishable from the other.

It is rather an *active between,* influencing interaction or even making it possible. Interfacing is not given by the introduction of *deformations* or *noise* in processes of interaction.

The extended trans-disciplinary understanding of the concept of interface may be introduced as the conceptual and effective *place* where processes of transformation, transition, representation, reformulation, balancing, negotiation and selection occur *among non-equivalences*.

Interfaces should be intended as variable and multiple, i.e. eventually combined and occurring simultaneously and sequentially.

In particular there are, for instance, adaptive or context-sensitive, learning and predictive interfaces.

Human-machine interfaces adapt themselves to the characteristics of their user. The actions in an adaptive system often affect the environment, and hence such a system belongs to a constant feedback loop with its environment (Carroll, 1989; Fiset, 2008).

The ability to adapt, in the case of software systems, characterizes the so-called intelligent systems and machine learning processes. The concept of adaptive system was introduced in 1947 by the British psychiatrist and cybernetician W. R. Ashby in a celebrated paper (Ashby, 1947).

It is a typical property of most complex systems, consisting of interacting autonomous agents, such as ant or bee societies and, more in general, communities within ecological systems.

We can assume to be dealing with *populations of interfaces*, of various kinds, specifying processes of interaction. This understanding can be applied, in particular to ecosystems where various intelligent dynamic interfaces rule a large number of simultaneous, superimposed interactions.

Populations of interfaces have a *resultant* level of *interfacing* which can be multiple, multidirectional, dynamical, mutual and possibly evolutionary, at whatever degree of complexity.

On the contrary, one may ask: where are there not interfaces of this kind? Probably where there is *no complexity*, where there is *single* homogeneity, structural regime and cardinality and no emergence.

Interfacing may be considered as reduced to active *bordering* in the case of protection and defence, when intended as sheltering, regulation and selection.

In this book, we focus on transience, on the *between* which can be represented by final states since the *between* is considered as the place where important kinds of phenomena, usually not considered by classical approaches and GOFS, occur, such as emergence and *negotiations* between macro and micro, as in the 'middle way' mentioned above (Laughlin et al., 2000).

Interfacing may be usefully discussed by considering logical openness (as in Sect. 2.7). Interfacing is often an inescapable or even unwilled *role*. What is *not* an interface? Spatial and temporal *adjacency* often makes interfacing inescapable. No interfacing may be considered coincident with *total* isolation and separation, often only partial or ideal, or with equivalence. Interfacing can also be considered to occur even in temporal processes of *transition* between social era, scientific or philosophical theories and approaches. In these cases, interfacing is initially bidirectional and then changing into unidirectional thus adapting the system to the new situation.

Consider such interfacing occurring between what is considered to be true or false. Can we consider as interfaces processes where the truth is becoming false and the false is becoming truth?

More concretely, we can consider *degenerative* processes when truth *decays* into falsehood and consider *correcting* the reverse. However, considering the first case, this decay is usually combined with, if not implied by, the emergence of a new truth. On the other hand, in general processes of the emergence of new truths, *the* ***truth comes first***.

Truth may be considered to come after the decay of another truth rather than as the transience from false.

The ***constructivist*** *dynamics of this process can be considered as second-order truth.*

This is presumably of some interest when non-trivially reduced to *relativism*. The *between* is given by processes of understanding, discovery, falsification, demonstrating, testing, conjecturing, proposing and validating. Regarding science, *truth* may be understood as demonstrated, robust, consistent and supported by experimental evidence. However, we may consider their *levels*. This is *liberating* since we are not supposed to be in an objectivistic or even non-objectivistic, constructivist in the latter case, network of dual possibilities but almost in a *fuzzy network* where *entities*, like concepts, theories, approaches, experiments and conjectures, have several levels or degrees of truthiness and links among them clustered within specific theories and disciplines.

In such a network, truth could be considered as an emergent property. Let us consider two examples.

The first one relates to the effectiveness of replicability for validation. The problem has been studied, for instance, in medicine when detecting the *declining effects* of drugs. In medicine this may be considered due to psychological effects or addiction, requiring however significant periods of time. The problem, named *the truth wears off* in newspapers articles, was studied in a more general way by also considering the expectations of researchers (Ioannidis, 2007; Schooler, 2011) and when ‘Research findings are defined here as any relationship reaching formal statistical significance, e.g., effective interventions, informative predictors, risk factors, or associations, for instance’ (Ioannidis, 2005, p. 696; Lehrer, 2010).

The second case relates to the results of the *placebo effect* and where medicines have significant and persistent effects if patients are *informed* of their administration (Colloca & Benedetti, 2005). This relates to concepts of *invented reality*, considered, for instance, by De Finetti (1974) and Watzlawick (1983), and *cognitive reality* discussed throughout this book.

2.7 Between Open and Closed

First of all, we need to clarify the two terms and its relative terminology.

Systems considered as being isolated from their environment, and which reach an equilibrium state, that is, a final state unequivocally determined by initial conditions, are considered as *closed* systems.

In *open* systems, on the contrary, stationary equilibrium states, where system composition is kept constant in spite of continuous exchange of components, can be established (Nicolis & Prigogine, 1977; Prigogine & Nicolis, 1967; Von Bertalanffy, 1950). An open system tends to resist perturbations tending to move it away from its evolutionary process, whereas this does not happen for closed systems. Systems may be closed to matter/energy flows, closed to information flows (independent) or closed to organization. Within standard macroscopic thermodynamics, a system is considered as closed if it is able to emit and absorb energy and information, but not matter. In contrast, with *open systems*, it is possible to prove that the same final state may be reached in different ways, even when starting from different initial states. Open systems may reach stationary states manifesting constant composition in spite of continuous component exchange with the environment. In open systems, there is permeability between them and the environment, due to the fact that there is an exchange of matter, as typically happens with living systems.

However, the reader is warned against relying on the difference between closed and open systems only as specified by standard macroscopic thermodynamics. On this point, we first stress that it is possible to use the attribute of open and closed by referring to specific aspects of a system: thus, a system could be simultaneously open and closed by referring to some of those aspects. For instance, systems composed of agents, each of them, in turn, equipped with a cognitive system, may be approached from different points of view (with reference to physical, thermodynamic and cognitive aspects) and therefore may be open for some aspects and closed for others.

It is easy to detect the complementary aspects of such openness and closure, which are significant when they show the direction(s) of process(es), that is, single or possibly multiple, simultaneous opening or closing.

*From this point of view, openness and closure have little meaning without considering their direction, multiplicity and dynamics***.**

The focus is on the transient to be considered not only as directional and multiple from a reductionist, linear and summative point a view but as a *place* where various multiple dynamical emergences may be acquired and which are then stabilized on opening or closing. *The latter could be understood as properties acquired during transience when a system is closing or opening and reaching multiple metastable openness or closure, i.e. a dynamical state of quasi-open and/or quasi-closed* (see Sect. 4.3). This way of understanding the question is suitable for complex systems rather than for simple, *complete* systems, i.e. those with few degrees of freedom representing *all* the properties which may be adopted.

More correctly, transience should always be considered not only between open-closed and closed-open but even between levels and kinds of openness and between levels and kinds of closure, ***when the between is the place for the quasiness****, referring, for instance, to non-equilibrium thermodynamics* (Attard, 2012; Lebon, Jou, & Casas-Vázquez, 2008; Nicolis & Prigogine, 1977).

After clarifying terminology and assumptions, our attention can now be turned to the two main corresponding cases of interest for systemics: (a) those related to *boundaries*, termed *thermodynamical* openness/closure, and (b) those related to *processing*, termed *logical* openness/closure.

The two subjects have been discussed in great detail in the scientific literature and also from an interdisciplinary point of view when considering, for instance, physics, chemistry, biology, psychology, economics and sociology.

For the benefit of the generic reader, only the main concepts characterizing the two kind of openness will be mentioned.

With reference to case (a), *thermodynamical* openness/closure, the main concepts are based on assumptions discussed above (see Sect. 1.3.8 for external-internal and Sect. 2.3 for separability). Within such a conceptual framework, systems which can be considered as *separated* and *isolated* from their environment, reaching an equilibrium state, which is a final state unequivocally determined by initial conditions, are considered *closed*. However, within standard macroscopic thermodynamics, a system is considered closed if it is able to emit and absorb energy and information, but not matter.

In *open* systems, stationary equilibrium states are established when system composition is kept constant notwithstanding the continuous exchange of components (Nicolis & Prigogine, 1977; Prigogine & Nicolis, 1967; Von Bertalanffy 1950). In open systems, the same final state may be reached in different ways and starting from different initial states, and there is permeability between them and the environment, due to the fact that there is an exchange of matter, as happens typically with living systems.

The thermodynamical view of openness-closure may refer to specific aspects of a system. In this way, a system could be *simultaneously* open and closed (Minati, Penna, & Pessa, 1996, 1998). Moreover, it is possible to hypothesize the existence of systems in which the property of openness and closure may be adopted dynamically (that is, as a function of time) and not only statically.

With reference to case (b), *logical openness*, introduced by Minati et al. (1996, 1998) and Minati and Pessa (2006, pp. 111–112), it should be considered as a first step towards the theoretical *generalization* of the concepts of thermodynamical openness and closure.

We can now consider the concept of *logically closed model* or *logical closure* with reference to its suitability for modelling the evolution of systems.

A model may be defined as *logically closed* when:

(a) A formal description of the relationships between all the state variables is available in the model's eqs.
(b) A complete and explicit description of system-environment interactions is possible and available.
(c) All possible asymptotic states and structural features are derivable in a unique way from the information in (a) and (b).

We stress at this point how *thermodynamically open systems* may be described by *logically closed* models. For instance, this is the case of *dissipative structures* described by the *Brusselator model* (Nicolis & Prigogine, 1977).

It should be noted at this point how the description of a given system is equivalent to precisely made assertions about its input and output processing modalities. For various new approaches see, for instance, Resconi and Licata (2014). Therefore:

- *Logically closed modelling* relates to rigid and foreseeable input processing modalities.
- *Logically open modelling* relates to such a description of the system when it is impossible to know, *in principle*, how the input-output will be processed. It is thus impossible to know the asymptotic states (if any) of the system. An example is given by a computer program playing a game with a player and by the evolutionary paths of complex systems as considered above.

Logical open modelling or *logical openness* may be introduced on the basis of violation of at least one of the three criteria (a), (b) and (c) listed above to describe *logical closed modelling*.

It is particularly interesting to consider the violation of the second criterion, when a complete and explicit description of interactions is available in order to model, explain and foresee the evolution of the system.

In this case, logical openness corresponds to the fact that system-environment interactions cannot be explicitly and completely described. One example considers the learning process of a neural network where the network-environment

Table 2.1 Levels of openness/closure

Levels of openness	Related levels of closure
1. Thermodynamic level: crossing of matter-energy across boundaries of the system	No crossing of matter/energy across boundaries of the system
2. Meaning assumed identical between sender and receiver	Crossing of matter/energy across boundaries of the system but no common meaning between sender and receiver
3. Interacting systems produce mutual context-sensitive models: systems have learning capabilities	Meaning assumed identical between sender and receiver, but the systems do not produce mutual context-sensitive models and have no learning capabilities
4. Interactive systems produce dynamic mutual context-sensitive models: systems have learning capabilities	Interacting systems produce mutual but not dynamic context-sensitive models: systems have learning capabilities
5. The system may continuously decide which level to use in interacting	Interactive systems produce dynamic mutual context-sensitive models, systems have learning capabilities, but they cannot continuously decide which level to use in interacting

interaction may be described only in an *implicit* way, i.e. by using weights and levels instead of values of symbolic variables which, in this case, are not available.

It is possible to consider different levels of openness (Table. 2.1).

Logically open models of zero degree may be coincident with *logically closed models*.

Logically open models of degree one, if we restrict ourselves to the context of physics, may be those describing systems in metastable equilibrium with their environment and which cannot be described in an explicit way. An example of such models and systems are those related to the so-called moving boundary problems (Chakrabarti & Brebbia, 2007; Crank, 1984; Peskir & Shiryaev, 2006; Sara, 2012), describing, for example, the solid-liquid interface during phase transitions. A prototype of this kind of process is given by the so-called Stefan problem describing the melting of a semi-infinite sheet of ice when the surface is maintained at a temperature greater than the melting temperature.

Logically open models of degree two, again within the context of physics, may be assumed to be similar to models of degree one, except that the law of dependence of system-environment interactions from the system internal state cannot be described in explicit terms because its form is dependent upon the internal state itself. An example is given by neural networks where *unsupervised learning* gives arise to *inner schemata* (Grossberg, 1988).

Thus, it can be seen how it is possible, at least within the domain of physics, to introduce a *hierarchy of logically open models*.

Let us introduce for this purpose the concept of *constraint of degree n*. We denote as a *constraint* any kind of explicit or implicit information related to the influence of the environment on the system. Examples of *constraints* are initial conditions, boundary conditions and parameter variation laws.

The concept of *constraint of degree n* may be defined recursively. A *constraint of degree zero* is a constraint that can be explicitly and completely specified without making reference to the system's internal state.

A *constraint of level n* is obtained when the *constraint of level n-1* is changed as being dependent on the system's internal state, where this law of dependence may be completely and explicitly specified without any reference to the system's internal state.

A hierarchy of *logically open systems* can then be introduced by considering *logically open models of degree n* as models specified on the basis of at least one *constraint of degree n* able to specify transience and quasiness of the between.

2.7.1 More on Logical Openness

With reference to an observer, avoiding objectivistic assumptions, it is possible to consider, for instance, different *levels of logical openness* and *related closure*, as shown in Table 2.2.

Other examples are also given when the interaction among people takes place using different kinds of technologies, which allow:

1. One-way interaction with no model of the receiver or real-time feedback, for instance, the author of a book.
2. One-way interaction with no model of the receiver but with real-time feedback, for instance, an actor on stage.
3. Two-way interaction with no model of the receiver, for instance selling by telephone/TV or the Internet.
4. Two-way interaction with a model of the receiver, for instance private direct selling.
5. Two-way interaction with a model of the receiver and of its context, for instance business marketing through sellers, etc.

2.8 Hypercomputation and Quantum Computing

We have already mentioned above the changes occurring from considering hard vs soft computing in Sect. 1.3.4.

However, they all occur within the theoretical framework of Turing computability as in Sect. 1.3.5.

The so-called Church-Turing thesis (Copeland, Posy, & Shagrir, 2013) states that a function is *algorithmically computable*, which is *computable* tout court, if and only if it is computable by a Turing machine.

Table. 2.2 Levels of openness/closure

Level 1	This is the classical thermodynamic level where matter and energy are able to cross a system boundary. At this level, to close a system it is sufficient to consider the system containing the original system *and* the other interacting systems (such as the environment). For systems able to send and receive information, this may be the case where systems are able to send and receive signals, but not to ascribe or process meaning. An example is given when two or more people physically exchange words with no common understanding because they speak different languages. In the same way computers may physically exchange signals between each other without having the software to process them.
Level 2	At this level the meaning of signals is assumed to be identical and constant between sender and receiver. The process of interacting is assumed to be context-independent. This is the classical approach based on objectivism. Examples are rules, instructions, and formal programming languages.
Level 3	At this level the process of interacting is assumed to be context-sensitive with reference to the sending/receiving systems. Systems reciprocally generate a model of the other having *learning capabilities* and the communication process is activated between models. Examples are interactions between teacher and student, seller and buyer, physician and patient, user and information systems able to process user profiles. It is also what usually occurs between corresponding agents via electronic mail on the internet who have never met in person.
Level 4	At this level during the communication process systems exchange signals, but also information about their context: The process of interacting is assumed to be context-sensitive with reference to the sending/receiving agents and to their environment. Messages are semantically processed with continuous reciprocal modelling of systems and of their context. A typical example is given when two agents are negotiating at different times, having the possibility to influence their contexts.
Level 5	At this level the system may *decide* which of the previous levels of openness to adopt depending on a strategy and on a contextual evaluation. The possibility to decide dynamically which level of openness to adopt may be considered as the highest level of openness. Each level of openness includes the *possibility* to adopt a lower one.

The various versions of the Turing machine are all equivalent. For instance, multitrack, multi-tape, multi-heads and multiple Turing machine are all *computationally equivalent* (Wolfram, 2002).

A *window* on different levels (Beckmann, Csuhaj-Varju, & Meer, 2014; Siegelmann, 1999) or kinds of non-equivalent computability was opened by Turing himself when he introduced the concept of *oracle*.

An oracle can be conceived as an abstract machine such as a Turing machine connected to a *black box* able to answer decision problems. This oracle machine is assumed able to solve decision problems of any class of complexity, such as deciding whether a number is in a given set as well as undecidable problems, such as the *halting problem*. However, the *halting problem* still hierarchically applies to the oracle machines. Actually, although they can determine whether particular Turing machines will halt on particular inputs, they cannot determine whether or not machines equivalent to themselves will halt.

It is possible to consider an arithmetical hierarchy of such machines, with increasingly more powerful halting oracles able to solve corresponding increasingly harder halting problems.

In short, an oracle machine is known as a *hypercomputer* (Copeland & Sylvan, 1999; Hogarth, 1994; Shagrir & Pitowsky, 2003; Siegelmann, 1995).

Hypercomputation is intended as *super-Turing computation* and refers to models of computation other than the Turing machine, i.e. non-equivalent to Turing computability and able to solve problems that Turing computation cannot (Cotogno, 2003; Siegelmann, 2003; Syropoulos, 2008). Hypercomputers may be intended, for instance, as real computers like:

- *Inductive Turing machines*, performing a list of defined instructions depending on initial states and series of successive states by applying *inductive reasoning* being environment-phenomenologically dependent (Burgin, 2005, 2010).
- Hypercomputation of the so-called Ω Chaitin constant or halting probability, a real number representing the probability that a randomly constructed program will halt depending on the program encoding used and its length (Chaitin, 1975, 2005, 2007). Various problems in number theory are equivalent to solving the halting problem for special programs, i.e. searching for counterexamples and halting if one is found. This is the case for the so-called Goldbach's conjecture stating that every even integer number greater than *2* can be expressed as the sum of two primes (Wang, 2002).
- *Nondeterministic* (when from a given input and state the abstract machine may jump to several different possible subsequent states) and *probabilistic computers* (when considering the probability of a given initial state given by a stochastic vector and the probability of a particular state transition) (Inoue, Ito, & Takanami, 1994; Martin, 2010).

Quantum computing is based on quantum properties such as superposition and entanglement. Quantum computers are based on the possibility to be in superposed states. While a bit can only have two states, i.e. *0 or 1*, a *qubit* state is a linear superposition of the basis states described by *probability amplitudes*. The possible states for a single qubit can be anywhere on the surface of a *Bloch sphere*, i.e. the geometrical representation of the state space of a two-level quantum mechanical system. Multiple qubits can exhibit quantum entanglement. The quantum universal Turing machine (QUTM) exploits the superposition principle and the entanglement among qubits (Calude, Dinneen, & Svozil, 2000; Deutsch, 1985, 1989, 2012; Deutsch & Jozsa, 1992; Penrose, 1989, 1994; Rosenblum, Kuttner, & Penrose, 2011) raising the research issue of whether or not it is a Turing machine.

In conclusion, the issues discussed above are interesting when considering the differences between explicit and non-explicit models, as mentioned in Sect. 2.7.

Table 2.3 Beyond the disciplinary heritages

Disciplinary heritages	New systemics
Define, organize everything, explicit, planning, degrees of freedom	Fuzzy, self-organization, emergence, non-symbolic, study, and induction to the *usage* of degrees of freedom
Optimization	Unique behaviours *between* degrees of freedom
Prescription of rules and degrees of freedom	Non-invasiveness and emergence (*proposals* to the system)
Massive dispenser	Leave the system to do the *dosing*
Unique configurations	Selection between multiple equivalences

2.9 Further Remarks

The topics discussed here and in Chap. 1 can be summarized as shown in Table 2.3.

With reference to the subject of matter, we have to consider the concepts introduced by QFT. For instance, and in contrast with the principles adopted by GOFS outlined above, the quantum vacuum is an *entity* that *precedes* matter, so it also must precede space and time (Preparata, 2002).

It is the quantum vacuum giving properties to matter, such as that of being always connected, and not a lack of matter being the vacuum.

The approach based on considering *material* entities as fields (of force) and not as particles has a long tradition in physics, from Faraday and Maxwell, and onwards to general relativity. Within this conceptual framework, the concept of particle is considered to denote regions of space where a field has a particularly *high* intensity. The subject of *such matter* considered as a *condensation* of emergent properties acquired by the quantum vacuum will be considered below. Higher levels of emergence acquire properties, considered by GOFS to be typical, such as dimensionality, weight, volume and mass.

Here, we attempt to understand matter as a *sequence* of levels. Topics to be studied, for instance, include:

1. Relationships between levels.
2. Transversality between levels.
3. Autonomy of levels.
4. Logic of levels.

Properties should be understood as properties of levels and their relations (see Chap. 6).

Box 2.1: Symmetry Breaking

The expression *symmetry transformation* denotes a transformation of suitable variables in the evolution equations of a given system (for a bibliography on these topics see, e.g. Itzykson & Zuber, 1986; Pessa, 1988; Sewell, 1986;

(continued)

Box 2.1 (continued)

Umezawa, 1993). Such a transformation can act both upon the form of these equations, as well as *on* the form of their solutions. We thus have *symmetry breaking* when a symmetry transformation leaves the form of the evolution equations invariant but changes the form of their solutions. A typical example is that of a sample of matter consisting of atoms which, at a given temperature, is paramagnetic. The form of the equations describing the atomic motion is invariant with respect to particular symmetry transformations constituted by space rotations around a given axis. The solutions of these equations also possess the same invariance. As a matter of fact, if the sample is exposed to an external magnetic field, whatever its direction, this will give rise, within the material, to an induced field exactly aligned with the external one. However, when the temperature is decreased, there is a critical point (the so-called Curie point) where a transition from the paramagnetic to the ferromagnetic phase occurs. This gives rise to an internal magnetic field of macroscopic dimensions, deriving from the alignment of the magnetic fields of the individual atoms due to their interactions. Besides the formation of North and South magnetic poles within the sample, the presence of such a field leads to the existence of a preferred direction: that of the internal magnetic field. Thus, although the form of the equations describing the motions of the atoms continues to be invariant with respect to the symmetry transformations constituted by spatial rotations, their solutions are not, as the preferred direction breaks such invariance. This phase transition could thus be associated with a breaking of symmetry.

We merely recall that the connection between symmetry breaking and bifurcation phenomena is a well-known and widely studied subject (see, e.g. Golubitsky & Schaeffer, 1985; Balashov 2002).

Box 2.2: Spontaneous Symmetry Breaking (SSB)

The occurrence of intrinsic emergence can be identified with a transition, triggered by a change in the value of a given parameter, in which (at least) one local energy minimum is split into a number (finite or infinite but always greater than one) of different local energy minima, all of which are *equivalent*, i.e. characterized by the same value of minimum energy (we refer to these states as *ground states*). Intrinsic emergence derives from the fact that if the system was, before the transition, in the state corresponding to the old energy minimum, the transition will certainly provoke the settling of the system into one of the new energy minima although we cannot forecast *which* of them will be chosen on the basis of the model we have, because

(continued)

Box 2.2 (continued)

all minima are equivalent to one another. This kind of transition is usually called *spontaneous symmetry breaking* (SSB) (Brown & Cao 1991; Kosso 2000).

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Chapter 3
Dynamics

Contents

This chapter introduces the reader to a non-classical understanding of the concept of dynamics. While the classical concept relates to changes in the *same* entity in classical space and time, here different approaches, suitable for the novel conceptual categories previously dealt with in Chap. 2, are considered. For instance, dynamics can be related to changes in the structural properties of the entities studied where entities are considered as collective (beings) and properties are related to networks, regimes of validity, levels and intra-levels and coherences.

This approach will enable us to understand and model this form of structural dynamics. Such a new view of dynamics is of paramount importance for post-GOFS.

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3.1 A Short Introduction to the Classical Concept

The word ‘dynamics’ has several disciplinary meanings. However, they all have in common the property of being related to *change* (Minati, Abram, & Pessa, 2012).

A partial, introductory disciplinary list may be:

(a) In classical physics, it describes, for instance, changes in metrical, structural and topological properties of bodies over time (see, e.g. Meriam & Kraige, 2012), the behaviour of gases, fluid dynamics (Ruban & Gajjar, 2014), Brownian motion (Schilling, Partzsch, & Bottcher, 2012) and the relationships between heat and mechanical energy in thermodynamics both at the microscopic and macroscopic level (see, e.g. De Pablo & Schieber, 2014). It is also possible to consider the dynamics of states adopted, for instance, by electronic (Mladenov & Ivanov, 2014) and chemical (Kuramoto, 2003) systems.
(b) In biology, it describes motion at the molecular level as well as changes at the macroscopic level (DiStefano, 2013).
(c) In computer science and information technology, it is used to describe the dynamics of information, its flows, and its processing (Vogiatzis, Walteros, & Pardalos, 2014).
(d) In cognitive science and psychology, it refers to the dynamical changes occurring in cognitive systems and cognitive models, produced, for instance, by learning (Gros, 2013).
(e) In economics and sociology, it is used when dealing with social, economic and cultural changes (see, e.g. Skyrms, 2014).
(f) The *general theory of relativity* introduced a very different understanding of the gravitational motion responsible for dynamics (Skinner, 2014). As is well known, the *special theory of relativity* consists of a reformulation of classical mechanics where the mathematical relationship between the measurements of space and time performed by two *inertial*[1] observers is given by a Lorentz transformation rather than a Galilean transformation. The *general theory of relativity* generalises special relativity and Newton’s law of universal gravitation, by introducing a representation of gravity as a geometric property of space and time. The two theories introduced a new representation and understanding of interactions and dynamics (currently being exploited by modern gauge theories).

At this point, we stress that dynamics is considered as being related to:

- Possible dynamical parameters describing properties *possessed* by *entities* such as physical, chemical, informational, cognitive and cultural over time.
- Interactions mediated, for instance, by some exchange of matter/energy and dependent on eventual environmental and space-time properties.

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[1] That is two observers, each one of which is at rest with respect to a specific inertial reference frame. The latter expression denotes a reference frame in which the first principle of classical dynamics holds. In special relativity these frames cannot undergo rotations or accelerations.

In the following we will understand the dynamics as being given by various *kinds* of changes such as *changes* in (1) constraints or degrees of freedom; (2) properties; (3) *ways of interacting;* (4) *structure,*[2] due to relational and interactional changes such as parametrical ones; (5) *states*; (7) coherences; (8) phases like in *sequences* of phase transitions; and (9) attractors. We will consider also sequences of structural changes as for complex systems – examining specifically the case of the cytoskeleton – intended as *sequences* of phase transitions where the *properties of such sequences* should be understood as constituting a structural dynamics, sometimes *coherent* within the context of particular complex systems.

3.2 Dynamical Coherence in Processes of Self-Organization and Emergence

Before entering into the topics of this and the following sections, several other aspects related to the concept of *coherence* already considered above in Sect. 2.1 must be introduced. For instance, a better understanding of coherence may be related to processes of *synchronisation*. Let us consider, for example, populations of oscillators, such as clocks, organized in dynamic clusters where synchronization is the *source* of their coherence (see, for instance, Mikhailov & Calenbuhr, 2002). Things become more interesting when oscillators interact and the internal cyclic dynamics of a population of N coupled oscillators, each characterized by a time-variable phase and a natural frequency can be given, for example, by (Acebrón, Bonilla, Vicente, Ritort, & Spigler, 2005; Kuramoto, 2003):

$$\dot{\theta}_i = \omega_i + \sum_{j=1}^{N} K_{ij} \sin\left(\theta_j - \theta_i\right)$$

where:

- $i = 1, \ldots, N$.
- $\dot{\theta}_i$ is the time derivative of the phase of the i-th oscillator.
- ω_i is the natural frequency of the i-th oscillator.
- K_{ij} denotes a coupling matrix.

Here the natural frequencies of the different oscillators are randomly distributed with a given probability density $g(\omega)$.

This model is known as *Kuramoto model*. It has been the subject of intensive studies, as its different implementations display a large variety of synchronization patterns. Here we will limit ourselves to mention the simplest case in which $K_{ij} = K/$

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[2] While *organization* deals with networks of relationships with undefined parameters, *structure deals with* networks of relationships having well-defined parameters. Relationships may consist of rules of interaction, see Sects. 2.3 and 3.2.2.

$N > 0$, where K is a suitable constant. Usually one refers to this case as *mean-field coupling*. It is possible to show that, when $K \rightarrow 0$, the synchronization disappears and each oscillator rotates with an angular frequency given by its own natural frequency. Instead, when $K \rightarrow \infty$, all oscillators become synchronized to their average phase (global synchronisation). Finally, if $K_C < K < \infty$, where K_C denotes a suitable *critical value* of K, we have the appearance of a *partial synchronization* state, in which a part of oscillators have the same (constant) phase, while other oscillators rotate out of synchrony. The value of K_C depends on the form of the function $g(\omega)$, and we will avoid any discussion about the details of its computation. In any case, the main contribution of Kuramoto and other similar models of interacting oscillators consists in the evidence of a number of different kinds of synchronisation, a circumstance which opens the way to the search for models describing the occurrence of multiple synchronisations within the same system (see, for examples of application of this model to Neuroscience Breakspear, Heitmann, & Daffertshofer, 2010; Schmidt, LaFleur, de Reus, van den Berg, & van den Heuvel, 2015).

As a matter of fact, such phenomena have been observed in a number of models, together with the occurrence, in some cases, of different synchronisations over time *when such multiplicity is in its turn synchronized*, possible in more complicated contexts such as the human nervous system. When such *upper synchronization* of multiple local instantaneous synchronisations is maintained, it can be considered as a form of *coherence* (see, for instance, Boccaletti, 2008). This applies also to the case of populations of chaotic systems (see, for instance, Ciszak, Euzzor, Geltrude, Arecchi, & Meucci, 2013; Boccaletti, Kurths, Osipov, Valladares, & Zhouc, 2002; Manrubia & Mikhailov, 2004).

A first popular example of these phenomena is given by the ensembles of globally coupled chaotic maps, first introduced by Kaneko (see, e.g. Kaneko, 1990; see also Mikhailov & Calenbuhr, 2002, p. 155). In the simplest case, their dynamics is described by laws of the form:

$$x_i(n+1) = (1-\varepsilon)f(x_i(n)) + \frac{\varepsilon}{N}\sum_{j=1}^{N} f\left(x_j(n)\right)$$

where:

- N is the number of chaotic maps.
- $i = 1, \ldots, N$ is a space index.
- $x_i(n)$ denotes the value of the i-th map in correspondence to the discrete time $n = 0, 1, \ldots$.
- The function $f(x)$ is given by $f(x) = a\,x\,(1-x)$ (logistic map).
- a denotes the nonlinearity parameter of the logistic map.
- ε denotes the coupling parameter.

The numerical simulations of the dynamics of such a system evidence that, when the coupling parameter overcomes a critical value ε_c (for instance, $\varepsilon_c \approx 0.355$ when $a = 3.8$), a state of *full synchronization* occurs, in which all maps, at any instant, have the same value, so that the whole system behaves like a single chaotic map. When $\varepsilon < \varepsilon_c$ the full synchronization disappears, and we observe the occurrence of a number of different clusters, each one containing a number of mutually synchronized units (for a detailed study of this phenomenon, see, e.g. Popovych, Maistrenko, & Mosekilde, 2001). If, now, we consider a system of globally couple maps in which the coupling parameter ε is allowed to grow, starting from a very small value, far lesser than ε_c, up to the situation of full synchronisation, we obtain a dynamics characterized by an ordered sequence of different synchronisations, ending in a situation of global coherence, similar to the one described above and quoted, for instance, in Boccaletti, 2008.

As expected, a far more complex phenomenology occurs when we consider more complicated systems, such, for instance, the ones in which the couplings are local instead than global. A typical case is the one of chains of coupled limit-cycle oscillators (see, e.g. Osipov & Kurths, 2001), generalizing the Kuramoto model previously quoted and described by equations having a generic form of the kind:

$$\dot{\varphi}_n = \omega_n + F(\varphi_n) + d\big(\sin\left(\varphi_{n+1} - \varphi_n\right) + \sin\left(\varphi_{n-1} - \varphi_n\right)\big)$$

where φ_n denotes the phase of the n-th oscillator, ω_n its natural frequency, d a suitable parameter and $F(\varphi_n)$a non-linear function responsible for the non-uniformity of rotations of the oscillator taken into consideration.

In these systems, besides the occurrence of clusters of synchronized elements, it is possible to observe the occurrence of *defects* which are present in the zones separating different and adjacent clusters. In many models these defects follow a specific kind of dynamics, which can imply even their appearance and disappearance. More complex patterns of synchronization phenomena can appear in spatially extended systems of non-linear oscillators (see, among the others, Hong, Park, & Choi, 2005).

The detection of the different forms of synchronization phenomena is more generally based on the use of various kinds of *correlation measures* such as those resorting to linear approaches like the ones underlying Bravais-Pearson coefficient. As well known, in statistics correlation refers to classes of statistical relationships involving dependence among random variables (Drouetm & Kotz, 2001). There is a large number of different correlation measures, most of which is introduced within the context of the study of brain signals. They can be subdivided into two classes: the *linear* and the *nonlinear* measures (see, for a review, Kreuz, 2011). Among the linear measures, which generalize the traditional Bravais-Pearson quoted before, the most popular is given by the *cross-correlation* function, applied to two time series having the same length N, whose values are denoted, respectively, by x_n and y_n (these values have been previously normalized so as to have a zero mean and a unitary variance). This function depends on the time lag τ, running within the interval from $-(N-1)$ to $N-1$, according to the following rule:

$$C_{XY}(\tau) = \begin{cases} \frac{1}{N-\tau}\sum_{n=1}^{N-\tau} x_{n+\tau}y_n & if \quad \tau \geq 0 \\ C_{XY}(-\tau) & if \quad \tau < 0 \end{cases}$$

The cross-correlation values can run from 1 (maximum synchronization) to -1 (loss of correlation). When the focus is on the frequency, rather than on time, the cross-correlation can be replaced by the so-called *cross spectrum*, defined by:

$$C_{XY}(\omega) = E\left[F_X(\omega)\, F_Y^*(\omega)\right]$$

where ω denotes the frequency, E the estimation function, F_X the Fourier transform of x and the star the complex conjugation. From the cross spectrum, it is possible to compute the *coherence* function through the relationship:

$$\Gamma_{XY}(\omega) = \frac{|C_{XY}(\omega)|^2}{|C_{XX}(\omega)|\,|C_{YY}(\omega)|}$$

As regards the nonlinear correlation measures, the domain is far more complicated than in the linear case, and many different choices are available. Without entering into further details (within the wide literature on this subject, we can quote only few references, such as Kantz & Schreiber, 1997; Pereda, Quiroga, & Bhattacharya, 2005; Dauwels, Vialatte, Musha, & Cichocki, 2010), we limit ourselves to mention only the names of the main kinds of measures, including mutual information, transfer entropy, Granger causality, nonlinear interdependence and phase synchronization.

As it can be seen both from the quoted literature and the previous considerations, synchronization (Pikovsky, Rosenblum, & Kurths, 2001), for example, between pairs of data, signals or waves, is the most often used among the possible measures of their *similarity* as a function of a suitable time-lag. While neglecting a further discussion about the possible measures of synchronization, we mention only a very simple and easily computable synchronization index, also called *coherence parameter*, used when dealing with the dynamical evolution of networks of interacting units. In order to introduce it (see, for instance, Van Wreeswijk & Hansel, 2001), we can supposedly deal with a network of N interconnected units (like neurons), each one of which is described by its momentary state of activation $V_i(t), (i = 1, \ldots, N)$. This knowledge allows to compute the momentary average network activation through:

$$A_N(t) = \frac{1}{N}\sum\nolimits_i V_i(t)$$

The fluctuations of the latter have a variance given by:

$$\varDelta_N = \left\langle A_N(t)^2 \right\rangle_t - \langle A_N(t) \rangle_t^2$$

As customary, the symbol $\langle \ldots \rangle_t$ denotes an averaging with respect to t. An analogous variance can be computed with respect to $V_i(t)$ through the formula:

$$\varDelta = \frac{1}{N} \sum\nolimits_i \left(\left\langle V_i(t)^2 \right\rangle_t - \langle V_i(t) \rangle_t^2 \right)$$

Then, the coherence parameter is given by:

$$\varSigma_N = \frac{\varDelta_N}{\varDelta}$$

Higher values of $\varSigma_N$ (close to 1) denote high synchronization between the network units, while very low values are associated to a diffuse asynchrony.

Another kind of correlation function has been introduced when studying the fluctuations in velocity within flocks of birds (Cavagna et al., 2010). Namely, in that case, one must take into account two different kinds of variables: the direction of the individual motion and the modulus of its velocity. In other applications of statistics (for instance, to data coming from psychology or sociology), the *coefficient of multiple correlation* can be used as a measure of how values adopted by a specific variable are given by a linear function of a set of one or more other variables (Huber & Ronchetti, 2009), provided, however, we exclude nonlinearity from our hypothesis, a circumstance still common in those domains.

Another example of a source of coherence is the occurrence of ergodicity in collective behaviours (see, for instance, Minati & Pessa, 2006, pp. 291–313) where the *same* system can be *both* ergodic and non-ergodic depending upon the time scale of the observer, as in polymers, or even temporarily ergodic. Moreover, it is possible to introduce degrees or indices of ergodicity. See, in this regard, the Sect. 4.5.1.

After these considerations on the concepts of synchronization and correlation, we now remark that the Post-GOFS approach requires the introduction of new possible variations of the concepts of *classical dynamics*. These latter could be applied, for instance, to networks or meta-structures in order to describe the nine structural changes mentioned in Sect. 3.1. We anticipate here a concept – the one of meta-structure – which is introduced in a more detailed way in the Sect. 3.8. *In short, a meta-structure is intended here as a dynamical set of simultaneous, superimposed and possibly* ***interfering***[3] *structures of interactions between elements, acting as rules (examples are shown in the* Table 3.1 *in the Sect. 3.8.2). Such different structures may of course be characterized by different starting times or durations.*

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[3] *As we will see two or more interactions are considered here to interfere when one is function of the other ones* in conceptual correspondence with the original formalization of system introduce by Bertalanffy as reminded at the Sect. 2.3. See Sect. 3.8.2.

Table 3.1 Example of populations of interactions for flock-like collective behaviours

Multiple structural interactions within a flock-like collective behaviour			
Agents	*Interacts by varying their*	*Depending on the*	*Rules of interaction* $Rint_{J:1\text{-}13}$
e_k	Speed	Speed of the closest agent or the average speed of the closest agents	$Rint_1$
e_k	Speed	Speed of agent(s) having its same direction	$Rint_2$
e_k	Speed	Speed of agent(s) having its same altitude	$Rint_3$
e_k	Speed	Speed of agent(s) having symmetrical, topological position	$Rint_4$
e_k	Direction	Direction of the closest agent or the average direction of the closest	$Rint_5$
e_k	Direction	Direction of agent(s) having its same speed	$Rint_6$
e_k	Direction	Direction of agent(s) having its same altitude	$Rint_7$
e_k	Direction	Direction of agent(s) having symmetrical topological position	$Rint_8$
e_k	Altitude by varying direction	Altitude of the closest agent or the average altitude of closest agent(s)	$Rint_9$
e_k	Altitude by varying direction	Altitude of agent(s) having its same direction	$Rint_{10}$
e_k	Altitude by varying direction	Number of agents having its same altitude	$Rint_{11}$
e_k	Altitude by varying direction	Altitude of the agent(s) having symmetrical topological position	$Rint_{12}$
e_k	Speed	Speed of the closest agent or the average speed of the closest agent	$Rint_{13}$

Among the new conceptual generalizations of classical dynamics, here we will limit ourselves to mention the ones related to the four different ways of understanding the *dynamical constraints* listed below. This list, for instance, is contained in two papers of Hooker (Hooker, 2011, pp. 3–90; Hooker, 2013) and includes the following conceptions of constraints, together with their possible generalizations:

1. Constraints intended as *variable* rather than *fixed* degrees of freedom and which can also vary with respect to single or multiple *coherences*, such as sequential or parallel ones (Raynor, 1977). Moreover, we should also take into account the cases in which system's dynamics *generates* new constraints during its behaviour like, for instance, '...a river altering its own banks, an accumulative process where the current constraints (banks) are a function of the history of past flows (currents), intra-cellular biochemical reaction processes where molecular structures constraining some processes are the products of other processes and vice versa; ...' (Hooker, 2011, p. 217). The mathematical description of such situations has mostly been obtained by resorting to a particular section of the theory of differential equations, dealing with *moving* or *free boundary problems* (among the textbooks on this subject we can quote Crank, 1984; Alexiades & Solomon, 1993;

Figueiredo, Rodrigues, & Santos, 2007). The typical moving boundary problems arise from the attempts to describe phase change phenomena. The most celebrated example is given by the so-called *Stefan problem* (see, e.g. Meirmanov, 1992). In its simplest formulation, the problem takes into consideration a semi-infinite one-dimensional block of a substance in a solid phase (for instance, ice) whose global boundaries go from 0 to $+\infty$. The initial temperature of the substance is the critical one corresponding to the melting of the solid phase (0 in our example). The introduction of a heat flux at the left boundary of the block produces a melting leaving the left part of the block occupied by the liquid phase (in our example water). Let us now denote by $u(x, t)$ the value of the temperature in correspondence to the position x at time t and by $s(t)$ the position of the point of separation between liquid and solid phase (i.e. between water and ice). Moreover, let us denote by $f(t)$ the function describing the time dependence of the heat influx. It is immediate to see that within the liquid region defined by $0 \leq x < s(t)$, the system must obey the heat equation which, in terms of suitable rescaled variables, can be written as:

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial x^2}$$

Of course, in order to grant for the solvability of this equation, we need to add an initial condition for $u(x, t)$, that is:

$$u(x, 0) = 0$$

Besides, the presence of a heat influx requires the introduction of a boundary condition holding at the left extremity of our system and given by:

$$-\frac{\partial u}{\partial t}(0, t) = f(t)$$

As regards the solid region, lying within the spatial interval $s(t) < x$ < $+\infty$, in this simple version of the model, we can only assert that within it the temperature is kept constant, that is:

$$u(x, t) = 0$$

Unfortunately, it is easy to understand that the previous equation and the enclosed conditions are not enough for finding a solution to the problem of finding the form of $u(x, t)$. Namely, they are unable to help us to find the form of the function $s(t)$, specifying the dynamics of the *moving boundary* between the two phases. In this regard, Stefan added a further equation (expressing a principle of energy conservation) ruling the behaviour of $s(t)$ and given by:

$$\frac{ds}{dt} = -\frac{\partial u}{\partial x}(s(t), t)$$

The presence of this new equation, complemented by the conditions:

$$s(0) = 0, \quad u(s(t), t) = 0$$

allowed Stefan to solve the problem of finding the functions $u(x, t)$ and $s(t)$. Such a circumstance justifies the name of *Stefan problem* attributed to the problem itself.

The model introduced within the context of Stefan problem, despite its linear nature and its apparent simplicity, stimulated an extended search for more general and complex models of phase change. Among these models the most popular one is described by the Cahn-Hilliard equation (see, for review papers, Novick-Cohen, 2008; Lee et al., 2014). Originally the latter has been introduced to describe a process of phase separation occurring within a binary fluid, when the two components separate and give rise to two spatial domains, each containing a single pure component. This description is based on a function c (x, t) specifying how the fluid composition depends on spatial position and time. Usually the values of this function are restricted within the closed interval from -1 to 1, each extremely corresponding to the presence of only a specific pure component. Thus, the function itself can be interpreted also as a measure of concentration. The basic form of Cahn-Hilliard equation is:

$$\frac{\partial c}{\partial t} = D\,\nabla^2\left(c^3 - c - \gamma\,\nabla^2 c\right)$$

Here D is diffusion coefficient, while γ is a parameter related to the width of the transition layer between the two regions containing the single pure phases. Namely, an equilibrium solution of this equation is given by $c(x) = \tanh\left(\frac{x}{\sqrt{2\gamma}}\right)$, a function of a sigmoidal form describing the transition from a left region in which $c = -1$ to another region on the right in which $c = 1$. Moreover, the symbol ∇^2 denotes the n-dimensional Laplace operator, that is:

$$\nabla^2 = \frac{\partial^2}{\partial x_1^2} + \ldots + \frac{\partial^2}{\partial x_n^2}$$

There are many relationships between the different models of phase change, often dealt with as moving boundary problems. Among these relationships we will limit ourselves to mention the one evidenced by Pego some years ago (see Pego, 1989). He showed that the asymptotic behaviour of solutions of Cahn-Hilliard equation (which is a non-linear equation) can be described by the solution of a (non-linear) Stefan problem.

Without entering into further details on this subject, we are content with remarking that many moving boundary problems can be transformed into *free boundary problems* (in which even the overall boundary of the problem is not fixed and changes with time). This circumstance occurs, for instance, when the changed phase is immediately removed from the system. Problems of this kind are usually called *ablation problems* (see, e.g. Akbari & Hsieh, 1994; Betterton, 2001).

2. Constraints characterized by a *holonomic* nature. The latter is endowed with a considerable importance mostly if we deal with systems hopefully described by suitable conservation principles and a Lagrangian or Hamiltonian dynamics. In this regard we shortly remind that for a classical system described by N position variables $x_1, x_2, \ldots, x_N$and a time variable t, an holonomic constraint must be expressed under the form:

$$f(x_1, x_2, \ldots, x_N, t) = 0$$

where f is a suitable function (see, e.g. the classical textbook Goldstein, Safko, & Poole, 2014, Chap. 1). In short, constraints are holonomic when they can be expressed in a purely geometrical way, independently from the behaviour of the system. 'While smooth (frictionless) sliding under gravity on a sloping plane is a case of holonomic constraint, a spherical bead rolling smoothly on the outside of a cylinder is not because the constraint alters its basic character when the bead falls off' (Hooker, 2011, p. 216). Unfortunately, most constraints used in dynamical system theory are *nonholonomic* (or, as some people uses to say, *anholonomic*). In the more general case, the existence of constraints of the latter type entails that the final state of the dynamical evolution of a given system with nonholonomic constraints depends on the intermediate values of its trajectory along the phase space. This circumstance, in turn, prevents from the existence of a conservative potential function. The impossibility of resorting to traditional methods of mathematical physics when dealing with systems of this kind stimulated a large number of researches trying to obviate to this inconvenient, at least in special cases (see for reviews Koon & Marsden, 1997; Bloch, Baillieul, Crouch, & Marsden, 2003; Flannery, 2005). However, despite the remarkable obtained results, the presence of nonholonomic constraints often induces to abandon the traditional methods of system dynamics for shifting towards new approaches.

3. Constraints of *different natures* may simultaneously act upon the system with *additive* (assumption of linearity) or non-linear effects. In their turn, such constraints may be dependent or independent of one another. Examples are given by mechanical or chemical constraints. However, in more recent times, the need for a theory of these multiple constraints arose within the domain of multi-objective optimization problems (see, for instance, Barichard, Ehrgott, Gandibleux, & T'Kindt, 2009). A typical application is given by mobile ad hoc networks, which are autonomous systems of mobile nodes connected by wireless links but devoid of any static infrastructure (Kumar Sarkar, Basavaraju,

& Puttamadappa, 2013; Loo, Mauri, & Ortiz, 2012). They can be used in many different contexts, such as military applications, emergency search and rescue operation, and require an autonomous self-programming system able to cope with the dynamical change of network topology. Instead of resorting to traditional optimization techniques, researchers directed their attention to methods based on multiple genetic algorithms, which allowed to achieve encouraging results (see, for an example, Sun et al., 2008).

4. Constraints of *passive* or *active* nature. Both these attributes are borrowed from a number of different disciplines, in which they assume different meanings. The latter, however, can be easily applied to characterize the constraints if we refer to the distinction between the system under consideration and the external environment. In order to simplify our considerations, we will assume that both can be distinguishable one from another even if, in most realistic situations, this is not always the case. Our conceptual distinctions are inspired by a clear analysis of the relationships between a biological cell and its extracellular environment, described in Ricca, Venugopalan, and Fletcher (2013). Let us, now, assume, as a reference system, the system itself under consideration and, as environment, just its environment. We are thus assessing every system-environment process by using, as a vantage point, the considered system. Then we use the attribute *active* for the actions produced by the system which are able to give rise to deep modifications of the environment, while we use the attribute *passive* for the system actions which give rise only to environment modifications compatible with the intrinsic properties of this latter. To make an example taken from biology, if the system consists of a cell and the environment of the surrounding substrate, an active action produced by the cell could, for instance, be the one changing the activation state of the chemical regulators of actin assembly present in the substrate, thus changing its nature and operation. On the contrary, a passive action produced by the system could be the one exerted by a mechanical pressure of the cell on its surround, resulting only in a viscoelastic deformation of the latter, ruled by the same laws of viscoelasticity which are used for inanimate bodies. If, now, we change our vantage point, going from the system to its environment, it is easy to understand that the same attributes can be used to characterize the actions of the environment itself. Thus, an action exerted by the environment on the system can be considered as *active* if it produces a deep change of the nature itself of the system, while is *passive* if the action produces only modifications of the system compatible with its intrinsic nature. Thus, for instance, a surround injecting a chemical substance inside the cell produces an active action, while a mechanical pressure exerted by the surround able to produce only a shift of the cell is a passive action. At this point we can apply the previous considerations to our main concern, that is, the role of constraints. Namely, we can see the constraints as special cases of the environment. Therefore we can qualify a constraint as *passive* if its occurrence does not change the intrinsic nature of the system, while it is *active* (a better attribute would be *reactive*) if its occurrence change the nature itself of the laws ruling the system. In most cases studied in system science, people takes into consideration only

passive constraints. They are related, for instance, to limiting resources such as geometrical spaces for the movement of bodies. This is the conventional *dis*abling understanding of the term. However, constraints and their *dis*abling effects may also *en*able the system to adopt new states and properties which are not available to the *unconstrained* system. At a first sight, this seems also the case in which the system *changes* its structure. Examples of structureless systems acquiring properties when structured include metal atoms in the vapour phase acquiring electrical conductivity when structured into their solid state lattice. In biology, a skeleton, although limiting the movements of limbs, also provides a frame for muscular attachments allowing articulated motions unavailable to the *unconstrained* system. However, a deeper analysis shows that all these cases occurred owing to the presence, even if difficult to detect, of active constraints. As it easy to understand, the study of models including active constraints (typically called *reactive media*) is very difficult. Many years ago it was appanage of a very small number of mathematicians. However the technological development following the introduction of quantum electronics and of the associated devices (mainly lasers) allowed the domain of reactive media to gain popularity, as witnessed by the appearance of books like Aris, Aronson, and Swinney (1991). As a matter of fact, this domain found practical applications in a number of interesting fields, such as the study of combustion (see, e.g. Yarin & Hetsroni, 2004), the understanding of phase transitions and the transport phenomena in geological media (Dentz, Le Borgne, Englert, & Bijeljic, 2011a). In more recent times, the study of reactive media became a part of a more general domain of study, of foremost importance for biologists, named *soft active matter* (among the main contributions, we can quote Marchett et al., 2013; Hemingway et al., 2015). It is, however, to be remarked that the research activities related to reactive media still require a very high mathematical competence. As a somewhat shocking example, we limit ourselves to show the explicit form of the reactive transport equation describing the space-time evolution of the concentration of a mobile solute liquid in presence of solidification, chemical reaction, diffusion and porosity (a case of interest in geology). The equation in question has the form: (see Dentz, Gouze, & Carrera, 2011b)

$$\begin{aligned}&\varphi_m \frac{\partial c_m(x,t)}{\partial t} + \frac{\partial}{\partial t}\int_0^t dt'\,\varphi_r(t-t')\,c_m(x,t') \\ &\quad + \nabla\left[q(x)\,c_m\big(x,t\big) - D_m \nabla c_m\big(x,t\big)\right] = -\textstyle\int_0^t dt'\,k(t-t')\,[c_m(x,t') - c^{eq}]\end{aligned}$$

Here the symbol $c_m(x,t)$ denotes the solute concentration, $q(x)$ is the liquid flow, φ_m the porosity of the medium, and D_m, c^{eq} are suitable constants. What creates serious mathematical problems are the two functions $\varphi_r(t-t')$ and $k(t-t')$. Namely, they describe *memory effects*, due to the fact that the local value of solute concentration depends on the local value of the solid concentration, in turn depending on the past history of the system. In other words, they act as nonholonomic constraints in the sense specified before. This obviously entails

> that we cannot resort to the usual methods of mathematical physics in order to study the previous equation. Moreover, this situation is general when we deal with reactive media and requires new advances of systems science allowing to cope with the problems raised by these interesting systems.
>
> Another phenomenon which can be included in this category is that of *allostasis* (Levy, Levy, Barto, & Meyer, 2013; Nibuya, Tanaka, Satoh, & Nomura, 2012), that is, the process through which a biological organism achieves stability through changes following deviation of the regulatory system from its normal homeostatic level. Allostasis is a mechanism which maintains stability through continuous, adaptive, constraint changes. In a number of cases, the allostasis is related to changes which could be dangerous for the organism (as occurs for substance dependence). In other cases, however, as the ones related to *psychological resilience*, the allostasis could give rise to positive outcomes (see, e.g. Ong, Bergeman, Bisconti, & Wallace, 2006; Reich, Zautra, & Hall, 2010, Sarkar & Fletcher, 2014).

New concepts and assumptions about dynamics will be considered here to study and model *collective phenomena* such as the establishment, sustaining and varying of generic *collective systems*, i.e. established by multiple interacting entities, and their properties such as collective motion. The latter subject, as it is well known, has been widely reported in the literature (see the review by Tamás & Zafeiris, 2012 with reference to collective motion).

*The **nature** of collective phenomena can vary and may be metrical, topological, networked, temporal, acoustic, relating to information or signals, economic or biological. The significance of the adjective **collective** relates, for instance, to the **nature** of a) relations and networks, b) interactions among **entities** establishing the phenomena, c) correlations among multiple systems and partial properties or d) the dependence of the acquired properties upon preserving the collective behaviour.*

3.2.1 Entities, Relationships and Interactions

Entities, relationships and interactions belong to the fundamental concepts used when dealing with dynamics. As regards *entities* they may be of different nature: words, physical bodies, agents, signals, processes, systems, networks establishing dynamics as on the Internet and *anything* considered in relation to and/or in interaction with, even with themselves at different times or on different scales. Similar considerations can be applied to relationships and interactions themselves, networks, nodes and agents. Generally entities, relationships and interactions are detected through the usage of suitable levels of representation and by cognitive systems applying different kinds of cognitive models as occurring in *constructivist approaches*. As is well known, *constructivism* (see Sects. 5.1.4 and 5.1.5) was introduced by authors such as H. von Foerster, E. von Glasersfeld, H. Maturana, F. Varela and P. Watzlawick (Butts & Brown, 1989; Von Foerster, 1979; Von

Glasersfeld, 1996; Maturana & Varela, 1980, 1992; Varela, Thompson, & Rosch, 1991; Watzlawick, 1983). This understanding and approach can be briefly represented by using the strategy of thinking based on *how it is more convenient to think that something is* rather than *trying to find out how something really is*. However, both questions should be considered, even if to differing extents, adopting empirical and not ideological viewpoints. In some contexts, like within DYSAM-like approaches (see Appendix 1, point 6), one question may be more helpful than the other. It may be more effective, for example, to account for a phenomenon in electromagnetic terms rather than in thermodynamical ones or vice versa.

Actually, sometimes it may be more *effective* to think that something *really* exists: in fact this approach may be considered as a particular case of the supremacy attributed to the first question (Minati & Pessa, 2006, pp. 50–54). However, suitable approaches must be adopted for establishing which are the entities to be taken into consideration as well as for dealing with and modelling the phenomena of interest. Some approaches may simply consist in assuming that entities have absolute validity, i.e. independently from the observer or the problem under study. Various levels of description are possible, however, when considering different variables and scaling transformations. Within this conceptual framework, some problems may arise, such as the need for *detecting communities* of elements as in social network analysis (Missaoui & Sarr, 2015) or in generic graphs (see, e.g. Fortunato, 2010) as well as in multilayer networks (Boccaletti et al., 2014). Moreover, among the methods useful to detecting the presence of suitable entities, we should include those studied by the approach based on the *renormalization group* (Creswick, Farach, & Poole, 2015).

The renormalization group allows systematic mathematical investigation of changes in a system on various distance scales. While self-similarity is related to scale invariance when the properties under consideration are independent from the scales and the most important information contained in the *flow* of renormalization is given by its *fixed points*, we should also focus on scale changes where, for instance, different laws and symmetries occur, energy-momentum and resolution distance scale in conformity with the uncertainty principle, thus making a *leap* from discrete to continuous as in quantum field theory (see Chap. 6). In such cases *non-equivalent representations of the same system are possible*.

> The attractiveness of the latter stems from the fact that within QFT, and only within it, there is the possibility of having different, *non-equivalent*, representations of the same physical system (*cfr*. Haag, 1961; Hepp, 1972; a more recent discussion on the consequences arising from this result, often denoted as ‘Haag Theorem’, can be found in Bain, 2000; Arageorgis, Earman, & Ruetsche, 2002; Ruetsche, 2002). As each representation is associated with a particular class of macroscopic states of the system (via quantum statistical mechanics) and this class, in turn, can be identified with a particular thermodynamical *phase* of the system (for a proof of the correctness of such an identification, see Sewell, 1986), we are forced to conclude that *only* QFT allows for the existence of different phases of the system itself. (Pessa, 2009, pp. 606–607)

This framework could be generalized by allowing the entities to be considered as being superimposed and entangled as in quantum models. In this case the nature of an entity should be intended as a ***role*** *rather than a state or property***.** These considerations acquire a foremost importance mainly when we deal with specific entities denoted in the literature as *agents*, which can behave, interact and possibly have cognitive abilities such as memory and learning (Taylor, 2014).

Taking now into consideration the relationships, we remark that a *relationship* is intended as a correspondence of any kind, such as quantitative, topological, logical, functional, phenomenological, philosophical, linguistic or any *combination* of these, between entities suitable for identifying that (those) *corresponding* to the other(s). Relationships apply to entities in a variety of possible ways such as causal and non-causal, simultaneous or not, homogeneous-inhomogeneous, constant or variable and context or non-context sensitive. An *interaction* is classically intended as occurring between entities when *properties (behaviour) of one affect the properties of another (behaviour)* and when collective entities such as collective systems affect in different possible ways other collective entities.

An interaction may be intended, for instance, as a process of mutual exchange of matter/energy, goods or money in the economy or information between entities affecting their mutual properties. In this view interactions are assumed to occur because of the properties possessed/acquired by the entities involved. Interactions may not only affect entity properties but also occur through possible structural modifications, such as adapting or learning.

However, beyond this classical understanding of the process of interaction, one should take into account also:

- The case of *active* entities, i.e. possessing autonomous behaviour or embedded into an environment structured in such a way that entity behaviour is induced to become interactive. This case, for instance, can occur when reducing degrees of freedom and increasing environmental density.
- The case of a hosting and *unavoidable* environment, occurring when the latter is a source, for instance, of energy and fluctuations. In these cases the entities may be considered as passive, interacting only in a suitable environment such as happens for many ecosystems.
- The presence of *fields* changing entities or making them to acquire properties.
- The case of dynamical geometrical properties of space such as deformations or relativistic effects. Other interesting cases occur when entities are dynamically networked and the structure of the network establishes the way of interacting between entities themselves (nodes).
- The case where two processes may be considered to interact when they simultaneously happen to the same entities. In this case there are *resulting* effects.
- The case where the interactions themselves may be allowed to interact through *interference*. This phenomenon is considered in physics when there is, for instance, a superposition of two or more waves, disturbances and distortions. The interference can change the interactions themselves *when parts of processes of interacting are inserted into one another* (see Sect. 3.8.2). This latter case

> includes the situations in which several entities, of the same or different kinds, in a stable or varying quantity, performing single or multiple interactions, may establish *collective entities*, possessing and acquiring properties different from those possessed by the single interacting entities.

The occurrence of multiple interactions, as considered below when introducing the concept of Multiple System (Sect. 4.5), is related to a) the ability of a generic agent both to interact with other agents by using dynamical, context-sensitive ***combinations*** *of specific rules of interaction and b) the* ***contextual*** *multiple roles or multiple significances of the results produced by specific interactions.*

We stress that this may apply to populations of interactions themselves interfering with each other. In this case, the interactions between entities will occur through resulting interactions *as discussed in Sect. 3.8.2*.

This may be of help from a phenomenological and interpretative point of view. Often models and simulations of collective behaviours are, however, based on different approaches such as stating constraints rather than combinations of rules of interaction. This is the case of the classical model (Reynolds, 1987) in which the agents acquire a flock-like behaviour by collectively moving while respecting behavioural constraints.

Furthermore, as will be seen below, many collective entities are considered to acquire coherence(s) between sequences of acquired properties. This regards the well-known processes of self-organization and emergence (Sect. 3.2.3) where suitable models are based on networks and meta-structures.

3.2.2 Organization, Structure and Abstract Structure

We need to specify, at this point, how we will use the concepts of *organization* and *structure*. Regarding the two concepts, a huge variety of disciplinary, and even non-equivalent meanings, is available in the literature.

According to Ashby, as proposed in his fundamental article (Ashby, 1947), the organization of a system consists of the functional dependence of its future state on its present state and its external inputs, if any. This suggests that it is possible to conceive *organization* as a set of relationships and *kinds* of interactions among entities of any nature (Maturana & Varela, 1973).

While organization relates to properties of sets of relationships and interactions, such as sequential, hierarchical, networked, exclusive, combined, based on levels, stable or dynamical or dealing with undefined parameters, *structure* is a *specification* of organization dealing with well-defined parameters (see Sect. 2.3 for a more specific discussion on the concept of structure). When dealing with *organization*, reference is made even to multiple and variable *networks* of relationships with *undefined* parameters, whereas in the case of *structure*, reference is made to networks having well-defined parameters.

An example of the difference between organization and structure is given by the existence of two different ways of describing an artificial neural network: either as a system, for instance, with *n inputs*, *m hidden layers* and *s outputs*, or as a network with precise values of connection weights and well-defined transfer functions associated with the individual neurons. Some authors speak of the former organizational description as a specification of network *architecture*.

When dealing with systems, *organization* is intended as relating to their *general architecture*, i.e. subsystems, active kinds of interactions, relationships, network and input-output processes. *Structure* relates to specified, parametrized organization when considering particular interactions, relationships and networks, with their current parameters. For instance, the organization of an electronic device is given by a general organizational scheme between types of components. The structure of an electronic device is given by well-specified interconnections between its individual components.

However, we remark that in mathematics, we can consider *abstract structures* over a set, such as algebraic structures (e.g. groups, rings and fields), equivalences of relationships, measures and metric structures (i.e. geometries), orders and topologies (see, for instance, Satake, 2014; Tonti, 2013). More generally, an *abstract structure* is then a *formal object* defined by a set of composition rules, properties and relationships. Such a formal object is defined by a set of coherent laws, rules, properties and relationships like occurs in games and juridical codes. In this case, organization and abstract structure may be considered as being generally *equivalent*.

3.2.3 Dynamics of Self-Organization and Emergence

When speaking of self-organization, one refers to sequences of structures, each associated with a different organization, and to their coherence, as discussed below.

In order to discuss a first distinction between the processes of self-organization and the ones of emergence, about which the literature reports a number of definitions (see, for instance, De Wolf & Holvoet, 2005; Fernandez, Maldonado, & Gershenson, 2014), it is useful to introduce the concept of dynamical coherence to allow generalization and adaptation to different conceptual frameworks. Such a distinction will enable effective approaches for acting upon such processes in order to have prospective suitable conceptual methodologies and tools to induce, maintain, modify, combine and eventually avoid or *deactivate* self-organization and emergence.

Before discussing such differentiation, one should recall that both processes of self-organization and emergence (particularly radical emergence) are characterized by radical structural changes as originally studied in the case of phase transitions. The reference is to physical phenomena associated with macroscopic changes in structure. In this regard one must resort to classical macroscopic thermodynamics, which constitutes the best starting point for a more precise analysis of these phenomena. It is virtually impossible to list here the plethora of textbooks on classical thermodynamics: traditional and comprehensive treatises include Callen, 1960; Rumer & Rivkyn, 1980; and Sears, 1955, and in the case of quantum phenomena, Gitterman, 2014 and Mahler, 2015.

At the end of this section, we ask why neither self-organization nor emergence can be considered as *coincident* with the traditional definition of a phase transition. We use here the attribute 'traditional' (or 'classical') to characterize the theories in which the phase transitions (PT) are studied in presence of volumes tending to infinity and in absence of external fluctuations. Most theories of this kind are based on classical thermodynamics. Quantum aspects, such as the ones related to quantum phase transitions (QPT), will be discussed in Chap. 6.

Within classical theories the processes of *phase transitions* are intended as the acquisition of, or change in, structure (Minati & Pessa, 2006, pp. 201–229; Pessa, 2008). This is the case for first-order phase transitions, e.g. water-ice-vapour allowing the coexistence of structures such as water and vapour or water and ice. In contrast, second-order phase transitions consist of an internal rearrangement of the entire system structure, occurring simultaneously at all points within the system. Each transition occurs because the conditions necessary for the stable existence of the structure corresponding to the initial phase *cease to be valid* being replaced by a new one. Standard examples are given by transitions from paramagnetic to ferromagnetic states or the occurrence of superconductivity or superfluidity. Theories which partly differ from the classical ones have been applied to study the very complicated transient dynamics between phases taking place when classical and quantum aspects mix (Gauger, Rieper, Morton, Benjamin, & Vedral, 2011; Sewell, 1986; Vattay, Kauffman, & Niiranen, 2014).

Furthermore it is possible to consider like phase transitions phenomena occurring in different domains as for cognitive processes with the occurrence, on suitable short temporal scales, of abilities and behaviours not predictable or explained on the basis of previous knowledge of the state or the abilities possessed by the agent considered. The inclusion of these phenomena within the category of phase transitions is often based on analogies rather than on rigorous thermodynamic criteria (which often are not fulfilled). In any case they are useful to suggest the need for a generalization of traditional PT theory. Other examples occur a) in language learning and usage through the extension of vocabulary and the frequency of using plurals (Robinson & Mervis, 1998), b) in cognitive science through the transition from the wrong hypothesis to the right one during the process of the discovery of a rule (Terai, Miwa, & Koga, 2003), c) in evolutionary psychology when a child gains the ability to grasp an object (Wimmers, Savelsbergh, Beek, & Hopkins, 1998) and d) in cognitive science when we have a transition from non-analogical to analogical reasoning (Hosenfeld, van der Maas, & van den Boom, 1997).

In order to understand the difference between the classical theory of PT and the theories of *self-organization*, we now shift our interest towards the latter concept. In this regard we remind that it was introduced by Ashby (Ashby, 1947) who understood a system to be self-organising when the system is changing by itself its own organization rather than being changed by an external action.

We start our considerations by remarking the difference between the processes of self-organization and the ones of *self-structuring* which have different disciplinary meaning like in ecology for spatial self-structuring (Lion & van Baalen, 2008), in the study of networked systems (Gang Chen & Song, 2014; Kermarrec, Mostéfaoui, Raynal, Trédan, & Viana, 2009) and in psychology, communication and education. The distinction between self-organization and self-structuring emphasises that processes of self-organization consists in the adoption of different possible organizations, each of them allowing different *possible* compatible structures.

Processes of *self-organization* are considered here as corresponding to continuous but *predictable*, for instance, periodic or quasi-periodic (Hemmingsson & Peng, 1994), variability in the acquisition of new structures. Examples are given by Rayleigh-Bénard rolls, structures formed in the Belousov-Zhabotinsky reaction, dissipative structures such as whirlpools in the absence of any internal or external fluctuations, and swarms having repetitive behaviour. In particular, in the Rayleigh-Bénard (Ching, 2013) case, there is metastability. In the experiments, the acquired direction of the rotation of the cells, or rolls, is stable and alternates from clockwise to counterclockwise horizontally. Their properties are very sensitive to initial conditions and show a distinct inability to predict long-term conditions typical of chaotic systems. When the temperature of the bottom plane is further increased, cells tend to approximate regular hexagonal prisms like the hexagonal cells of beehives (Getling, 1998).

Processes of self-organization may be understood as ***regular*** *sequences* ***of phase transitions when their changing or transition*** *over time is regular, e.g. cyclic and quasi-periodic when adopting a* ***single*** *coherence.*

Let us now take in consideration the processes of *emergence* (Minati & Pessa, 2006, pp. 145–279). They are considered here as corresponding to the continuous but *irregular* and *unpredictable* (a typical case is given by some kinds of symmetry breaking processes) *coherent* acquisition of new multiple sequences of different structures. Due to coherence, such sequences display to the observer the *same* emergent, acquired property. Examples include the properties of collective behaviours adopted by bacterial colonies, cells, flocks, industrial districts, markets, mobile phone networks, morphological properties of cities, nano-swimmers, nematic fluids, networks such as the Internet, protein chains and their folding, queues and traffic signals, rods on vibrating surfaces, shaken metallic rods (interaction involves reacting), swarms and systems of boats (Minati & Licata, 2012, p. 9; Vicsek & Zafeiris, 2012). In the literature, the difference between *strong* and *weak* emergence has been considered, which can be related, for instance, respectively, to *non-deducibility* and *unexpectedness* from low levels of treatment (see, for instance, Bar-Yam, 2004; Bedau, 2008; Chalmers, 2006; Hovda, 2008).

Processes of emergence may be understood as the occurrence of possibly multiple simultaneous sequences of processes of self-organization when the corresponding acquired dynamic structures are ***coherent****, i.e. display the same* *property in spite of adopting multiple coherences (an example is given by the theory of 'dual evolution' for adaptive systems, introduced by Paperin, Green, & Sadedin,* 2011*).*

Let us now deal with the fundamental question if the PT can be considered as examples of processes of emergence. If we resort to traditional PT theory, the answer is obviously negative. However, if we adopt more complex theoretical models, it is very difficult to prove the validity of this answer. The interest for this question arose when studying the symmetry breaking PT within the context of quantum field theory (see Minati & Pessa, 2006, Chap. 5.4; Liu & Emch, 2005; Batterman, 2011; Landsman, 2013). Without entering in too hard technical details (a very good reference is given by Brauner, 2010), we limit ourselves to remind that a spontaneous symmetry breaking occurs when the dynamical equations ruling a given system continue to keep an invariance with respect to a specific symmetry group, while its ground state loses it. In other words, the system changes its previous ground state (invariant with respect to the same symmetry group) for assuming a new ground state (no more invariant). The phenomenon is spontaneous when it is generated by the change of value of a parameter, without any external force. The two ground states (before and after the symmetry breaking) are different and non-equivalent with respect to unitary transformations acting on system states. In short, they describe two different kinds of physics (just like what happens in traditional PT). In most models of interest for physics, we have a plurality (or even infinity) of possible ground states available after the symmetry breaking, and the specific choice of the new ground state is unpredictable by traditional PT theories. This circumstance is suggested to identify the symmetry breaking transformations with cases of radical emergence.

But is this picture correct? A number of deeper analyses (see Brauner, 2010; Landsman, 2013) showed that it is incomplete. First of all, already in the sixties, first Nambu (Nambu, 1960) and then Goldstone (Goldstone, 1961) showed that the occurrence of a symmetry breaking transition is associated with the presence of bosonic long-range excitations of zero mass, the so-called *Nambu-Goldstone* (NG) bosons (these results have been generalized to quantum field theoretical models by Goldstone, Salam, & Weinberg, 1962). This circumstance holds under the hypotheses of continuity of the symmetry to be broken and of Lorentz invariance of the dynamical equations ruling the theory under consideration. However, it has been shown (see, Brauner, 2010; Watanabe & Maruyama, 2012) that a similar situation occurs also in the case of spontaneous breaking of Lorentz invariance (or of other space-time symmetries) or of rotational or translational invariance. The only change consists of the fact that NG bosons are replaced by suitable quasi-particles.

In the second place, it has been shown that the choice of the new ground state after the symmetry breaking is, in the realistic contexts, not casual and unpredictable but dictated by the influence of external environment upon the system under study. A simple example is given by the second-order PT from the paramagnetic to ferromagnetic state. Here the rotational symmetry is broken (namely, we are in presence of a preferred magnetization direction) and the corresponding NG boson is replaced by a quasiparticle called *magnon*, consisting in a spin wave produced by a collective oscillation of the magnetization direction. But who is the actor specifying the preferred magnetization direction – a random, unpredictable choice made by the system itself during the transition, in absence of any external influence? We understand that this answer would be absurd, just because the divergence of magnetic susceptibility is close to the transition critical point. A factory producing magnets would go bankrupt if expecting the inner system random fluctuations for designing its products! Namely, what really happens is that the preferred magnetization is one of the *external magnetic field* acting on the system in the moment of transition. This implies that a theory of PT which not includes the role of the environment is useless.

The combination of the two aforementioned circumstances gives rise to a somewhat paradoxical situation. On the one hand, a PT is an emergent phenomenon, owing to the presence of NG bosons which help to 'keep' the choice of the new ground state after the symmetry breaking (a fact denoted as 'generalized rigidity' by Anderson in some celebrated papers; see Anderson, 1981; Anderson & Stein, 1985). So they act as 'coherence keepers', a role characterising one of most important aspects of emergence. On the other hand, this emergence is far from being unpredictable, being determined by a specific choice made by external environment. And, as a matter of fact, the NG bosons (or magnons in the case of ferromagnetism) undergo amplitude oscillations around the preferred direction.

For a number of years, the solution of the paradox has been based on the choice of making all volumes tending to infinity. Namely, in this way the role of the local choice of preferred direction made by the environment loses its primary importance. At the same time, we can deal with an exact theory of PT instead of obtaining only approximate results. However, even this hypothesis leaves unsolved an important question: what can make NG bosons? What is their dynamics? In this regard we remark that all previous results do not give any information about the amplitudes of the NG modes which, in principle, could have a whatsoever value. Moreover, the few studies performed on this subject evidenced the existence of different kinds of NG bosons, some of which characterized by different forms of dispersion relations, that is of relationships between ω and κ or, which is the same, between energy and momentum.

This situation suggest the need for adopting a point of view based on the primary role for which NG bosons have been introduced: the one *reacting* to inner and external perturbations in such a way as to act as coherence keepers. It is easy to understand, in this regard, that both kinds of perturbations are, in principle, unpredictable. And, because they must be counteracted by NG bosons which they are free to act in different ways, we must conclude that the whole story of perturbations and corresponding reactions, allowing to keep the coherence of the chosen ground state, is not only endless but consists of a series of acts, each one of which is unpredictable. We can thus assert that a PT associated with a symmetry breaking must be followed by an infinite series or different and unpredictable emergences, each one granting for the keeping of the global coherence corresponding to the new ground state. This story, could, in principle, be experimentally detected by resorting to microscopic observations. As regards the magnetic materials, it is possible to observe some partial effects of this story by looking at the structure of magnetic domains. In short, the previous paradox can be solved, and PT can be considered as cases of radical emergence, provided we take into account realistic contexts of interaction between the system and the environment, taking into account random fluctuations and finite volumes.

We may summarise by saying that PTs relate to order-disorder transitions and can be viewed as cases of radical emergence only if we take into account fluctuations and finite volumes. The self-organization allows to acquire coherence, and emergence allows to acquire ***possibly*** *multiple coherent coherences (****coherent collective self-organization***[4]*) when distinguishing, for instance, from* ***multiple synchronizations*** (see Chap. 7 and Pikovsky et al., 2001). Synchronization also relates to multiple maintaining of the same distances of any nature, e.g. spatial, electrical, acoustical, etc., between phenomena. Coherence is considered here, see Sects. 2.1, 3.2.4, and 7.2.1, as maintaining the same emergent property(ies) notwithstanding a continuous structural change.

With reference to scale-free correlations in collective behaviours (Cavagna et al., 2010; Hemelrijk & Hildenbrandt, 2015), we consider self-organization as corresponding to the establishment of a single correlated domain, and emergence as corresponding to the correlation of multiple correlated domains where different, but constant, correlation lengths occur, such as, for instance, when changes in size occur.

Different understandings about the difference between processes of self-organization and emergence (De Wolf & Holvoet, 2005), as well as the *self-organization of processes of emergence* are available in the literature (De Wolf, Holvoet, & Samaey, 2006; De Wolf, Samaey, & Holvoet, 2005a; De Wolf, Samaey, Holvoet, & Roose, 2005b; Samaey, Holvoet, & De Wolf, 2008). Processes of emergence, for instance, of coexisting states, multi-stability and attractors within different disciplinary contexts should also be considered (Feudel, 2008).

An example of multiplicity for processes of self-organization and emergence is given by considering the *hopping* itinerancy of neural activities between attractors (Marro, Torres, & Cortés, 2007) and in sequences of *quasi-attractors*, local regions of convergent/divergent flows. The quoted paper by Marro et al. can be considered as representative of the modelling works in the domain of biologically inspired neural networks. Typically in this context, the multiplicity is produced by resorting to probabilistic processes ruled by stochastic equations. In the paper cited above, the authors introduce networks of N binary neurons whose individual activities

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[4] We consider cases where a specific phenomenon of self-organization *differentiates* into different coherent self-organized possibly subsequent, superimposed phenomena such as swarms or flocks having repetitive regular behaviour following perturbation or when subjected to internal fluctuations due to predator attack. This corresponds to the concept of Multiple Systems, Collective Beings (see Sect. 4.5), or *quasi-synchronization* consisting of multiple superimposed synchronisations (Pikovsky et al., 2001), and is at the base of the concept of meta-structures, see below and Sect. 3.8.

$s_i\,(i = 1,\ldots,N)$ can have only the values 1 or -1. These totally connected neurons communicate through synapses whose intensities are given by a general law having the form:

$$w_{ij} = w_{ij}^L x_j$$

where w_{ij}^L is an average weight value, while x_j is a random value. The model is designed to act as an associative memory, loaded from the beginning by a set of M random binary patterns, stored according to the traditional Hebbian learning rule:

$$w_{ij}^L = M^{-1} \sum_{\mu=1}^{M} \xi_i^\mu \, \xi_j^\mu$$

If we denote by $m^\mu = N^{-1} \sum_{i=1}^{N} \xi_i^\mu \, s_i$ the *overlap* between the μ-th memory pattern and the activities of network neurons, it is possible, once introduced a probability distribution for the values of x_j, to compute the local activity fields deriving from the interactions between the neurons through the formula:

$$h_i = \left[1 - \gamma \sum_{\mu=1}^{M} (m^\mu)^2\right] \cdot \sum_{\nu=1}^{M} \xi_i^\nu \, m^\nu$$

Here the symbol γ is given by the expression:

$$\gamma = (1 + \Phi) \cdot (1 + \alpha)^{-1}$$

in which $\alpha = M/N$. The constant denoted by Φ appears because one of the goals of the model is to describe the neurobiological phenomenon of *synaptic depression* and consisting in the fact that the synaptic weight of a neural connection decreases under repeated presynaptic activation. The value of Φ is just a measure of the amount of this decrease and, as such, appears within the law describing the probability distribution for the values of x_j and, therefore, into the formula for computing h_i.

The final part of model description regards its time evolution which, obviously, has a stochastic nature. This means that, for each network unit, the probability $P\left(s_i \rightarrow s_i'\right)$ that its state s_i at time t be updated to the state s_i' at time $t + 1$ is given by a law having the form:

$$P\left(s_i \rightarrow s_i'\right) = \Psi\left[\beta_i\left(s_i' - s_i\right)\right] \cdot \left[1 + \Psi\left(2\beta_i s_i'\right)\right]^{-1}$$

where $\beta_i = h_i/T$ and T is a parameter controlling the degree of stochasticity (the so-called *temperature*), while the function $\Psi(u)$ is arbitrary, except for the fact that it must fulfil the conditions:

$$\Psi(u) = \Psi(-u)\exp(u)\ ,\ \Psi(0) = 1\ ,\ \Psi(\infty) = 0$$

A practical example of a function fulfilling these conditions is given by:

$$\Psi(u) = \exp[-(1/2)(u - u_0)]$$

where u_0 is a generic constant.

Needless to say, the behaviour of the model must be studied not only by resorting to analytical considerations but mostly performing numerical computer simulations. The latter evidence, both a chaotic evolutionary trend as well as attractor hopping phenomena, however occurs when the number M of the stored pattern is large. The previous model has been worked out with some details in order to show in an explicit way the mathematical techniques most often used to describe emergence in complex systems endowed with attractors. As well known, attractors and quasi-attractors are associated with memories, perceptions and thoughts, the chaos between them occurring with searches, sequences and itineraries in processes of recalling, thinking, speaking and writing (Kanamaru, Fujii, & Aihara, 2013). Chapter 7 shows that it is possible to consider, for instance, *layers of emergence* and *top-down emergence*, whereas the same *self-organization* is rarer.

Another aspect of the dynamics of self-organization and emergence considers quasi-emergence, quasi-self-organization and their dynamics of changing as in Sect. 4.7.

3.2.4 Dynamical Coherence

When dealing with collective systems, their dynamics is here identified with the changes in the way through which their elements interact, contrarily to classical dynamics which is given by parametrical changes in the fixed form of evolutionary laws.

In the former case, the *structure* of the system is considered as being given by the ways in which each element interacts with the others. It is thus possible to take into consideration temporal sequences of different rules and temporal sequences of different combinations of rules (Sect. 3.8.2), with different coherent networks governing the system.

Different *kinds* of change are possible, such as changes in the way of interacting mentioned above, subsequent *structural* changes as for the cytoskeleton and for complex systems intended as *sequences* of phase transitions where the properties of such sequences should be understood as a structural dynamics, coherent in complex systems (Minati & Licata, 2013). Different possible cases may occur separately or together in any combination:

1. *Change* in structure, i.e. from one structure to another.
2. *Acquisition* of a structure, i.e. change from a non-structured configuration to a structured one.

3. *Loss* of structure, i.e. change from a structured configuration to a non-structured one.
4. *Combinations* of structures.

These may occur both for PTs and networks.

We may also consider *structural regimes*, where for structural regime we intend the current validity, given appropriate thresholds and distributions, of some sequences and combinations of rules of interaction or networks (Sect. 3.8.5). These include *single structural regimes of rules*, *multiple and overlapping* fixed *structural regimes of rules* and *multiple and overlapping* variable *structural regimes* (see Tables 3 and 4).

The dynamical coherence of collective systems has a phenomenological nature, given by the *preservation* of acquired properties, such as behaviour and shape, in spite of the underlying structural dynamics. This is known only a posteriori, and the idea *to zip* the essential characteristics of change and particularly its coherence by using a set of ideal equations is often unsuitable. This occurs because the coherence we have in mind is related to multiple continuous changes which can be represented by sequences of analytical models suitable for representing coherence when used one at a time.

Actually, this conceptual framework has been dealt with by using statistical approaches, whereas here we are considering new post-GOFS approaches, such as networks, meta-structures, preservation of scale-invariance and power laws (see Sect. 3.7). Moreover, it is to be taken into account that more recent advances in the theory of modelling and simulations (see, for instance, Zeigler, Praehofer, & Kim, 2000; Zeigler & Sarjoughian, 2013) make available a number of tools helping the modeller to increase its storage of usable models. Among these tools we can quote the *systems of agents* and the *molecular dynamics* (see, for overviews, Schweitzer, 2003; Helbing, 2010). They allow, mainly in presence of a suitable amount of phenomenological data, to detect a number of useful regularities, in turn suggesting specific local (or global) models, endowed with a suitable, even if temporary, validity (an example of application within a social domain is contained in Budka, Juszczyszyn, Musial, & Musial, 2013).

The concept of coherence, when suitably modelled using ideal approaches (here the attribute 'ideal' is used by making reference to the distinction between ideal and non-ideal models made in Sect. 5.6), can be applied to collective systems working under *stable* environmental conditions, i.e. considered conceptually as a phenomenon occurring *within* closed systems without an active environment with which to interact. Examples include synchronized oscillators, non-perturbed swarms established by suitable initial conditions, populations of fireflies (Buck & Buck, 1966) and traffic jams with hovering data clouds (Fekete, Schmidt, Wegener, & Fischer, 2006) reaching stationary states in a non-perturbed environment.

In contrast, processes of dynamical coherence, i.e. coherence which is changing or the development of multiple coherences which may together show coherence, which often cannot be suitably modelled using ideal approaches, occur, for instance, when a system must also *process* environmental perturbations.

Finally, there is the case in which the system must process *internal changes*, due to reasons such as the occurrence of *intrinsic fluctuations* (of various natures: non-linearity, stochastic noise, chaotic behaviour or quantum-like phenomena) or *decisions* made by autonomous entities. *It should be stressed that the concepts considered above also apply when dynamics relates to changes occurring within* populations of properties *and* configurations *to be intended as entities, as for the dynamics of networks* (Nolte, 2014).

A more comprehensive discussion is given in Sect. 7.2.2 and Appendix 1 when dealing with levels of emergence and with networks.

3.3 The Case of the Dynamics of the Cytoskeleton

One example of complex structural dynamics is given by the dynamics of the ***cytoskeleton*** *(Fletcher & Mullins, 2010). Within the cell cytoplasm, the cytoskeleton consists of a network of protein fibres and is characterized by its structural dynamics since its parts are continuously destroyed, renewed or newly created.*

In recent years there has been an increased interest in the dynamics of the cytoskeleton, fomented by the theories of Penrose and Hameroff on the role that quantum processes regarding the microtubules might have in explaining the phenomena associated with cognitive activity and, more generally, consciousness (see, for example, Hameroff, 1994; Hameroff & Penrose, 1996; Penrose, 1994; more recent formulations and proofs are contained in Hameroff & Penrose, 2014a, 2014b). Given the difficulty of carrying out experiments to confirm or deny the validity of these theoretical proposals, it is necessary to build models of the dynamics of the cytoskeleton which allow the prediction of effects which can be experimentally verified.

Currently such model-building is very difficult, given, on the one hand, the complexity of the structure of the cytoskeleton and, secondly, the existence of major limitations linked to the simulation of quantum processes. In all the modelling approaches proposed so far, the cytoskeleton has been considered as a network of biopolymers comprising three main types of filaments (for a review see Pullarkat, Fernández, & Ott, 2007): those of actin, the microtubules and the intermediate filaments. Usually these are disregarded, given that they seem to play only a passive role of reinforcement. Almost all models are based on descriptions of a classical type, focused on the macroscopic hydrodynamics of the cell, and mainly on the rheology of the cytoskeleton, related to the role of the cytoskeleton in determining the mechanical properties of the cell (for reviews, see Jülicher, Kruse, Prost, & Joanny, 2007; Levine & MacKintosh, 2009). Some of these models are inspired by a general theory concerning biological matter, known as the theory of tensegrity, proposed by Ingber (Ingber, Heidemann, Lamoureux, & Buxbaum, 2000). This theory postulates that all biological structures, on any scale, guarantee the stability of their shape, as well as the ability to perform movements in a coordinated manner through the combined action of forces of tension and compression exercised locally. In particular, in the cytoskeleton, tensions would be sustained by filaments of actin, while the microtubules would be responsible for compression (for an example of a model of the cytoskeleton based on tensegrity, see Cañadas, Laurent, Oddou, Isabey, & Wendling, 2002).

Computer simulations of microtubule models (see, for instance, Deymier, Yang, & Hoying, 2005; Baulin, Marques, & Thalmann, 2007; Glade, 2012; Zelirski & Kierfeld, 2013; Gao, Blackwell, Glaser, Betterton, & Shelley, 2015; Muratov & Baulin, 2015), often conducted on systems comprising hundreds of microtubules, revealed two critical aspects: (1) the rheological properties of the cytoskeleton observed so far can only be obtained with a very careful choice of the values of the parameters of the model, suggesting that these properties do not have generality and (2) there is no evidence of any particularly significant influence of the quantum character of microtubule dynamics, except the case where interactions between microtubules and the intracellular fluid are particularly intense. These circumstances suggest, on the one hand, the need to reflect upon the theories proposed relating to the role of the cytoskeleton and, on the other hand, the opportunity of extending the models to avoid too rough approximations of a very complex biological reality. In any case, the simulations performed and the critical examination of their results are a necessary step towards the construction of a general theory of the dynamics of the cytoskeleton.

3.4 Ontological Dynamics of Systems

Ontology (see also Sect. 9.4) is the philosophical study of the nature of existence, of *being* (Brenner, 2008; Effingham, 2013). It is considered a part of the branch of philosophy known as *metaphysics*. Ontology deals with questions concerning the *existence* of entities, their categorization, grouping within hierarchies or according to similarities or differences related to different kinds of applications (Casellas, 2011).

Ontology is intended in philosophy as the science of what is *currently existent*, of the kinds, structures and properties of objects, events, processes and their relationships in every area of reality (van Inwagen, 2014).

However, the term 'ontology' is associated with different meanings in different disciplines, the bridge between them being given by making reference to ***cognitive existence****.*

Ontology, then, is a matter of inquiry, research, development and application in disciplines related to computation, information and knowledge like, e.g. artificial intelligence, knowledge representation and information science, dealing with *categorising and structuring concepts and entities of interest* (see Sect. 9.4). Examples of disciplines applying ontological principles include information science, communication, geography, linguistics, mathematics, medicine and sociology. In all cases each discipline establishes some specific ontological domain in order to consider structures of concepts and meanings pertaining to that discipline.

Let us consider *represented knowledge* (Jakus, Milutinovic, Omerovic, & Tomazic, 2013; Mazzieri & Dragoni, 2012). Formally, it is based on the conceptualization as being a formal, symbolic representation of entities, such as objects and concepts, assumed to be *existent. Ontology is then intended as an explicit specification of such conceptualization.* In *computer science*, for instance, the term is used to denote a file containing the formal definition of terms and relationships.

An ontology should be built by analysing the domain to be represented and by conceptualizing it *explicitly*, i.e. symbolically. That is, to allow a Turing machine *to understand* the conceptualization, being endowed with a complete deductive system to logically *infer* all consequences of the available domain knowledge. The *intelligence* of the machine is intended as its ability to find *implicit consequences* of the explicitly represented knowledge.

Such ontologies are studied and used in many fields such as web semantics and databases (Kishore, Sharman, & Ramesh, 2004) for classifications, search engines and web languages (Glimm, Horrocks, Motik, Shearer, & Stoilosm, 2012) and as *computational models* enabling certain kinds of *automated reasoning* (Steward, 1997).

Structured knowledge representations, i.e. ontologies and terminologies, are widely used in *biomedicine* (see, for instance, Gruber, 1993 and the World Health Organization (WHO, 2013).

Another related disciplinary field is the *Gene Ontology project* (see the Gene Ontology Consortium in the References) whose goal is to standardize the representation of gene and gene product attributes across species and databases. As a byproduct, vocabularies of terms for describing *gene product characteristic* and *gene product annotation* are available in the literature (see in the References the entry geneontology).

Let us consider now processes implying *changes of ontologies, which* appear, from the point of view of mathematical logic, as a matter of syntactical change through either the addition or removal of an axiom in the formal system under study. These processes introduce problems of consistency since the ontology might acquire sets of axioms which are mutually incompatible (Haase, van Harmelen, Huaang, Stuckenschmidt, & Sure, 2005).

The changes of ontologies are taken here into consideration as they could be relevant for representing structural changes and changes in properties, i.e. *acquisition or loss, of a system and its levels of coherence(s) during processes of emergence.*

The subject is not new and has been explored by several researchers with reference to the presence and evolution of levels within systems (see, for instance, Baas, 1994; Heard, 2006; Silberstein & McGeever, 1999; Wimsatt, 1994). It is, however, to be taken into account that in this context, it is virtually impossible to establish simple and understandable links between the ontology changes and the processes of emergence occurring within systems. Namely, if we deal with systems made by entities endowed with some sort of cognitive system, as it is the case when we study social systems, we are faced with two fundamental difficulties: (1) there is no commonly shared definition of ontology and (2) we still lack a sound theory explaining how an ontology (which is a mental entity) can have a relation with actions of the members of a social system (which are physical processes). The solution of the latter problem, if any, would be equivalent to the solution of the 'hard problem of consciousness' (using the terminology introduced by David Chalmers; see Chalmers, 1995, 1996). It consists in understanding how the private and subjective personal experience (of mental nature) can be connected with our action-perception system operating in the physical environment.

In this situation, all we can practically do requires the introduction of a specific research context in which all concepts can acquire well-defined meanings. Among the available contexts, so far the most convenient is the one of artificial intelligence. Namely, within it the ontologies are important elements for the design of software tools having specific concrete applications. This allowed the introduction of formalized definitions of ontologies, which overcome the problems related to the older definitions, based on natural language and directly derived from the philosophical tradition. A very popular formalized definition of ontology is, for instance, the one introduced by Kalfoglou and Schorlemmer (2003), according to which an ontology is a pair $\langle S, A \rangle$, where S is the *vocabulary* (often called *signature*), that is, mathematical structure whose elements are the terms used in the ontology, and A the set of *ontological axioms* specifying the interpretation of the vocabulary within a given domain. Such an approach allowed the formalized logico-mathematical study of most processes concerning ontologies, such as ontology changes (see, for instance, Flouris, Manakanatas, Kondylakis, Plexousakis, & Antoniou, 2008; Khattak, Batool, Pervez, Khan, & Lee, 2013; Mahfoudh, Forestier, Thiry, & Hassenforder, 2015).

In turn, the results obtained in these studies allowed practical implementations within specific kinds of models, designed to perform quantitative computer simulations. Among these models we quote the *agent models*, already mentioned in this chapter, and the ones based on the so-called *memetic algorithms* (an introductory paper is the one of Ong, Lim, & Chen, 2010; reviews are contained in Le, Ong, Jin, & Sendhoff, 2009; Chen, Ong, Lim, & Tan, 2011; textbooks are the ones of Goh, Ong, & Tan, 2009; Neri, Cotta, & Moscato, 2012). As it is well known, the term *meme* has been introduced many years ago by the biologist Richard Dawkins to denote a unit of cultural evolution which can undergo biological-like processes such as evolution, propagation and refinement (see Dawkins, 1976). With the years, the original (but imprecise) ideas of Dawkins have been transformed to denote a class of models and algorithms, more often designed to solve optimization problems, but having in common the characteristic of working under a suitable combination of global evolutionary algorithms (like, for instance, genetic algorithms) with local (that is, acting on single individuals) search techniques (like, for instance, the ones based on learning procedures). When these tools are used to simulate the behaviour of agents, whose cognitive systems include ontologies based on memes, it is immediate to understand that models of this kind are suited to describe many evolutionary processes occurring in social systems.

Without entering into technical details, we shortly illustrate a general scheme concerning the application of a memetic algorithm within the context of problem solving through artificial neural networks. This scheme is adapted from a paper by

Chandra (2014). The latter deals with the solution of grammatical inference problems through recurrent neural networks with Elman architecture. In practice these networks consist of three layers of units: the *input* layer, the *hidden* layer and the *output* layer. These layers are connected through standard feedforward links, like usual perceptrons. However, they differ from the latter because the hidden layer has also a feedback link which sends the activations of its units to another layer, parallel to the input layer and called *context* layer. This circumstance allows the units of the hidden layer to receive at the same time t two kinds of inputs: the ones coming from the input layer and the others coming from the context layer (containing the activations of the hidden layer at time $t-1$. Therefore the activation values of the hidden layer units are given by a law of the form:

$$y_i(t) = f\left[\sum_{k=1}^{K} v_{ik} y_k(t-1) + \sum_{j=1}^{J} w_{ij} x_j(t-1)\right]$$

In this formula K and J denote, respectively, the numbers of units belonging to the hidden and input layers, while v_{ik} and w_{ij} are the weights associated with the related links. The symbol f denotes a traditional sigmoid activation function.

In order to implement the memetic algorithm, the first step consists in decomposing the set of problems to be solved in such a way that each network can be subdivided into subcomponents, each one of which is deputed to solve a specific subset of problems. Without entering into details about the subdivision procedure, here we will limit ourselves to remark that each subcomponent (coded through the connection weights that define it) can be interpreted as a representation of a specific *meme*. Now the next step implies that, once introduced a particular set of memes (that is, subcomponents), we must compute the *fitness* of each meme in solving the subset of problems associated with the considered subcomponent. Obviously, the method used to perform this computation depends on the chosen fitness measure and, therefore, on the nature of the problems to be solved. For this reason we will not insist on the details of this procedure. Let us now introduce the further step of this processing scheme, which is based, for each subcomponent, on a global evolution of the population of memes according to standard rules, for instance, used when applying a *genetic algorithm*. This evolution will give rise, after a suitable number of generations, to a new population of memes, including the ones characterized by the highest fitness. At this point we can introduce a local search procedure, acting on the latter memes, designed to further improve their fitness. While neglecting the details of this procedure (for instance, it could be based on hill-climbing methods), we must remark that it is applied to specific selected memes rather than to their whole population. At the end of this procedure, we can re-assemble the obtained best memes in such a way as to reconstruct the whole network, which, then, is the best suited one for solving the problems belonging to the original set.

While the scheme previously sketched can appear as complex and resource-consuming with respect to traditional learning methods, the experience showed that it is far more effective, also because it helps to understand the deep nature of the problems to be dealt with. This effectiveness, then, becomes evident when we are interested in simulating the behaviour of social systems rather than solving optimization problems.

We recall also an important aspect of ontology, consisting in the fact that often it is used to individuate entities which exist independently from an observer such as a human subject, that is, without any subject having thought of them or otherwise related itself to the entity. They then exist not only epistemologically but also ontologically, i.e. having independent, objective and materialistic existence: reality. This area of research aims to explain emergence by considering the ontology of levels (Emmeche, Koppe, & Stjernfelt, 1997).

This line of thought and research is being considered here not for any interest in classical objectivism, but because the independence from an observer can be viewed as equivalent to considering the observed and observer represented as one in terms of the other, (the case where conceptually the system *contains* the generator of meaning) and also because *different coherences,* as introduced above, might be considered as levels of emergence. In this case we may speak of *super-coherence*, i.e. coherences between coherences, as an ontology of levels.

This involves transformations and transitions. This is the case even within GOFS for the transformation of structured sets into systems where composing elements interact in suitable ways. It also includes phase transitions where the change relates to the structure of the system moving from one phase to another. *Radical emergence* is yet another case.

As made already evident in artificial intelligence, the ontological aspect of transitions is shown through the acquisition of new properties from entities, requiring new ***names*** *and new specifications of relationships among them. The references quoted before when speaking of the formalized theories of ontologies illustrate the achievements already obtained in the study of changing ontologies.*

The subject is considered here in order to explore the problems of a) the ***identity*** *of emergent systems and b) equivalences. Identity (*see Sect. 3.5) *is considered as being related to the robustness of coherence(s) and their possible* ***super coherence***[5] *as in the case of networks* (see, for instance, Cohen & Havlin, 2010; Peixoto & Bornholdt, 2012; Zhou, Gao, Liu, & Cui, 2012) where the coherence of multiple emergent properties is maintained.

In this regard it is important to mention the fact that for a long time, the notion of multiple coherences has been introduced mainly in the study of stochastic systems described by suitable time series of experimental data (a very old contribution on this subject is the one of Goodman, 1963; among more recent contributions, we can quote the ones of Brillinger, 1975, Potter, 1977; Kay, 1999; Box, Jenkins, Reinsel, & Ljung, 2015). However, despite the sound mathematical origin of this notion, it has been generalized to account for multiple local coherences in conceptual changes related to learning process in school students (see, for instance, Rosenberg, Hammer, & Phelan,

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[5] We recall that the concept of super coherence originates and is specific to quantum physics when dealing with coherence among dominions of coherences considered in the case of water (Del Giudice & Tedeschi, 2009).

2006; Scherr & Hammer, 2009). In any case, the concept of multiple coherences has acquired a paramount importance mainly within quantum physics. Namely, in this context a state can be formed through the coherent linear superposition of a whatever number of elementary states, a circumstance that allows the superposed state to be characterized by a number of different frequencies, each one corresponding to a particular kind of coherence. Then, a suitable detecting apparatus can work in such a way as to extract from the same superposed state, one at time, different frequencies. Such a property widens the possibilities of spectral analysis of complex system behaviours and is at the basis, for instance, of techniques such as nuclear magnetic resonance (see, e.g. Ernst, Bodenhausen, & Wokaun, 1987; Mathew et al., 2009).

We conclude this section by focussing upon correspondences between aspects of super coherence, identity, ontological dynamics and structural dynamics all of which can be considered as ontological when *the* system goes through levels of emergence or mutations (see Sect. 7.2.2). This is valid when considering the possible *persistence* of properties following the disappearance of original constituents from which structures having such properties emerged (see Klaers, Schmitt, Vewinger, & Weitz, 2010 for a case where photons can *autonomously* persist in Bose-Einstein condensation).

Ontological dynamics of systems relates to the applicability of the same, different or equivalent models and their coherence to be used as within DYSAM-like approaches (see Chap. 5 and Appendix 1), and non-equivalent unitarily quantum representations (Blasone, Jizba, & Vitiello, 2011).

Furthermore, structural system dynamics can be considered as transformation, redefinition or equivalence between ontological identities and the transient as well as the ***dynamics of meanings and their coherence****.*

3.5 Systems Identity

Possession of clear demarcation, stability and permanence, no fuzziness, and structural invariance, all denoting *systemic closure*, are examples of requirements classically considered to deal with *identity*.

Since the opposite, such as openness as non-closure, may be achieved in a variety of dynamical cases, it may be more difficult to define identity rather than through related properties such as coherence, stability or regular dynamics. The subject of identity in philosophy is also called *sameness*, making an entity definable, recognizable and entities distinguishable (see, for instance, Wiggins, 2001).

Here ***identity*** *is considered as being given by the* ***permanence*** *of* ***emergent*** *properties or the* ***permanence of properties of the way in which change can occur at any level*** *such as coherence(s), super coherence and ontological dynamics*. One typical example is life itself.

Such an understanding of identity may be considered within various representations and scales such as in the cases of networks or mesoscopic scale, intermediate between microscopic and macroscopic ones, when dealing with the *middle way* (Laughlin, Pines, Schmalian, Stojkovic, & Wolynes, 2000).

The crucial point is that some representations, such as network or mesoscopic ones, have in common the adoption and validity of specific criteria and thresholds decided upon by the *theoretically active observer*, no longer a noise-generator or source of relativism, but a generator of *cognitive reality* as in constructivism (see Sect. 5.1 and Licata & Minati, 2010). On the other hand, representations could be introduced by considering nodes and links for networks, or clusterisations and introduction of thresholds for mesoscopic representations (Haken, 2005), or based on other criteria such as *optimisations* of the number of variables represented, or even by adopting mixed approaches (Giuliani, 2014).

The subject of 'systems identity' can be understood as being articulated into various issues having possible multiple philosophical ontological interests and scientific aspects. For instance:

1. *Relationships among identities*. The issue arises in various cases, such as when (a) identities are given by stable systemic properties; (b) the same entities establish different systems due to different interactions, e.g. multiple systems where the same elements have multiple roles and synchronization is the source of their coherence; and (c) identity is given by coherence(s) or the properties of the dynamics of their sequences. Mesoscopic identities are explored as meta-structural in Sect. 3.8 and Chap. 4. We should consider *multiple identities* as well the *nature* of this multiplicity. Identity may be given, for instance, by the properties of networks, indices of ergodicity or correlations. The ontological aspects relate to the possibility of acting upon a semantic classificatory network and considering its properties in order to detect properties such as absences, irregularities, or defects as clues of other possible *cognitive realities*. An example is given by the *missing* elements in Mendeleev's table where coherence is intended as *phenomenological*.
2. *Acquisition of identity and the acquisition of properties*. The subject becomes more interesting when identity relates to the *ability to acquire properties* rather than to the acquisition of a specific property. It is a kind of *system* currently *without systemic properties*, in a systemic situation of 'metastability' and *readiness* to acquire systemic properties. This readiness and metastability should be considered as a *pre-identity* of the system available to *adopt*, for instance, its collapse, to degenerate or to acquire a real property. Although a structured system such as an electronic device acquires systemic properties as functionalities and degenerates into structured sets when no longer powered on or when *broken*, we can refer to populations of configurations of interacting elements as being ready to *collapse* into one of a variety of possible *equivalent* (see Sect. 3.6) systems, due, for instance, to noise, fluctuations or symmetry breaking. This relates to processes of the acquisition of coherence(s) and requires a minimum level of complexity.
3. *Maintaining properties*. This subject is more interesting when identity relates to the *ability to keep properties* and their relationships, e.g. sequential, simultaneous or in any other way, rather than to keeping a specific property. It is a kind of *transversal* general property. It may be considered as a *virtual property* ready

to be applied within specific contexts and for configurations having a suitable level of complexity. It is *potential*. It is typical of systems having the property of maintaining acquired properties such as the ones of systemic nature, their sequences, coherence(s), networks or meta-structural ones. In this case a very special *stability* ensues, i.e. maintaining those properties or the ways of acquiring them, whatever they be.

4. *Maintaining equivalence*. This case relates to the ability of a system to maintain as *equivalent* any version of itself over time, e.g. *without* going through structural changes for any reason. The case is trivial when considering the *same* system without acquiring any new properties. It, however, may be interesting when considering multiple systems or sequences of systems. Equivalence in this case may refer to equivalent structural dynamics or coherences. It is also possible to consider equivalence within systems going through evolutionary phases, such as, for instance, growing or aging. This issue relates to topics such as the possibility to *transfer cognitive systems*, then operating as *joint* cognitive systems (Thraen, Bair, Mullin, & Weir, 2012; Woods & Hollnagel, 2006); in linguistics the equivalence among formal languages or among non-formal languages (Dreyer & Marcu, 2012; Jumarie, 1981, 1982; Kapetanios & Sugumaran, 2008); or in knowledge transfer (Holyoak & Morrison, 2013).
5. *Maintaining transience*. This relates to the *same way* of changing of a system when, for instance, it is acquiring or losing or changing its properties, coherence or structures. The same transience can occur in different situations. Trivial cases relate to modalities such as linear, exponential or periodic. Non-trivial cases occur where *uniqueness is repeated*, that is, when evolutionary systems acquire unique configurations or properties in different possible ways. The issues considered in the preceding point, related to cognitive systems, languages and knowledge, equally concern us here, considering, for instance, *processes of generation of singularities*, through fluctuations or noise. These are categories of logical and physical processes able to generate uniqueness. A typical example is given by chaotic systems. Can this transience be considered autonomously and various versions of it be applied to systems in general? Transience should become an object of study as in physics when considering classical and non-classical aspects of transitions since it is the *place* where uniqueness is generated as, for example, in the dynamics between quantum and classical stages (see, for a review, Kapral, 2006).

The above comments about *system identity* are related to the original classical approach considering a *theory of the general system* (singular) introduced by von Bertalanffy (Von Bertalanffy, 1968, 1975) and as also presented by Boulding (Boulding, 1985; Mesarovic, 1972; Rapoport, 1968).

With regard to the term *general*, the subject has been previously discussed (Minati & Pessa, 2006, p. 4):

> ‘A collection of his essays was published in 1975, three years after his death. This collection (Von Bertalanffy, 1975) included forewords written by Maria Bertalanffy (his wife) and Ervin Laszlo. The latter added the following considerations about the term

> *General Systems Theory*: 'The original concept that is usually assumed to be expressed in the English term *General Systems Theory* was Allgemeine Systemtheorie (or Lehre). Now – Theorie- or Lehre, just as Wissenschaft, has a much broader meaning in German than the closest English words *theory* and *science*.'
>
> The word *Wissenschaft* refers to any organized body of knowledge. The German word *Theorie* applies to any systematically presented set of concepts. They may be philosophical, empirical, axiomatic, etc. Von Bertalanffy's reference to *Allgemeine Systemtheorie* should be interpreted by understanding a new perspective, a new way of *doing science* more than a proposal of a *General Systems Theory* in the dominion of science, i.e. a *Theory of General Systems*'.

We may consider that von Bertalanffy and the early system scientists had in mind a kind of idealistic, ontological view concerning the properties of *existence* of systems in general. Von Bertalanffy wrote:

'... we postulate a new discipline called *General System Theory*. Its subject matter is the formulation and derivation of those principles which are valid for 'systems' in general'. (Von Bertalanffy, 1968, p. 32).

It is a line of research looking for such general principles, such as that relating to identity listed above, that is still acceptable.

This understanding is not reducible to approaches such as considering the general validity of the *same* models by changing the meanings of variables or by them having the *same* model properties. This is the *local* view of interdisciplinarity dealing with families of problems and approaches mutually translatable and reformulated one into the other.

The ontological approach may be intended as the search for *fundamental systems*, if not *the* system, to be then considered in different non-equivalent *actualisations* into *real* systems. Is such an approach still viable? *Can we look for* ***the*** *general network?*

Such an approach may be considered appropriate for collective systems with structural dynamics and where coherence(s) and related properties are the *invariants*.

3.6 Equivalence/Non-equivalence

The problem of *equivalence* can be considered from different points of view (within the domain of mathematics see, for instance, Olver, 2009). It consists, generally speaking, in finding the criteria enabling to consider as *equivalent*, for instance, actions, approaches, configurations, drugs, inputs, levels of descriptions, models, processes, outputs, properties, states and systems.

A trivial case occurs when it is possible to *substitute* one *issue* with another, equivalent because they have the *same* property, such as effect, meaning or role. They are assumed to be *interchangeable*, because one can substitute, replace, the other. Various kinds or degrees of substitutability are possible: total, partial or temporary. The degrees determine the difference between equivalence and equality.

Another case occurs when considering processes. A viable approach may consist of considering them as being equivalent when they provide outputs possessing the *same* properties. Furthermore, processes may be considered as equivalent when the processing of a specific input produces an output equivalent to various possible degrees: total, partial or temporary equality.

Another case occurs when dealing with *equifinal* systems . The topic related to finality has been discussed over a long period in philosophy and science. The subject has been considered by the fathers of systemics, such as Kenneth Boulding who stated (Boulding, 1956, p. 204]):

> The fifth level might be called the genetic-societal level; it is typified by the *plant*, and it dominates the empirical world of the botanist. The outstanding characteristics of these systems are first, a division of labour among cells to form a cell-society with differentiated and mutually dependent parts (roots, leaves, seeds, etc.), and second, a sharp differentiation between the genotype and the phenotype, associated with the phenomenon of equifinal or "blueprinted" growth. At this level there are no highly specialized sense organs and information receptors are diffuse and incapable of much throughput of information – it is doubtful whether a tree can distinguish much more than light from dark, long days from short days, cold from hot.

The subject was also present in von Bertalanffy's founding book (Von Bertalanffy, 1968). von Bertalanffy wrote (von Bertalanffy, 1950, p. 25):

> A profound difference between most inanimate and living systems can be expressed by the concept of *equifinality*. In most physical systems, the final state is determined by the initial conditions. Take, for instance, the motion in a planetary system where the positions at a time t are determined by those of a time t_0, or a chemical equilibrium where the final concentrations depend on the initial ones. If there is a change in either the initial conditions or the process, the final state is changed. Vital phenomena show a different behaviour. Here, to a wide extent, the final state may be reached from different initial conditions and in different ways. Such behaviour we call equifinal.

von Bertalanffy discussed three kinds of finalities, respectively associated with the following situations:

- The dynamical evolution of a system reaches asymptotically over time a stationary state.
- The dynamical evolution never reaches this state.
- The dynamical evolution is characterized by periodic oscillations.

In the first case, the variations in the values of the state variables may be expressed as a function of their distance from the stationary state. System changes may be described as if they were to depend upon a future final state. Such a circumstance could be related to a teleological view expressed, for instance, by *minimum or maximum principles* (of a local or global nature). von Bertalanffy noticed how this form of description is nothing but a *different expression of causality*: the final state corresponds simply to a condition of extreme in the differential equations ruling the dynamical evolution. We could, however, view such a condition also as describing a particular kind of finality, that is, the so-called *equifinality*. The latter characterizes those dynamical systems which are able to reach the same final state independently from their initial conditions or input .

On the contrary, there are situations where the system displays very high sensitivity to initial conditions, as for *chaotic systems*.

An interesting situation occurs when the behaviour of systems occurs in situations where the next state to be adopted is one of several different ones all *equivalent* for the given system. For instance, the direction of rotation of Bènard rolls. The *decision* is 'made' by noise and fluctuations. Let us now consider the case for models. In order to assess their equivalence/non-equivalence, there are different criteria:

- The level of description adopted and possible correspondences.
- The *transformability* of one model into another.
- The possible *transformability* of representations modelled, one into the other.

Examples of general incompatibility, i.e. non-equivalence, are given when considering quantum and non-quantum models, Turing-machines and quantum computing devices, thermodynamic and electromagnetic models.

The practice of DYSAM (Minati & Pessa, 2006, pp. 64–75 and Appendix 1) can be used by considering both equivalent and non-equivalent models since the focus is on the changing of models and the properties of their sequences, such as coherence.

The DYSAM approach considers systems, in real time or not, in parallel, synchronously or sequentially, depending on the kind of process to be dealt with, the dynamic identification of levels of representation of the case to be modelled which allow *multi-model*-based processing. This is typical for processes of emergence where the complex system acquires coherent sequences of new properties and the observer must use n different levels of description corresponding to n different models.

From an ontological viewpoint, equivalence/non-equivalence could be considered as the ***ontological essence*** *of the relationships among identities.* ***We recall the relationship between*** *equivalence* ***and*** *non-completeness,* ***where the latter is the space for multiple equivalences*** .

We conclude this section by mentioning the interest in studying the possible equivalence/non-equivalence between coherences modelled, for instance, using network models or meta-structures as introduced below.

3.7 Acting on the Dynamics of Emergence

The subject of this section concerns examples of prospective conceptual representations, models and approaches, methodologies and tools, to induce, maintain, modify, combine and eventually *deactivate* the dynamics of processes of emergence.

Examples of suitable interventions are given by acting *macroscopically* on the resources available such as energy, by setting obstacles and *distortions* in the interactions among agents and by changing general environmental conditions.

This is the subject of the current science of complexity. Among the various possible research approaches related to the *observability* of complex systems (Yang-Yu Liua, Slotine, & Barabási, 2013), below there are some examples of research topics for tools suitable for acting, for instance, upon:

1. *Acquisition, change and the use of constraints or degrees of freedom*. The concept of degree of freedom in mathematics relates to the number of independent quantities necessary to express the values of all the variables describing a system. For instance, a point moving without constraints in *3D* space has three degrees of freedom because three coordinates are necessary to specify its position. Eventual constraints *reduce* the number of degrees of freedom, for instance, when considering a *simple pendulum* having only one degree of freedom since its angle of inclination is specified by a single number. *In this book we consider the concept of degree of freedom in a more generic way as used in daily language,* i.e. *intended as a constraint on values adopted by single independent variables, such as geometrical or physical*. Following the discussion in Sect. 3.2, we may also consider values of max and min and the usage of the *between*. For instance, we may consider that the value of a variable adopted to respect such constraints may *use* a well-defined percentage of the degree of freedom, i.e. *[Dmax - Dmin]* allowing the researcher to detect that such usage has properties such as always being close to the max or min, or is periodic, random or given by distributions having suitable properties. Moreover, the degrees of freedom may be variable, multiple and quantitatively related.
2. *Environmental properties*. As we stated above, the *separation* of a system from its environment is a matter of simplification, whereas research focuses upon open, non-complete representations, layers (Sect. 2.7), environment (Sect. 2.3) and the *between* (Sect. 1.3.8 and 7.1), where systems and environment may be represented one as a function of the other, as for an observer and observed.
3. *Ways of interacting*. Ways of interacting are covered in Sect. 3.8.2. They may be *fixed*, based on the exchange of matter-energy, *context sensitive*, depending on environmental properties, or *evolutionary,* based on learning for autonomous systems provided with sufficiently complex cognitive systems. They may be multiple and apply in different ways.
4. *Available states*. The system may have available a predefined set of possible states to occupy. Interest may focus, for instance, on two different *modalities*. In the case of *multistability*, we consider both states and attractors when stability is given by the restoring or changing of stability following perturbation of the system. The other states are the *metastable equilibrium states* discussed in Chap. 2 and Box 3.3. The states available tell us something about the degrees of freedom of the system, but without saying anything about the *modalities* for reaching them, moving among them, their possible combinations, or temporal constraints.

5. *Coherences*. More emphasis is placed on coherence rather than, for instance, on equilibrium. Dissipative systems, for example, can maintain stationary states *far from thermodynamic equilibrium* through the transfer of entropy to the environment through the dissipation of matter, as do whirlpools (the same kinds of structure exist in atmospheric phenomena such as hurricanes) and living structures dissipating material flows such as air, water, food and, in certain cases, light to remain far from thermodynamic equilibrium, i.e. thermodynamic death. The process of dissipation allows emergence and the preservation of ordered structures and properties. However, there are processes of emergence which do not require dissipation to establish coherence(s), as is the case for collective behaviours in general. The focus is on the search for *coherence* (Sects. 2.1, 4.7, and 7.2.1), rather than equilibrium, and coherence(s) among eventual multiple dynamic equilibriums, and levels of coherence(s) as for super-coherence discussed in Sect. 3.4. Interventions are then made on processes of dissipation and the establishment of coherence(s) by acting, for instance, on networks, scale invariance, power laws or meta-structural properties introduced later.
6. *Emergent properties*. In the following chapters, particularly Chap. 5, we present new theoretical frameworks to be adopted when studying emergence and representations of its dynamics using strategies without *explicit prescribability*, no- or low-intensive invasiveness, and low energy in order to *induce* processes of emergence without *regulation* since *explicit*, *intensive* interventions are *incompatible*, non-processable by complex emergent systems, as discussed in Sects. 1.3, 4.2.7, and 5.6. Examples include *weak* (with reference to original values) changes in prices, taxations and exchange rates in economy and biochemical equilibria in living systems. Examples of radical invasive interventions are given by possible *necessary substitutions* then continuing with processes such as transplants or social rejection. Then the approach based on using Perturbative Collective Behaviour (PCB) to influence collective behaviour (see Sect. 3.8.4.5) will be considered.

3.8 Methods and Approaches to Model and Act upon the Dynamics of Emergence: Research on Meta-Structures

As we have previously showed, there are different possible methods and approaches to act upon the dynamics of emergence. Their list includes:

- The science of networks (see, for instance, Barabási, 2002; Baker, 2013; Lewis, 2009; Valente, 2012), discussed in Chap. 8.
- The quantum theories (see, for instance, Carati & Galgani, 2001; Clifton & Halvorson, 2001; Del Giudice, Doglia, Milani, & Vitiello, 1985; Pessa, 1998; Sewell, 1986), discussed in Chap. 6.

- The study of meta-structures (Minati & Licata, 2012; Minati, Licata, & Pessa, 2013; Pessa, 2012), presented immediately below.

The meta-structures are to be intended as structures whose elements are in turn structures (Pessa, 2012). In biology, for instance, a meta-structure may be an organism, consisting of structured arrays of cells, each of which is a complex structure composed of a large number of macromolecules. Another example is socio-economical and cognitive phenomena where the hierarchical networks of complex relationships offer examples of meta-structures, often even more complex than biological ones. In physics, meta-structures involve interactions between different structured and coherent domains, as in liquids or magnetic materials.

From the point of view of the relationships between components of meta-structures, it is possible to consider different *types* of meta-structures, for instance:

1. Those in which individual components can simultaneously belong to different structures, which are not related through their hierarchical relationships (*horizontal* meta-structures).
2. Those in which individual components can simultaneously belong to different structures which do have hierarchical relationships between them (*vertical* meta-structures).

Examples of horizontal meta-structures include individuals who have relationships both with their colleagues and with those who share the same hobby.

Examples of vertical meta-structures include individuals who have relationships with both colleagues and executives of the company in which they work, supermolecules and multiple networks (Nicosia, Bianconi, Latora, & Barthelemy, 2013).

Vertical meta-structures are very common in the world of physics and biology, and therefore their study is important.

The interest for a theory of meta-structures arose after the birth of so-called *mesoscopic physics* (for introductory reviews see Imry, 1986; Altshuler, Lee, & Webb, 1991; Katsoulakis, Plecháč, & Tsagkarogiannis, 2005).

As introduced above in Sect. 2.4, mesoscopic physics deals with the domain of length scales in between the microscopic and macroscopic, where unexpected phenomena can occur.

A number of different descriptions of meta-structures and their dynamics have been introduced in many different domains, such as *metalattices* (Han & Crespi, 2001), *multilevel neural networks* (Breakspear & Stam, 2005) and *agent systems* (Johnson & Iravani, 2007). However, we are still lacking models of emergence of meta-structures from situations in which they were initially absent. When introducing the approach considered below, the concept of structure will be taken as the *structure of interaction* between entities.

Multiple Systems (Minati & Pessa, 2006) are considered to be based upon the occurrence of multiple interactions, having possibly different durations and starting time, involving the same entities which may belong (simultaneously or successively) to different systems (see Sect. 4.1 and Fig. 3.1 corresponding to specific

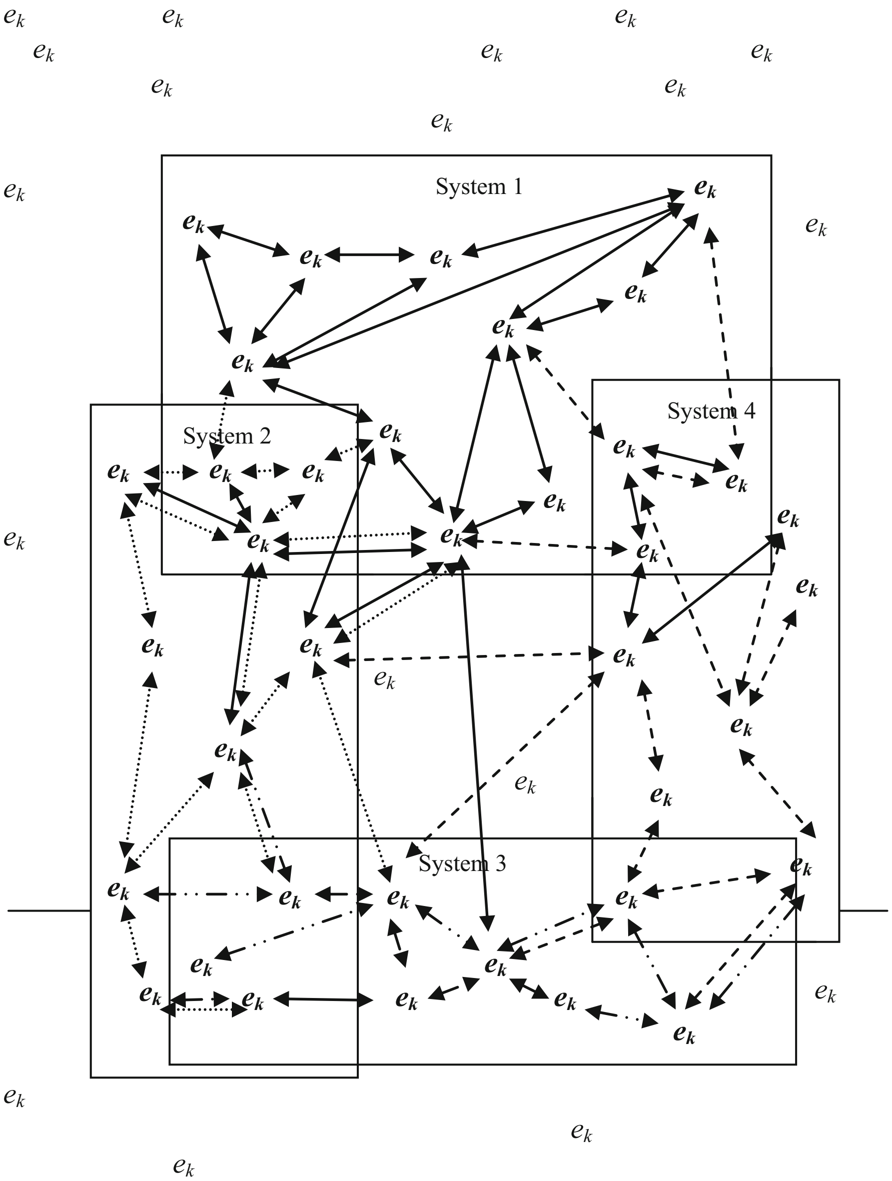

Fig. 3.1 Multiple interactions

interaction). An example of multiple interactions is given, for instance, by the rules listed in Table 3.1.

In this case it is possible to consider a meta-structure as being given by a *set of structures* of the different systems, i.e. multiple interactions, establishing a given

Multiple System together with possible relationships between the component systems. Multiple structures may also relate to multiple networks and sequences of adjacent units in lattices.

It is possible to consider a simplified case by taking a Multiple System established by two systems with binary and classifiable relationships (Pessa, 2012, p. 115) as:

- *Fully hierarchical*, in which the elements of one of the two systems are a proper subset of the set of elements of the other system and, moreover, the larger system influences the average dynamical behaviour of the smaller one (at this stage a detailed description of this influence is not necessary).
- *Partially hierarchical*, where, while almost all the above conditions are satisfied, the sets of elements of the two systems have only a partial overlap.
- *Non-hierarchical*, where the sets of elements of the two systems are totally disjointed.

However, three main characteristics seem to be indispensable to give rise to hierarchical structures (Pessa, 2006, 2012, p. 120), which are:

- *Locally causal* interactions between system elements.
- *Long-range* correlations between those elements.
- *Local inhomogeneities* in the activities of those elements.

3.8.1 The Meta-Structure Research Project

Collective behaviour can be distinguished from collective interaction, such as Brownian notion (Nelson, 1967), since the former adopts emergent properties due to coherence(s) as correlation(s). This may work as a criterion, as may other approaches which can be distinguished by considering the presence or absence of properties such as scale invariance or power laws.

In the meta-structure research project (Minati, 2016a, 2016b; Minati et al., 2013; Minati & Licata, 2012, 2013, 2015; Pessa, 2012), a meta-structure consists of sets of multiple structures of interaction, i.e. more than one, and their properties which may simultaneously be *combined*, for instance, linearly or non-linearly, or involve their *interference* as in Sect. 3.8.2.

Thus, the research considers as meta-structural *real interactions*, i.e. combined single rules of interaction or through interference among them, occurring within populations of entities establishing collective behaviours. A simplified case is given by *bipolar* meta-structures, i.e. when real interactions, occurring for specific couples of entities per instant, involves the same elements belonging to other couples interacting in turn in different ways with different entities as represented in Fig. 3.1.

It should be stressed that this understanding is conceptually different from approaches based on considering *effects* of interactions to which, for instance, statistical methods or macroscopic approaches such as looking for indices (see, for instance, Stephen et al., 2011) are applied. Macroscopic properties may also be considered as having a meta-structural nature since they *summarise* as *global indices*, e.g. temperature and pressure, the effects of multiple structures of interactions. However, they are of limited interest here since they miss all microscopic references and, because of that, *they allow very limited actions on the process itself.*

In the project, there is the assumption that a well-defined and stable, however, contextually parameterized, *library* of structures of interaction is available to the entities involved during the process.

The typical process to study is collective behaviour, natural or simulated, established by a number of interacting *agents*, from here onwards referred to with the more general term *entity*, where all microscopic information is available and to which non-macroscopic approaches are applied. Microscopic data are considered to be available from suitable processes, such as (1) ad hoc simulations (Minati, 2016a, 2016b) where the software simulates a flock-like collective behaviour based on the classic Reynolds approach (Reynolds, 1987); (2) *stereometric digital photogrammetry* data related to real flocks (Cavagna et al., 2010) where authors detected scale-invariance (3) ad hoc electronic devices of coupled oscillators generating emergence (Minati, 2014; Minati, 2015); and processes with available phenomenological data such as social, economical and financial from so-called *big data*, very large data sets where analysers apply techniques of data mining to find, for instance, regularities, cross-correlations, frequency, performance and statistical evaluations (Davenport, 2014; Franks, 2012).

The approach considered here was inspired by von Bertalanffy with the concepts of *dynamic morphology* (Von Bertalanffy, 1975, p. 47) and by considering that ‘Life is a dynamic equilibrium in a polyphasic system’ (Von Bertalanffy, 1968, p. 123).

Meta-structures are an attempt to model structural dynamics and its eventual coherence as introduced above.

Moreover, the coherence of emergent collective behaviours cannot be suitably modelled by considering *only* rules of interactions. This latter approach conceptually corresponds to considering *networked sequences of stimulus-reaction* when dealing with agents.

The point missed regards the *usages of rules of interactions*. In the case of living agents, it is important to consider their cognitive systems which are responsible for using the rules of interactions and for processing information which is not reducible to networked sequences of stimulus-reaction being, for instance, context-dependent.

However, evidence that biological agents establishing emergent collective behaviours do so by using the *same cognitive* system is given by the fact that they are all of the *same* type, i.e. of the same species or same genus.

The sharing of the same cognitive system using the *same* cognitive model may be assumed as possibly being a *necessary* but not *sufficient* condition for establishing collective behaviours among agents.

Different usages of rules of interactions may be assumed to occur for non-living agents, i.e. without natural cognitive systems. Analytical intractability combines with generic equivalences (considered hereafter as interchangeability) and mesoscopic approaches continuously trading between the microscopic and macroscopic.

Several possibly necessary conditions may be considered, such as assuming the conceptual interchangeability of agents playing the same roles at different times and allowing *ergodicity,* in this case *responsible for coherence* (see for a discussion Minati & Pessa, 2006, pp. 104–110).

Such conditions, i.e. possession of ergodic interchangeability or meta-structural properties, also apply to collective behaviours established by *living systems provided with no cognitive systems* such as amoeba, bacterial colonies, cells and macromolecules and by *non-living systems* such as electrical systems, mobile phones or Internet networks, morphological properties of cities and traffic signalling systems.

In the latter cases, possible ergodic-like interchangeability or meta-structural usage of rules is not due to *decisions* taken by cognitive systems through cognitive models but is rather a way to *model the coherence of collective behaviours.*

Another possibly necessary condition considered here is the coherent usage of rules of interaction represented, for instance, by meta-structural properties as introduced later (see Sect. 3.8.4) and meta-structural regimes introduced in Sects. 3.2.4 and 3.8.3. Discussed below is the approach based on considering the properties of mesoscopic variables, as in Sect. 3.2.4, in order to represent, at a suitable level, multiple interactions, as in Sect. 3.8.3.

However, examples of other approaches where *meta-structural properties are not mesoscopically represented* consider, for instance, scale invariance (Cavagna et al., 2010; Hemelrijk & Hildenbrandt, 2015), topological distance (Balle Ballarini, et al., 2008), maximum entropy (Cavagna et al., 2013), network properties (see Chap. 8 and Barabási, 2002; Lewis, 2009), the global consistency of an adjacency matrix in lattices (Tasdighian et al., 2014), topological constraints and scale-free graphs for Self-Organizing Networks (Licata & Lella, 2007).

As will be seen below, *meta-structural properties are all properties of multiple structural dynamics as for Multiple Systems. This understanding is based on switching*

- *From* ***a priori*** *approaches based on adopting known fixed general analytical rules of interaction.*
- *To* ***a posteriori*** *approaches, different from* ***statistical ones at the microscopic level*** *while looking, for instance, for collective mesoscopic properties,* i.e. *meta-structural properties, assumed to represent analytically* ***incognizable*** *rules of interaction.*

Multiple Systems are always metastable *too* (Kelso & Tognoli, 2006) presenting criticalities and invariance of scale (Chialvo, 2010). Multi-structural dynamics, a possible conceptual example of which is shown in Table 3.1, is analytically, explicitly *intractable*. Classical approaches are of a statistical nature. However, our interest is in finding possible alternative representations, such as networks in order to consider coherence, levels of coherence, quasi-coherences and multiple coherences possibly superimposed. In cases such as those considered in Table 3.1 related to flock-like collective behaviours, possibly generalizable when rules are analytically represented, structural dynamics occur, for instance, as variations in altitude, direction, distance or velocity.

Properties of their dynamical parametrical combinations and interferences should be considered as ***clues*** *and* ***representations*** *of aspects of coherence. Such properties are intended in the following as being represented by meta-structural properties of suitable mesoscopic variables and clusterisations* ***transversally*** *intercepting such structural dynamics* as in Sects. 3.8.2, 3.8.3 and 3.8.4.

Meta-structural representations and understanding of complex behaviours are introduced to allow strategies of intervention in order to modify complex behaviours and their properties, such as for systems of cells, traffic, markets and crowds.

The general purposes of considering meta-structural properties is to contribute towards a post-GOFS developing approaches and models which can act upon complex systems by participating *in their change rather than regulating, prescribing or deciding it.*

3.8.2 Interactions

Consider a hypothetical library of *rules of interactions such as* $Rint_{j:1-13}$ as in Table 3.1. This table shows an example of multiple rules of interactions for flock-like collective behaviours where we consider a population of $k > 3$ interacting agents, with k fixed as a simplified case for the entire observational time T. This example considers the simplistic case where interactions may be explicitly represented by symbolic rules, considered to *completely* represent the phenomenon.

More realistically, ***resulting interactions*** *will be due to any combinations, interference or timing since the time scalarity might not simply coincide with the beginning or end of* ***any*** *interaction.*

Resulting interactions $Res\text{-}int_j$[6] applied to agents e_k per instant will be due to possible *partial* (because of different durations) linear or non-linear combinations of $Rint_j$ as well from interferences among $Rint_j$, i.e. as a function of various $Rint_j$ as will f_i introduced below.

Example of linear combination is given by adding the effects of rules.

Example of non-linear combination is given by computing the resultant effects of rules such as $(\text{effect of } Rint_1 + \text{effect of } Rint_j)^2$.

Example of a generic interference f is given by

$$Res - \text{int} = f(Rint_{1,}, Rint_2, Rint_6),$$

---

[6] Resulting interaction $Res\text{-}int_i$ may be a variable number where i is the number of resulting interactions per instant.

Table 3.2 Original rules of interaction from Table 3.1 considered for the following example

$Rint_1$	Consists of varying	Speed	Depending on	Speed or average speed of closest agents
$Rint_2$	Consists of varying	Speed	Depending on	Speed of agent(s) having same direction
$Rint_6$	Consists of varying	Direction	Depending on	Direction of agent(s) having same speed

Table 3.3 Resulting rule of interaction *Res-int* following interference *f* among $Rint_1$,$Rint_2$, $Rint_6$

Res-int	Consists of varying	Speed and	Depending on	Speed of closest agent having same direction [1]and
		Direction		Direction of closest agent having same speed [2]

[1] Added to $Rint_2$ the required *closest agent*. *Average speed of closest agents* in $Rint_1$ is not considered

[2] Added to $Rint_6$ the required *closest agent*

where from original rules of interaction (Table 3.2) following interference *f* (see notes 1 and 2 in Table 3.3) one obtains the resulting rule of interaction *Res-int* (Table 3.3).

Examples of more complex cases occur when, for instance:

$$\begin{cases} Res - int_1 = f_1(Rint_2,\ Rint_6) \\ \dots \\ Res - int_5 = f_5(Res - int_1,\ Rint_5,\ Rint_{10}). \end{cases}$$

The e_k agents may interact, for instance, in pairs by using any linear or non-linear combination of the interactions $Rint_j$ and/or given by any f_i of $Rint_{J:1-13}$:

$$Res - \mathrm{int}_i = f_i(Rint_1, Rint_2, \dots, Rint_{13}).$$

In the simplest cases, f_i will act on parameters. Resulting interactions *Res-int*$_j$ will, of course, be time dependent in correspondence with $f_i(t)$. Furthermore agents e_k may interact in any possible combinations per instant.

Furthermore, interactions could be represented by non-symbolic rules and in a non-comprehensive manner, such as probabilistically or fuzzy.

Position, speed, direction and altitude of a specific agent e_k at time t_{i+1} is *considered calculated* by the model, using one or more combinations of, or interference with, the *13* rules and using the values possessed by the agent (s) considered at time t_i.

Computation of the new state at the time t_{i+1} by applying the rules above gives specific, positive or negative, incremental changes regarding the state, as for speed and/or altitude and/or direction.

The elementary cases listed in Table 3.1 should be considered as *parameterized* by considering, for instance, context-sensitive parameterisations.

Furthermore, incremental changes should be computed by considering the need to respect ranges allowing *continuity* given, for instance, by maximum discontinuities, levels and degrees of inhomogeneity within the collective behaviour and *compactness* allowing consistency.

Computation of the new state, depending on interaction rules, is also carried out by *choosing* from among several possible equivalent incremental changes. For instance, in the classical Reynolds model (Reynolds, 1987), the choice is made in such a way as to ensure:

- Alignment: agents must compute the interaction by pointing toward the average direction of the local or adjacent agents,
- Cohesion: agents must compute the interaction by pointing toward the average position of the local or adjacent agents, *being able to appropriately vary speed, direction and altitude*.

Different and more complex options are, of course, possible for rules of interactions, computing and selection from among equivalent possible incremental changes.

An example of interactions occurring through multiple rules of interaction is considered in Table 3.1 and graphically represented in Fig. 3.1 (Minati & Licata, 2012, p. 292).

Interactions may occur between *properties* of behaviours of agents e_k such as topological ones, properties of systems of rules of interactions, multiple ones, or those having different dynamics possibly represented by systems of macroscopic indices, such as volume.

With reference to the ***temporal granularity*** *for both simulations and detection of real collective phenomena, it is important to cope with the fact that interactions are assumed to occur with* ***dynamically changing different starting times and durations****, being values of mesoscopic variables representing those phenomena.*

3.8.3 Mesoscopic Variables

The *microscopic* level of description is that corresponding to descriptions of properties of entities considered as *ultimate*, i.e. when they can no longer be suitably further decomposed. Examples are descriptions in terms of molecular variables, such as position or speed of pollen grains or water molecules.

The *macroscopic* level of description corresponds to descriptions of properties of entities whose composition is not of interest. For instance, this level could be adopted for describing the motion of a ball or of a fluid, by considering only the *resultant* effects of properties of a large number of microscopic variables.

The *mesoscopic* level is between these two. At this level reduced variables are considered *as* at the macroscopic level, but without completely ignoring the degrees of freedom present at the microscopic level, i.e. when dealing with the *middle way* (Laughlin et al., 2000). See Sect. 2.4.

For instance, by considering the system established by road traffic circulation, a mesoscopic variable is given by considering cars that *cannot accelerate*. With this selection, both cars can be considered as stationary, in line with constant speed or decelerating when, for instance, approaching an obstacle. Another example considers the quantity of people on the stairs of a building. Here, people are considered as walking up or down or standing on the stairs.

Meaningful variables at the mesoscopic level are known, in the science of complexity, as *order parameters* introduced with synergetics (Haken, 1987, 1988). When complex systems undergo phase transitions, a special type of ordering occurs at the microscopic level. Instead of addressing *each* of a very large number of atoms of a complex system, Haken showed, mathematically, that it is possible to address their fundamental *modes* by means of *order parameters*. The very important mathematical result obtained using this approach consists of drastically lowering the number of degrees of freedom to only a few parameters. Haken also showed how *order parameters* guide complex processes in self-organizing systems.

When an *order parameter* guides a process, it is said to *slave* the other parameters, and this slaving principle is the key to understanding self-organizing systems. Complex systems organize and generate themselves under far-from-equilibrium conditions:

> *In general just a few collective modes become unstable and serve as 'order parameters' which describe the macroscopic pattern. At the same time the macroscopic variables, i.e. the order parameters, govern the behavior of the microscopic parts by the 'slaving principle'. In this way, the occurrence of order parameters and their ability to enslave allows the system to find its own structure.* (Graham & Haken, 1969, p. 13)

'*In general, the behavior of the total system is governed by only a few order parameters that prescribe the newly evolving order of the system*' (Haken, 1987, p. 425). Mesoscopic order parameters in the science of complexity have the purpose of extending to systems far from thermal equilibrium concepts used for systems in equilibrium. It is possible to obtain an effective mesoscopic description by considering a very limited number of order parameters: only a few may manifest instability and be taken as significant in transitions. Others may be ignored either because of their very fast dynamics or because of their essentially stability.

A subsequent step is then taken using the so-called *collective variables* widely used in theoretical physics, as mesoscopic ones '...where it allows a shift from a representation of a system based, for example, upon a set of isolated atoms, mutually interacting in a very complicated way, to a new collective representation (physically equivalent to the previous one) based on isolated atoms interacting in a simple way only with suitable collective excitations (so-called *quasi-particles*)'. (Minati & Pessa, 2006, pp. 236–237).

As introduced above, mesoscopic variables are essentially suitable clusterisations (Minati, 2016a, 2016b).

We are interested in considering mesoscopic variables ***representing structural dynamics*** *occurring through combinations, interference and various temporal durations as shown in the examples in* Table 3.1 *and Fig.* 3.1 *where the collective interactions are coherent. Coherence of collective interactions – meta-structures – is studied here as represented by properties of mesoscopic variables.*

This approach uses mesoscopic variables whose values *indirectly* represent the *effects* on entities of multiple interactions in *3D* as listed above and which are suitable for simulations.

Examples of mesoscopic variables, clusterisations, suitable for representing multiple simultaneous, different processes of structural dynamics occurring where each agent *may select*, for any reason such as perturbations, energetic reasons, boundary conditions or possibly cognitive reasons when provided with a cognitive system, to use any combinations of the available rules (see Sects. 3.2.4 and 3.8.1) are presented below. Consider a situation, typically a simulation, where the number k of interacting agents e_k (such as oscillators or logistic maps) is finite and fixed for the entire finite observational time T. This approach is a conceptual extension of the simpler case when dealing with populations of interacting oscillators which consider variations in phases or frequency. In the following, we consider the case of flock-like collective behaviours as introduced above in Sect. 3.8.2.

3.8.3.1 Correlation and Synchronization *of Single Agents*

Mesoscopic variables are considered here as synchronized, multiply synchronized or correlated clusters of *agents*. Processes of synchronization and correlations were considered in Sects. 3.2 and 3.2.3.

A simplified view consists of considering an ***optimized temporal granularity*** *where all synchronisations and correlations start and end within the* ***same*** *temporal interval*.

We recall the non-transitivity of the *property of being positively correlated* as demonstrated by Langford (Langford, Schwertman, & Owens, 2001).

Another form of correlation occurs when such explicit data may be represented as *networked* (Lewis, 2009).

Mesoscopic variables are given in this case by clusters of networked synchronized or correlated agents, corresponding parametrical values such as phases, correlation values, ergodic parameters or, for instance, by numbers of agents, their spatial distributions, data on their possible multiple belonging or density when considering the space identified by the cluster.

3.8.3.2 Communities and Clusters

Several approaches are presented below for considering aggregations *among agents* as mesoscopic variables when considering their general *similarity in behaviour*. The problem may be approached in different ways such as looking for community detection in complex networks (Kaneko, 1990; Ovelgönne & Geyer-Schulz, 2013; Shalizi, Camperi, & Klinkner, 2006; Sobolevsky, Campari, Belyi, & Ratti, 2014), functional clustering (Filisetti, Villani, Roli, Fiorucci, & Serra, 2015; Tononi, McIntosh, Russel, & Edelman, 1998) or large aggregates of data by adopting approaches such as data clustering (Aggarwal & Reddy, 2013; Gan, 2011), data matching (Christen, 2014) and data mining (Gorunescu, 2011).

There are also the usual well-known statistical approaches (Shevlyakov & Oja, 2016):

- Multivariate Data Analysis (MDA) and Cluster Analysis, to identify classes (Everitt & Landau, 2011; Hair & Black, 2013).
- Pearson Product Moment Correlation Coefficient (PPMCC), to measure possible linear dependence between two or more attributes (Rupp & Walk, 2010).
- Principal Component Analysis (PCA) to identify non-explicit rhythms and deterministic structures (Jolliffe, 2002).
- Principal Components (PCs) to generate low-dimensional descriptions (Vidal, Ma, & Sastry, 2016).
- Recurrence Plot Analysis (RPA), see (Webber, Ioana, & Marwan, 2016).
- Recurrence Quantification Analysis (RQA) to quantify the number and duration of recurrences as trajectories in phase space (Webber & Marwan, 2016).
- Time-Series Analysis (Box et al., 2015).

Mesoscopic variables are given in this case by clusters of agents and, for instance, their number of agents, spatial distributions, possible multiple belonging and density when considering the space identified by the cluster.

3.8.3.3 Sameness

Similarities are considered as suitably represented by clusters of agents grouped by closely similar values of a specific variable considered *as if* respecting *virtual* thresholds computed ex-post, i.e. after clusterization.

It is possible to consider clusters of agents at a given instant having the same or different *thresholds* per type of cluster allowing to assume two values adopted by a variable be considered as equal when less than the threshold value:

1. The *maximum* distance(s).
2. The *minimum* distance(s).
3. The *same* distance(s) from the nearest neighbour.
4. The *same* speed(s).
5. The *same* direction(s).
6. The *same* altitude(s).
7. The *same* topological position, such as at a *boundary*. Generic agents e_k are considered to be at a boundary at instant t_i by considering properties of their position (x_k, y_k, z_k). Agents are at the boundary when their geometrical coordinates respect at least one of the following conditions *max or min*(x_k), *max or min* (y_k), *max or min*(z_k) or any of their possible combinations.

Thresholds can be statistically *derived* when considering the ordered sets of values adopted by specific variables per instant in order to identify the more significant ones. By using suitable statistical methods, it is possible to identify *statistical extremes*, i.e. *aggregates* of agents possessing the four properties considered above (distance, speed, direction and position), allowing computation of the resulting corresponding thresholds to be considered for subsequent modelling purposes.

Examples of techniques used include top-down and bottom-up clustering, the so-called *Self-Organizing Maps* (SOM) and in particular processes of clustering techniques, *K-Means*, *K-median*, and *K-medoids* (Everitt, Landau, Leese, & Stahl, 2011; Mirkin, 2012).

In cases 1, 2 and 7 listed above, we have a single corresponding set of values per instant.

In cases 3–6 we may have more than one set of values at any instant when ordered elements are clusterized in classes such as:

- $n\text{-}dis_1$ number of agents e_k at same distance $dist_1$, $n\text{-}dis_2$ number of agents e_k at same distance $dist_2$, etc.
- $n\text{-}spe_1$ number of agents e_k at same speed $speed_1$, $n\text{-}spe_2$ number of agents e_k at same speed $speed_2$, etc.
- $n\text{-}dir_1$ number of agents e_k having same direction dir_1, $n\text{-}dir\ _2$ number of agents e_k having same direction dir_2, etc.
- $n\text{-}alt_1$ number of agents e_k at same altitude alt_1, n_2 number of agents e_k at same altitude $d\text{-}alt_2$, etc.

It is thus possible to consider vectors consisting of a) values of the property considered, b) the number of agents belonging to the cluster and c) the values of the thresholds computed *ex-post* as minimum and maximum values.

For instance, in the case of distance when n_1 agents e_k are at distance d_1, n_2 are at distance d_2, etc. It is then possible to consider a vector $Vd(t_i)$ given by triple scalar values $Vd(t_i) = [(d, q, t)_1, (d, q, t)_2, \ldots., (d, q, t)_v]$where

- d is the distance considered.
- q is the number of elements e_k at the *same* distance d.
- t is the threshold value computed.

The same applies to the other variables.

Mesoscopic variables are given in this case by the values adopted by vectors $Vd(t_i)$, and consider eventual spatial distributions of agents, their possible multiple belonging and density when considering the space identified by the cluster.

3.8.3.4 Differences among Agents per Instant

Consider, for instance, operating with the sets of *all differences* between values of positions or speeds or directions or altitudes possessed *per instant* by *all* $[k!/(k-2)!]/2$ *couples* of agents such as $[e_m(t_i), e_j(t_i)] \equiv [e_j(t_i), e_m(t_i)]$where $m \neq j,\ m > 0, j > 0 \text{ and } m \leq k, j \leq k$.

It is thus possible to consider, at given point in time, significant clusterisations of differences, e.g. possessing minimum differences among them.

Mesoscopic variables are given in this case by clusters of differences having the minimum differences between them.

3.8.3.5 Variations of Single Agents over Time

Consider, for instance, operating with the displacement (as a particular case of a variation) vector $Vspace(t_i)$ of size k whose elements correspond to the individual agents $e_k(t_i)$ and which contains their respective spatial positions x_k, y_k *and* z_k at a given instant.

For a generic agent $e_k(t_i)$, it will be possible to consider, for example, its spatial positions in (t_{i-1}) and (t_i) which allow one to calculate the displacement vector Vs $[e_k(t_i), e_k(t_{i-1})] = [Vspace_k(t_{i-1}) - Vspace_k(t_i)]$.

One can thus construct a vector of size k $Vspost(t_i)$ whose elements correspond to the individual agents e_k and contain the spatial displacement x, y, z of each $e_k(t_i)$ at a given instant relative to the previous position and $e_k(t_{i-1})$.

One can then consider the historical sequences related to variations in position, speed, direction and altitude for each agent $e_k(t_i)$ and study *homogeneous* correlations, i.e. between historical sequences of changes in speed *or* position *or* direction *or* altitude, or *non-homogeneous* correlations, i.e. between historical sequences of changes in all variables.

It is thus possible to consider clusterizations having the *same* or *correlated* variations as displacement, per instant, and at the same or at different computed thresholds per type of cluster. It is possible to cluster on the basis of the *same* variation as displacement of homogeneous variables.

Related *mesoscopic variables* are given, for instance, by the number of clusterized variations, their possible correlations and properties of related agents possibly belonging to other possible different clusterisations.

3.8.3.6 Classes

We consider here clusters as introduced in Sect. 3.8.3.3. The maximum and minimum values assumed by a variable establishing a cluster, considered ex-post as given by suitable threshold, can be intended to identify classes. Clustered values of variables may by aggregated in classes *h:1-C* as in the table below.

Class *h*	*1*	*2*	...	*C*
Distances	$M_1 < dist(e_i,e_r) < M_2$	$M_3 < dist\ (e_i,e_r) < M_4$	...	$M_n < dist\ (e_i,e_r) < M_s$
Speeds	$S_1 < speed\ (e_i) < S_2$	$S_3 < speed\ (e_r) < S_4$	...	$S_p < speed\ (e_s) < S_q$
...	...	...	...	...

At any given point in time any e_k may:

1. Belong only to a single cluster.

2. Belong simultaneously to j ($j < C \wedge j > 0$) different clusters. Here, one must consider that a specific distance may a) have different extremes, i.e. distances between different agents e_k, or b) share one *extreme*, i.e. a *same* agent e_k. In the second case, a same element e_k can belong simultaneously more times to the same distance class and to different distance classes. At any given point in time *t*, each distance class will be characterized by the number of elements e_k falling within it.

This applies to the classes such as differences in altitudes, directions and velocities for each agent for all temporal periods t_i and t_{i+1} where *i:1,T*.

Classes and their relative number of agents per instant are considered to constitute *mesoscopic variables*.

This section is also preparatory to Sect. 3.8.4.2 on Ergodicity.

3.8.3.7 Degrees of Freedom

In this case, mesoscopic variables are considered as being given by statistical clusters of percentages per agent of their usage of degrees of freedom.

Consider the *absolute* maximum and minimum values, for instance, reached ex-post, at the end of the observational or simulation time, among all speeds, directions, altitudes and distances.

At each instant values of speed, direction and altitude of each agent may be computed as specific percentages of the maximum or minimum values as detected above a posteriori.

Consider sets of all the percentages of maximums or minimums per agent and per variable detected a posteriori.

At this point it is possible to consider clusterisations of percentages: clusterisations given by aggregations of agents whose values of corresponding variables respect such percentages.

Mesoscopic variables will then be given by clusterization of percentages per instant and per corresponding agents when considering, for instance, their number.

3.8.4 Meta-Structural Properties

We apply here the principles outlined in Chap. 2, such as the need to be non-complete; non-precise, to assume lightness; and non-explicitness as properties to capture complexity when meta-structural, i.e. *multiple, multiphase, and superimposed, interactions and interference is the* ***place*** *of partial or dynamic equivalences,* ***trading*** *between possibilities contending to become* ***effective becoming****, the emergence of new coherences.*

We consider possible multiple, simultaneous, properties of clusters and communities established not through commonalities of microscopic properties, e.g. *speeds, but by clusters and communities of clusters having* ***properties of multiple relational properties***[7] *and* ***properties of their dynamical intersections*** *as introduced below.*

Several approaches are possible to formulate meta-structural properties. With reference to mesoscopic variables, as mentioned in Sect. 2.4 and 3.8.3, one can consider their values and the properties of the sets of their values. The values of mesoscopic variables are considered to *intercept* and represent the structural dynamics as the application of multiple rules.

Generic examples of meta-structural properties are given by:

(a) Properties of the values acquired by mesoscopic variables, single or crossed, such as any regularities including periodicity, quasi-periodicity and chaotic regularities possibly with attractors which characterize specific collective behaviours.
(b) Properties, e.g. geometrical, topological, of distribution, or statistical, of sets of generic agents constituting mesoscopic variables and their change over time.
(c) Properties related to the usage of degrees of freedom as introduced above.
(d) Relationships between properties of sets of clustered generic agents and macroscopic properties such as density, distribution, scale-freeness or numerical properties such as percentages.
(e) Properties of the thresholds adopted for specifying the mesoscopic general vector.
(f) Possible topological properties of network representations, power laws and scale-invariance.
(g) Possible levels of ergodicity.

However, examples of some specific meta-structural properties are presented here below.

3.8.4.1 Correlation and Synchronization *of Mesoscopic Variabl*es

In this case synchronized, correlated values of mesoscopic variables are considered rather than microscopic values related to properties of agents such as speed, weight, age, etc. as in Sect. 3.8.3.1.

Here, a meta-structural property is given by synchronization and correlation parameters and their possible dynamics among the values taken by mesoscopic variables, such as their number of elements. In the latter case, the meta-structural property also consists of considering the properties and parameters of such dynamics.

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[7] *Multiple relational properties* represented by mesoscopic clusterisations. *Multiple relational properties* and *properties of their dynamical intersections* represented by meta-structural properties.

3.8.4.2 Ergodic Passage from one Class to another and *Mesoscopic Ergodicity*

With reference to classes introduced in Sect. 3.8.3.6, for any value of t, there is a distribution of agents within the different classes. Let π_{ht} denote the total number of agents belonging to class h at time t. Then the vector $\pi_t = (\pi_{1t}, \pi_{2t}, ..., \pi_{ct})$ defines the state of this distribution at time t.

This allows the introduction of the probability P of the transition of an agent from a class i at time t_{-1} to a class j at time t, denoted as p_{ij}.

The first order Markov assumption (which turns out to be a very good approximation in most real cases) implies that the status of the world π_t depends only on $\pi_{t\text{-}1}$ through Markov's transition matrix $[P_{ij}]$.

This implies that $\pi'_t = \pi'_{t1}P$.

A distribution is ergodic if $\pi' = \pi' P$.

In this case, classes allow detection of ergodicity.

In such cases meta-structural properties are given by ergodic properties.

At this point we can introduce the concept of *mesoscopic ergodicity*. As considered at the Sect. 4.5.1, it is well known that over a given observational time and considering a system composed by finite, constant over time number of elements, if:

- $Y_\varphi\%$ is the average percentage of time spent by a single element in state S.
- $X_\varphi\%$ *is* the average percentage of elements lying in the same state, the degree of ergodicity is given by:

$$E_\varphi = 1/[1 + (X_\varphi\% - Y_\varphi\%)^2].$$

We have ergodicity when $X_\varphi\% = Y_\varphi\%$ and the degree E_φ then adopts its maximum value of 1.

However, in a correspondent way, we may consider as state S, called here *mesoscopic state*, the belonging of elements to a specific cluster.

Consider n interacting entities e_k.

The simpler single instantaneous mesoscopic state is given when considering a single instantaneous cluster related to values of a single variable. For instance, a mesoscopic state is given by the clustered elements

$$e_j, ..., e_h$$

having all similar value of a variable, for instance, aggregated in clusters where elements e_k have the *same* distances $dist_1, dist_2, ..., dist_n$ between each other.

Clusterisations per instant will occur by considering different clustering distances $dist_1(t), dist_2(t), ..., dist_n(t)$.

The mesoscopic variable related to distances $[n_{dist1}, n_{dist2}, ..., n_{distn}]$ considers the *number* of elements e_k having per instant the same distance, $dist_1(t), dist_2(t), ..., dist_n(t)$ between each other. We know the number of elements $n_{dist1}, n_{dist2}, ..., n_{distn}$, but we do not know *which* elements, being them mesoscopically equivalent, i.e. one can play the role of the other, that is to increase the number of elements belonging to the cluster.

The same values of a mesoscopic correspond to a variety of different microscopic configurations of elements.

In this way clusters of the same mesoscopic variable are established by different *equivalent* configurations of same elements, then considerable in equivalent different ordered sets. In this way are considered as equivalent elements having possible important differences given however by properties related to other variables such as their altitude, speed and direction. Crossing evaluations will occur when consider crossing correlations.

Furthermore an element e_k belonging to the cluster $dist_1(t_n)$ can belong to a different cluster $dist_1(t_m)$ or do not belong to any cluster at a different time with $m \neq n$).

We may summarise by considering:

- $Y_\varphi\%$ as the average percentage of time spent by *equivalent* elements belonging to a specific cluster.
- $X_\varphi\%$ *as* the average percentage of *equivalent* elements belonging to this specific cluster. The degree of mesosocopic ergodicity is then given by:

$$E_\varphi = 1/[1 + (X_\varphi\% - Y_\varphi\%)^2].$$

Also in this case, we have mesoscopic ergodicity when $X_\varphi\% = Y_\varphi\%$ and the degree E_φ adopts its maximum value of 1.

Notes:

- The number of clusters per mesoscopic variable is fixed for the entire process (for instance, when clustering by using K-means).
- The number of elements belonging to the same cluster is different along time.
- The mesoscopic variable is then composed of the same number of clusters having different numbers of belonging elements along time.
- We consider the total time spent by each element to belong to a specific cluster along time and how many elements belong to this specific cluster per instant.
- Correspondingly we may consider the average of all percentages of time spent by each element to belong to a specific cluster along time and the average of all percentages of the number of elements belonging to this specific cluster per instant.
- In this case ergodicity relates to single specific clusters. It is possible to consider the ergodicity of each cluster along time and different ergodicities are possible for the different clusters constituting the mesoscopic variable.
- Furthermore we may consider mesoscopic ergodicity when averaging among all the clusters constituting the mesoscopic variable.

We then consider the ergodicity among mesoscopic states, given by taking in count percentage of equivalent elements belonging to a mesoscopic state mesoscopic, i.e. to a cluster, in an instant t_i, versus percentage of time spent by those equivalent elements to belong to that mesoscopic state, by ways in which E_φ oscillates around 1 in time. Other related meta-structural properties are given by correlations among ergodicities for different variables.

However we stress that the same degree of mesoscopic ergodicity can be given by different microscopic configurations due to possible multiple roles played by *interchangeable* elements along time. This is the case for Multiple Systems and Collective Beings considered in the Sect. 4.5.1. *A specific mesoscopic state identifies a set of instantaneous* ***equivalent*** *microscopic states. For example, the set of elements establishing clusters where microscopic states of elements are considered equivalent,* e.g. *having similar values of the same variable and considered* ***interchangeable*** *when do not* ***altering*** *the global coherence,* e.g. *of a collective behaviour, or when* ***inducing*** *assumption of equivalent coherences,* i.e. *different equivalent collective configurations.*

Mesoscopic ergodicity does not *prescribe microscopic properties but equivalences allowing theoretical incompleteness* (Minati, 2016a, 2016b)*, reason of unpredictability.*

Suitable levels of degrees of mesoscopic ergodicity can be considered as meta-structural properties since corresponding to levels of coherence (see Sect. 3.4*).* The suitability is given by the possibility to *represent* or *prescribe* not only local temporal or spatial coherence, but generalized coherence typical of collective behaviours. *In this case it is matter of coherence having* ergodic nature.

3.8.4.3 Mesoscopic *Slaving*

This section considers an approach corresponding, conceptually, to the identification of order parameters (variables in this case) representing a kind of *mesoscopic slaving* as considered in synergetics.

It is important to find dynamical *summarizing variables representing the collective behaviour and considered suitable for modifying it, by using non-explicit approaches.*

Consider a matrix $K \bullet M(t_i)$ where K is the number of agents e_k, and M is the number of mesoscopic properties considered. Element $KM_{k,m}(t_i)$is equal to *0* if the generic agent e_k does not possess the mesoscopic property m at time t_i or to *1* if the generic agent e_k does possess that property m at time t_i:

$$\begin{matrix} KM_{11} & KM_{12}\ldots & KM_{1m} \\ KM_{21} & KM_{22} & KM_{2m} \\ \ldots. & & \\ KM_{k1} & KM_{k2} & KM_{1m} \end{matrix}$$

It is possible to consider at time T, i.e. at the end of the simulation or of the real phenomenon under study, for instance, the sequences of previous matrices.

Properties of such sequences are considered as meta-structural properties.

Examples of properties are given when considering trends, periodicities, correlations and statistical properties of sets of values, such as:

(a) Number of agents and which agents possess at least one mesoscopic property and the total number of properties and which properties are possessed by agents after the global observational computational time. The trends of acquisition of properties should be detected.

(b) Number and *which* agents have the same or more or several or no mesoscopic properties over time. This labelling allows to identify *zones* of agents possessing mesoscopic properties, their topology and dynamics.

(c) The repetitiveness or quasi-repetitiveness (unless one, two, ..., *n* cases being level of repetitiveness) of same matrixes and their temporal distributions.

(d) Number of agents and *which* agents possess a specific topological position. Agents may:

   - Be *topological centre* of the flock, i.e. all topological distances between the agent under study and all the agents belonging to the geometrical surface are equal. This agent may be *virtual* and be considered as a *topological attractor* for the flock. Its trajectory may *represent* the trajectory of the flock.
   - Belong to the geometrical surface or to a specific zone of interest.
   - Have a specific topological distance from one of the agents such as temporary leaders and agents belonging to the geometrical surface or a specific area of interest.

These are examples of meta-structural properties both *representing* the collective behaviour under study and the meta-structural variables to be used to influence the possible further evolution of the collective system after time *T*.

However, from the data above, it is possible to compute a posteriori, i.e. at the end of the collective behaviour, the sequences and the sum of all the previous matrices per instant:

$$\sum_{\substack{k:1,K \\ m:1,M \\ t:1,T}} KM_{km}(t_i)$$

It is thus possible to identify the ***maximum intersections****,* i.e. *not only the agents which possessed the maximum number of mesoscopic properties, but those which possessed the maximum number of* ***specific*** *mesoscopic properties, with special reference to the case where* ***this possession occurred at the same time*** *or with particular sequences and correlations in time*. In the latter case, it is of great interest to identify the sequences of agents possessing multiple mesoscopic properties per instant and their *persistence* over time.

Such sequences, their properties and their possible correlations are intended as meta-structural properties.

When properties of sequences and of their intersections are significant, they are intended to meta-structurally represent the collective behaviour under study.

The significance of such sequences allows representation and possible modifying actions upon them leading to generalized effects on the global collective behaviour, for instance, by introducing suitable environmental perturbations having the purpose to facilitate or avoid specific properties of sequences. Examples of perturbations are given by introduction of obstacles and changing environmental properties *to which agents are sensitive,* e.g. *temperature, lighting, air currents and acoustic.* We will consider at the Sect. 3.8.4.5 the insertion of suitable *Perturbative Collective Behaviour(s).*

3.8.4.4 Networks

This is the case where there are no microscopic data to be networked but clusters, as above, and so networks of clusters have to be considered. It is question of networked mesoscopic variables. Properties of such networks, see Sect. 8, are intended here as meta-structural properties.

3.8.4.5 Perturbed Meta-Structures

It is possible to consider the *introduction* of suitable Perturbative Collective Behaviour (PCB) allowing *combinations* of meta-structural properties of the perturbed collective behaviour and of the PCB. As introduced previously (Minati et al., 2013), it is possible to consider various approaches such as when elements of the original collective behaviour to be modified are *invisible* to the component elements of the PCB, appearing as *dynamic obstacles*.

This approach is inspired by the *order parameter* used in synergetics or in the *doping* of materials such as silicon, processes of delocalization and restructuring within damaged brains and networks and meta-materials.

A PCB, having meta-structural properties different from those of the collective behaviour to be modified, may consist of external elements or even of some original *mutated* elements, i.e. when artificially adopting different meta-structural rules. Therefore the insertion of a suitable PCB may occur, for instance, in at least two ways:

- By allowing the original collective behaviour to interact with another one, inserted in a suitable way and acting as mobile coherent *obstacles*, i.e. nothing to do, for instance, with prey-predator interactions. Components of the collective behaviour must adapt their behaviour, whereas the PCB acts independently.
- Some elements of the collective behaviour *mutate* their behaviour, i.e. interact differently from before. Such mutation may be stable, temporal, following some temporal regularities, have different possible levels of homogeneity or coherence and possibly following rules of another type of collective behaviour. The distribution of such mutated agents may be of any type such as following topological or metrical criteria.

The number of components of the PCB can vary. In order to model or to adopt approaches to modify the original collective behaviour, it is possible to consider, for instance, the dynamic percentage of mutated or external agents, their distribution, lifespan and topology.

This also relates to complex systems where aspects such as multiple meta-structural properties are simultaneously active each with their own distributions over time, having scale invariance or topological properties as for networks.

3.8.4.6 Further Considerations

Macroscopic variables such as measures of $Vol(t_i)$, volume of the collective entity over time (used to compute density) and $Sur(t_i)$, measure of the *surface* of the collective entity over time, can be used to complement the models even when correlated with other meta-structural properties. The volume and surface of a collective entity should be modelled by using suitable approaches such as considering lattices.

We stress that the examples considered here relate to spatial properties in ***3D*** *although similar approaches can be used for non-spatial contexts such as for economics.*

It is also possible, as mentioned above, to consider properties of *physical* clusters of *corresponding* agents, i.e. represented by mesoscopic variables. For instance, when considering the mesoscopic variable given by the clusters of elements having the *same* distance from the nearest neighbour at a given point in time or above the average, *instead* of taking into account the *number* of elements one can consider other properties of each cluster, such as:

- The measure of the volume and surface of the cluster.
- Its density; the distribution of belonging agents within the cluster.
- Geometrical and topological properties of the configuration of the belonging agents.

On the basis of such properties one can consider, for instance:

1. *Structure* of individual clusters, such as topology, distribution and properties of the connections, i.e. networks, between components.
2. *Topological position* and distribution of the clusters in the collective system overall.
3. *Connections and compactness*. Consider the *space occupied* by a cluster whose volume and surface is measured, and its inside where there are possibly components *extraneous* to the cluster (i.e. they do not ‘belong’ to the mesoscopic variable). One can then consider the extraneous entities, such as agents belonging to other clusters or not belonging to any cluster, as contextually fixed, e.g. obstacles, or moving entities, such as preys. This allows an evaluation of the properties of physical structures *where* clusters of agents are. For instance, by considering the inside of the space occupied by a specific cluster of agents, it is possible to evaluate how *diluted* it is, percentages of agents and extraneous entities, separation of agents by extraneous entities and superpositions of configurations.

4. *Persistence,* or even partial iteration, over time of properties for the same or different clusters is also possible. The properties of their sequences and relationships can be studied.
5. *Sequences of clusters*, corresponding to the same mesoscopic variable by considering their possible homological or co-homological relationships.

3.8.4.7 Mesoscopic Dynamics

Consider the collective behaviours of agents e_k as above and, in particular, the cases considered in Sect. 3.8.4.3, for which one can study the values adopted by the *mesoscopic general vector*, i.e. lines of the previous matrix:

$$V_{k,m} = [e_{k1}(t_i), e_{k2}(t_i), \ldots e_{km}(t_i)].$$

This mesoscopic general vector represents the diffusion over time of the mesoscopic properties possessed by single e_k agents per instant. The evolution of this vector represents the *mesoscopic history* of single agents of the collective behaviours under study.

Reversely we may consider as mesoscopic general vector the columns of the previous matrix:

$$V_{km}(t_i) = [e_{1,m}(t_i), e_{2,m}(t_i), \ldots e_{k,m}(t_i)].$$

The mesoscopic general column vector represents how specific mesoscopic properties are diffused, i.e. possessed by single agents per instant. The evolution of this vector represents the *mesoscopic history* of single mesoscopic properties of the collective behaviours under study.

Thus one can consider the general *mesoscopic dynamics* of the matrices or of specific mesoscopic general vectors whose eventual coherence represented by properties such as synchronisation, periodicity, statistical or, more generally, correlations represents collective behaviour (see Table 3.4) as specified below (De Wolf et al., 2005b; Minati et al., 2013). There are at least four exemplary cases, as shown in Table 3.2.

1. *All agents that simultaneously possess all the same mesoscopic properties and values of associated mesoscopic and parametric variables, such as thresholds, are* ***constant*** *over time*. Agents all simultaneously respect the degrees of freedom *and* the parametrical values defining mesoscopic variables that are *constant*, i.e. changes are *insignificant* within the adopted threshold.

For any agent e_k and for $\forall$ mesoscopic property $m(t_i)$, $V_{km}(t_i) = [1, 1, \ldots, 1]$, where $m(t_i) = m(t_{i+1})$ and parameters are constant *over time.*

2. *All agents simultaneously possess all the same mesoscopic properties and values of associated mesoscopic and parametric variables, such as thresholds, are* ***constant*** *per instant, but* ***variable*** *over time*. Agents all simultaneously respect the degrees of freedom and the parametrical values defining mesoscopic variables that are constant per instant, but variable over time, i.e. changes are

Table 3.4 Mesoscopic dynamics

	Mesoscopic dynamics		
Structural properties / Properties of the collective behaviours	Structure of interaction	Mesoscopic properties	Meta-structural properties
Case 4 Collective behaviours structurally at high variability, e.g., flock under attack	Multiple and superimposed variations in the structures of interaction	Agents possess different mesoscopic properties per instant and over time. However their parametrical values, such as thresholds, are *constant* per instant, but *variable* over time.	Non-trivial meta-structural properties
Case 3 Collective behaviours structurally variable, e.g. perturbed flock	Multiple and superimposed variations in the same structures of interaction	Agents possess different mesoscopic properties per instant and over time. However, their parametrical values, such as thresholds, are *constant* over time.	Non-trivial meta-structural properties
Case 2 Collective behaviours structurally at low variability, e.g., flock dealing with fixed obstacles	Changes in the *same* structure of interaction	All the agents simultaneously possess all the same mesoscopic properties, and values of associated mesoscopic and parametric variables, such as thresholds, are *constant* per instant, but *variable* over time.	Trivial meta-structural properties
Case 1 Collective behaviours structurally 'fixed', e.g., flock with repetitive behaviour	Structure of interaction fixed	All the agents simultaneously possess all the same mesoscopic properties and values of associated mesoscopic and parametric variables, such as thresholds, are *constant* over time.	Trivial meta-structural properties

insignificant within the threshold adopted per instant, whereas they can change significantly over time.

For any agent e_k and for $\forall$ mesoscopic property $m(t_i)$, $V_{km}(t_i) = [1, 1, \ldots, 1]$, where $m(t_i) \neq m(t_{i+1})$ and parameters are constant *per instant*, i.e. for all instantaneous different situations.

3. *Agents possess different mesoscopic properties per instant and over time. However, parametrical values, such as thresholds, are* ***constant*** *over time.* Agents simultaneously respect the degrees of freedom and the parametrical values

defining mesoscopic variables are constant, i.e. changes are insignificant within the adopted threshold. For any agent e_k and for ∀ mesoscopic property $m(t_i)$, per instant, there will be different configurational varieties of the vector $V_{k,m} = [e_{k1}(t_i), e_{k2}(t_i), \ldots e_{km}(t_i)]$ such as:

$$\begin{aligned} V_{1,m}(t_i) &= [1,0,0,\ldots,0] \\ V_{2,m}(t_i) &= [0,1,0,\ldots,1] \\ V_{3,m}(t_i) &= [0,1,1,\ldots,0] \\ V_{4,m}(t_i) &= [1,0,1,\ldots,1] \\ V_{5,m}(t_i) &= [0,0,0,\ldots,1] \\ &\ldots \\ V_{k,m}(t_i) &= [0,1,0,\ldots,1] \end{aligned}$$

Reversely the same situation is represented by the column vector $V_{km}(t_i) = [e_{1,m}(t_i), e_{2,m}(t_i), \ldots e_{k,m}(t_i)]$.

Parameters are constant *over time*.

4. *Agents possess different mesoscopic properties per instant and over time. However, parametrical values, including thresholds, are* ***constant*** *per instant, but* ***variable*** *over time.* Agents simultaneously respect the degrees of freedom, and parametrical values defining mesoscopic variables are constant per instant, but variable over time i.e. changes are insignificant within the threshold adopted per instant, whereas they can change significantly over time.

For any agent e_k and for ∀ mesoscopic property $m(t_i) \neq m(t_{i+1})$, per instant, there will be different configurational varieties of the vector $V_{k,m} = [e_{k1}(t_i), e_{k2}(t_i), \ldots e_{km}(t_i)]$ such as:

$$\begin{aligned} V_{1,m}(t_i) &= [1,1,0,\ldots,0] \\ V_{2,m}(t_i) &= [0,1,1,\ldots,0] \\ V_{3,m}(t_i) &= [1,0,1,\ldots,1] \\ V_{4,m}(t_i) &= [1,0,1,\ldots,0] \\ V_{5,m}(t_i) &= [0,0,0,\ldots,1] \\ &\ldots \\ V_{k,m}(t_i) &= [0,1,0,\ldots,1] \end{aligned}$$

Reversely the same situation is represented by the column vector $V_{km}(t_i) = [e_{1,m}(t_i), e_{2,m}(t_i), \ldots e_{k,m}(t_i)]$.

Parameters are constant *per instant*, i.e. for all instantaneous different situations.

An interesting research issue could consider the four classes of *mesoscopic dynamics* as possibly conceptually related to the four classes of cellular automata introduced by Wolfram (Wolfram, 2002) as in Table 3.5.

Table 3.5 Four classes of cellular automata

Classes	Kinds of evolution
Class 4	Emergence of local and surviving dynamic structures
Class 3	Chaotic evolution. Spread randomness
Class 2	Evolution into stable or oscillating structures. Local randomness
Class 1	Evolution into stable, homogeneous structures

3.8.5 Structural Regimes of Validity

A number of possible *regimes of structural validity* should be considered for the behaviour of agents interacting by respecting degrees of freedom, whether single, multiple, fixed or variable. As considered in Sect. 3.8.2 and discussed above, there are various possibilities, at least the four listed in Table 3.4.

Elementary examples of *extreme* structural regimes of validity are given by:

1. Usage of the *same* rule of interaction by *all* interacting agents.
2. Usage of the *same* rule of interaction by subsets of interacting agents.

   In this case various options are possible, such as:

   - Single *fixed* subsets or clusters of agents using the *same* rules of interaction over time, the rules being different from subset to subset.
   - Single *fixed* subsets or clusters of agents using the *same* rules of interaction per instant, the rules being different from subset to subset.
   - *Variable* single subsets or clusters of agents using the *same* rules of interaction over time, the rules being different from subset to subset and varying per instant.

   It should be noted that subsets or clusters can have any intersection or diffusion, while the same agents may even belong to more than one subset.
3. The usage of different rules of interaction may be variable and multiple. In this case, fixed or variable subsets or clusters of agents use the rules of interaction by following *specific,* whether *fixed or variable, modalities*, such as:

   - *Regular* repetition of different rules per single agent while the rules used may be single or multiple.
   - *Regular* repetition of different rules per fixed, or possibly variable, subsets or clusters of agents.
   - Probabilistic assumption of different rules per fixed or possibly variable subsets or clusters of agents.

In this view, the *minimum degree of freedom* for structures or, better, for a structural regime of validity, is given by case 1.

The *maximum degree of freedom* is given by the *random* adoption of different rules for any subsets or clusters of agents.

Properties of structural regimes (see Table 3.6) are significant when related to the area *between* such extremes and when having some regularities such as

Table 3.6 Elementary structural regimes

Single structural regime	At each step all the agents will interact according to one of the 13 rules valid for all.
Multiple structural regime	At each step each agent can choose which of the 13 rules should be used to interact.
Multiple, fixed and superimposed structural regimes	At each step each agent can choose to interact with $m > 1$ of the 13 rules. The number m is constant for all agents per instant.
Multiple, variable and superimposed structural regimes	At each step each agent can choose to interact with *any* $s > 1$ of the 13 rules. The number s is variable per agent.

periodicities or distributions *between* such extremes. Given the 13 rules of interaction listed in Table 3.1, we can summarise as shown in Table 3.4.

Such structural regimes may be valid with various combinations and timings in an inhomogeneous way. At this point, we note that rules of interactions and adoptions of structural regimes of validity do not ensure the *uniqueness* of the global configuration identified at time t_{i+1} nor *coherence(s)* among sequences of configurations.

The coherence between configurations is considered here as being given and represented by the validity of suitable properties, possibly meta-structural properties as in Sect. 3.8.4. This should be intended as a *degree of freedom* in selecting the structural regimes and their possible combinations. Several configurations may respect suitable current properties or meta-structural properties and are thus *authorized* to occur. This can happen while respecting different structural degrees of freedom.

There are thus $q(t_i)$*-equivalent* configurations for which there must be a strategy of choice.

Sect. 3.8*, dedicated to* ***Methods and approaches to model and act upon the dynamics of emergence: research on meta-structures****, summarises the research on meta-structures and its modelling. Its purpose is to provide approaches for detecting the establishment of emergence of collective phenomena, their dynamics and possible interventions for modifying them.*

3.9 The Transient

As mentioned above, structural dynamics can be understood as changes between, for instance, phases, ontologies, levels of emergence and properties.

Here, we consider aspects related to the *between* as given by modalities, *properties* of potentialities and boundary conditions, as already mentioned in Sects. 2.4, 2.6 and 2.7.

Focus is on modalities and properties of transience, such as continuity, discretisation, convergence or irregularity.

Networks and meta-structural properties are intended here as a way of representing and prescribing structural properties, modalities and properties of their dynamics.

Networks and meta-structural representations of processes and phenomena are intended to obtain and represent their *structural* invariants, modalities, and their *non-explicit properties*, i.e. non-analytically, that cannot be *zipped*, non-exhaustible in analytical formulas. That is represented by their implicit imprinting intended as *implicit* because it is not represented *symbolically*, but by using networks and meta-structural properties.

On the other hand, approaches suitable to *prescribe* networks and meta-structural properties can be applied to processes having a *significant 'between'* amidst their phases such as processes of emergence. Prescriptions of networks and meta-structural properties are expected to be able to induce and orient complex behaviours by allowing *varieties of equivalences* as for the structural regimes considered above. Prescription of networks and meta-structural properties may be intended as a way to *prescribe a general future*, by prescribing modalities able to ensure the acquisition of *kinds* of properties through the processing of almost any environmental or internal inputs or fluctuations. This may apply, for instance, to complex systems in general whereas it may be not suitable for systems having very tight degrees of freedom as in closed, deterministic systems or devices.

Thus, the focus is on the study and prescriptions of equivalences, by setting meta-structural and network levels where alternatives may become equivalent. Here, two phenomena should be mentioned:

- *Meta-structural transience* where the transience relates to the acquisition, change or loss of a specific meta-structural property.
- Transience between meta-structural regimes of validity where meta-structural properties are still maintained, but in different ways, i.e. through different parameters in given structural regimes.

These are important lines of trans-disciplinary research dealing with *general systemic properties*, i.e. *properties of properties*, impossible to deal with in the context of GOFS.

Examples of non-explicit prescription consist of varying meta-structural properties as presented in Sect. 3.8.4. For instance, by using *mesoscopic slaving* as introduced in Sect. 3.8.4.3; properties of Networks of mesoscopic variables as mentioned in Sect. 3.8.4.4 (see Chap. 8); by *inserting* a Perturbative Collective Behaviour *within* the collective behaviour to be influenced as in Sect. 3.8.4.5; or by acting upon properties such as parameters of synchronisation, correlation or usage of degrees of freedom, and environmental as in Sects. 3.8.3.1 and 3.8.3.7.

3.10 Further Remarks

This concluding section focuses upon general aspects considered in this chapter and considers possible future research.

Identity and meaning is considered from a dynamical point of view, i.e. through the properties of dynamics such as coherence or meta-structural properties.

The ontological meaning of existence should here be considered as the properties of change. By adopting the sayings of *Heraclitus*, we can consider change as *coming first* as the quantum vacuum precedes matter, not being simply the lack of matter. Levels and states should be intended as *simplifications* at certain levels of descriptions.

Emergence could be intended as *normality* represented using simplified levels assumed to be states, with their changes and dynamics considered as the dynamics among those states.

Emergence could be intended as coming first, as a property of *pre-matter*, of the vacuum. The quantum void could thus be intended as a kind of field of potentialities ready to collapse but always pervasive as are the probabilistic features of Quantum mechanics (QM).

The identity of matter should then be given by the properties of levels where one can consider ontological being and non-being.

What are the advantages of considering such approaches and assumptions? The idea is that in the new, post-GOFS the standard is not given by the statics, its states and their properties but by a continuous flux of change and the properties of its dynamics, the static option being a mere simplification. The reconstruction of the dynamics from given states will be very complicated for complex systems whereas it could be simplified by choosing the reverse. The same is true when considering openness starting from closed systems, intending *openness as non-closeness, rather than the reverse*.

Such comments should be considered as a preview of the need for new *tools* to describe dynamics in mathematics other than the classical approach.

We conceptually refer to approaches where dynamics, openness and environment ***come first*** *and then a state, closure and bodies can be defined* ***through*** *them.*

Examples are given by representations of change not by states but, rather, through the properties of the change as for networks, meta-structural properties and structural regimes. In the dynamics of such change, several microscopic configurations are *equivalent* and possible.

Such properties are also able to prescribe microscopic behaviour, e.g. topological distance and number of links, other than that given by the classical fixed *degrees of freedom* as for macroscopic properties.

Box 3.1: Mermin-Wagner theorem

States that, in QM and QFT, in dimensions ≤ 2 *within systems with sufficiently short-range interactions, continuous symmetries cannot be spontaneously broken at finite temperature*[1], i.e. *long-range fluctuations can be created with little energy cost and they are favoured since increase the entropy*. This allows an understanding of why it is impossible to have phase transitions in a one-dimensional system, and it is nearly impossible in a two-dimensional system.

In general, reduction in the number of degrees of freedom increases stability. For instance, by constraining a spiral motion to lie only on a two-dimensional plane, escape along the third dimension (and whence the loss of stability) would be precluded. It can thus be considered that, in general, *3D* CollectiveBehaviours is an entity which, in principle, is more stable than its local constituent parts, and this stability is, in turn, granted only by the constraints defining it.

This explains, using a further example, why some collective behaviours, such as those of two-dimensional flocks, seem to violate this theorem (Mermin & Wagner, 1966). This occurs because a flock exists and survives as a consequence of suitable constraints between the motions of individual birds belonging to it and the presence of these constraints lowers the dimensionality of the available phase space, in turn increasing the stability of the whole system and rendering untenable the thermodynamic arguments upon which the Mermin-Wagner theorem itself is based.

[1] In order to allow that heat exchange takes place between two bodies, a finite difference of temperature between them is required, even if ideally this difference temperature may be infinitesimal. In the later case for exchanging a finite amount of heat are necessary a surface infinitely extended or infinite time. The concept applies in thermal quantum field theory or finite temperature field theory.

Box 3.2: Theorem of Smale

It was shown that, on increasing the number of variables and parameters, it became impossible to group the patterns of change into a small number of categories (e.g. Arnold, Afrajmovich, Ilyashenko, & Shilnikov, 1999). This circumstance, already present in previous and celebrated theorems such as that of Smale on *structural stability* (see, e.g. Arnold, 1988; Palis & de Melo, 1982; Smale, 1966), practically dominates the world of chaotic phenomena and of partial differential equations.

In short: *given a system of dynamic equations that describe the evolution in time of the values of at least three dependent variables, the probability that it has chaotic solutions is infinitely close to 1.*

Box 3.3: Metastability

Once identified a global equilibrium state (in principle we could have more different states of this kind), in some contexts called a *ground state*, all other equilibrium states are called *metastable equilibrium states*. This term denotes the fact that all these states, in presence of fluctuations, have a finite lifetime, as there will be a nonzero probability of having a fluctuation of such amplitude that ~~it~~ will push the system outside the basin of attraction of the metastable equilibrium state, letting it to fall into the global equilibrium state. If the latter is unique, its lifetime in presence of fluctuations will be instead infinite, as every fluctuation, even if putting temporarily the system into the basin of attraction of a metastable equilibrium state, will be first or later counterbalanced by another fluctuation letting the system abandon the metastable situation and fall again in the global equilibrium state. For this reason the metastable equilibrium states are also called *far from equilibrium stationary states*.

A typical example of stationary state far from equilibrium is given by the case of Bénard cells. When the considered system, in order to manifest Bénard instability, gradually moves away from equilibrium (equilibrium in this case is when there is uniform temperature in the whole liquid), it reaches a critical instability point where the so-called Bénard cells, ordered hexagonal cells, honeycomb-like, emerge.

The most celebrated examples of systems lying in far from equilibrium states is given by the *dissipative structures* introduced by Prigogine and his school.

More generally when while at short time scales the system appears to be in a quasi-equilibrium, i.e. metastable state, at longer time scales rapid transitions, induced by random fluctuations, between meta-stable states occur (Antman, Ericksen, & Kinderlehrer, 2011; Kelso, 2012; Tognoli & Kelso, 2014).

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Chapter 4
From Collective Beings to Quasi-systems

Contents

This chapter is dedicated to explore among different post-GOFS systemic properties of different *nature* like ones considered above and based on the concepts of *quasi* already used in different disciplines since long time. The concept of quasi relates here to quasi-systems, quasi-dynamic coherence and the passage from Multiple Systems-Collective Beings to Quasi-Multiple Systems-Quasi-Collective Beings. The simplified idea assumed by GOFS to deal with systems *or* nonsystems is unsuitable and having reductionist aspects when dealing with complex systems and multiple phenomena of emergence, having structural dynamics and levels of coherence where DYSAM-like approaches are more appropriated.

We will elaborate the concepts of pre-properties, quasi-systems and related pre-properties, quasi properties, system propagation as environmental or field property and dynamic coherence for quasi-systems. We will consider the case of the cytoskeleton as typical example of quasi-system.

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Such quasiness asks for appropriated approaches such as network based and meta-structural.

4.1 Pre-properties

With the concept of pre-property, we consider the process of *acquisition* and eventually emergence of properties. There are several aspects that may be considered in such processes of establishment of properties when, for instance, *previous phases* or *states* are compatible, convertible, necessary, converging and of regular-irregular increasing strength.

Conceptually we may also consider correspondent *post-properties* in *degenerative* processes and the occurrence of incompatibility, inconvertibility, no necessity, instability and decreasing strength.

The concept of pre-property may relate both to properties to be *continuously acquired* through processes of emergence like coherence or eventually gradually *possessed* and to the *nature of the property* rather than the process of acquisition.

Our interest focuses here on the first case related to acquisition.

Differently from the concept of quasi-property introduced later and considered later as *structurally partially* possessed by a quasi-system in an eventual inhomogeneous and instable ways, a pre-property is to be considered as *implicit*, potential or *step* of an eventual process of acquisition.

For instance, *pre-openness* may manifest in quantum and classical ways (Schaller, 2014), through *irregular converging episodes* and *levels* of openness interesting a variety of specific properties of *different nature* like related to energy, matter, information, behaviour, cognition and adaptation, considered *less important* than ones determining the *status of system* like being anticipatory or its periodicity. Irregular episodes of openness may relate to properties assumed *irrelevant* for specific statuses of system like openness to light, thermal energy and vibrations, when their eventual openness is considered, for instance, given by environmental influences. Let consider, for instance, a *device* whose peculiar systemic property is its ability to *function*. Its functional systemic openness is its ability, for instance, to process in *fixed* ways external inputs, supply and having some capacity of self-regulation as context sensitivity. However the device may have some other pre-openness aspects such as related to the design and material used. The design, for instance, may allow the possibility for the *functioning* device to *materialize* previous *implicit* aspects of openness different from the ones related to the functioning like *structurally* adapt to external perturbations, e.g. thermal or mechanical, the possibility to be converted into another one allowing different *compatible* usage (s) and the possibility to set a different system of which the device is part. They can all be preceded by ways of functioning *compatible* with *reuse*. The subject of reuse is at focus in different ways like in architecture (Baum & Christiaanse, 2014) and connected with recycle (Morgan, 2009).

In the same way, *pre-synchronization* (see, for instance, for synchronisation Acebrón, Bonilla, Vicente, Ritort, & Spigler, 2005; Boccaletti, 2008; Pikovsky, Rosenblum, & Kurths, 2001; for pre- and post-synchronisation in information transfer see Szmoski, Ferrari, Pinto, Baptista, & Viana, 2013; for partial synchronization see Pogromsky, Santoboni, & Nijmeijer, 2002; Wagg, 2002; Yu & Parlitz, 2008) may manifest through irregular converging episodes and levels. For instance, the process of synchronization of fireflies is crucial for their collective coherent flashing being other variables, like orientation and topological aspects, irrelevant. On the contrary these aspects are crucial for spatial collective coherent motions.

The concept of pre-property may be intended even as *meta* (Pan, Staab, & Aßmann, 2012), since eventually *representing* sets of properties visited or acquired by the system over time by keeping *levels of coherence* (for instance, by considering per instant the quantity of coherent elements, the number of different simultaneous coherences and their relations interesting different and same elements, temporal durations of local or temporary coherences and possible properties of levels) while assuming *definitive* convergence to one specifically. The system may *converge* to a way, e.g. periodic, or *jump* from a property to another one in a region of a suitable theoretical *space of properties* eventually equivalent (see Sect. 7.2). However, at this point the system must select to explicitly acquire *one* of these properties. *We may say that pre-properties are differently convergent eventually to a specific property*.

This is conceptually different from quasi-openness as at the paragraph 4.3.

The concept of quasi-property, introduced later, relates to the nature and the structure of the property rather than the way of acquisition. A quasi-property is ***stable in its incompleteness*** (Minati, 2016). *A quasi-property is permanently, structurally quasi-property.* ***However an instant of a pre-property may coincide with an instant of a quasi-property***.

There is a large variety of possibilities to consider pre-properties such as when dealing with clues and multiple nonhomogeneously and noncoherently superimposed different properties assuming slow and irregular convergence to the dominance of a single one like for order parameters (Sethna, 2006). An example is given when considering the *hopping* itinerancy of neural activities between attractors as in (Marro, Torres, & Cortés, 2007). A very well-studied example is given by the so-called *self-organized criticality* (SOC) when dynamical systems have a critical point as an attractor (see, for instance, Pruessner, 2012; Turcotte, 1999).

Similar concepts may correspond to *degenerative* cases when *post-properties* are precedents to the disappearing of properties like in the case of *missing* of robustness, stability and fuzziness and acquiring malfunctioning.

Pre- may be intended as related to situations where several balances and coherences are possible. Metaphorically speaking, we may consider a continuous *drafting* when keeping the status of pre-property or when collapsing or converging consists of the acquisition of a property like for *unstable phase transitions* (Keskin & Ekiz, 2000; Lei & Leng, 2010).

As we will consider at Sects. '4.6 System propagation' and '5.4.1 Non-invasiveness', eventual abilities to act on pre-phases may be effective to act on processes of acquisitions of properties like acting on initial, boundary conditions, attractors and topologies of networks.

Cases of interest occur (Falkenburg & Morrison, 2014) when *areas* of pre-properties are equivalent or nonequivalent, and approaches DYSAM-like are necessary to deal with their occurrences when the system displays linearity and non-linearity, classical and quantum properties and simultaneous roles like for Multiple Systems (see Sect. 4.5.1).

This multiplicity[1] is at the core of the systemic nature of pre-properties.

The prefix pre- does not mean that the property is expected to necessarily convert into an explicit form, i.e. materializing into something possessing and representing it.

The pre- should be understood to take place when interacting or noninteracting configurations of entities and systems acquire a meaning or role independently from their current properties and the status of pre- is kept.

Examples related to a particular case by which we may represent pre- are given by ***statuses of dissipative systems*** *keeping far from equilibrium even if the equilibrium is the final status and converging in very different,* ***unique****, several ways. The subject relates to the possibility to act on, and usages of, the multiple pre-converging statuses or eventual* ***temporary*** *properties.*

We may have classical pre-properties and nonclassical pre-properties outlining a future, for instance, of classical *or* quantum properties, e.g. different superconductor materials at different temperatures, even double regimes like during some complicated transient dynamics between phases taking place when classical and quantum aspects mix (Parisi, 1998; Sewell, 2002) and structural regimes of validity as at paragraphs 3.8.5 and 7.1.2 occur.

However the case of our interest here concerns processes of pre-self-organization and pre-emergence differentiated as considering dynamics of self-organization and emergence at the paragraph 3.2.3.

Indeed, we may consider pre-properties compatible or incompatible with processes of self-organization and emergence. In case of compatibility, for instance, scale invariance and power laws are clues, compatible and even pre-properties.

The interest relates to the possibility to act on compatible pre-properties to facilitate or even avoid acquisition of self-organization and emergence.

We consider a similar case for ergodicity in Collective Beings at Sect. 4.5. We may also consider, for instance, pre-network, pre-meta-structural and pre-chaotic properties relating to aspects suitable to *converge* and even *diffuse* and *contaminate* the nature of other aspects and properties.

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[1] We like to recall here how some of the conceptual keywords we are considering here for a post-GOFS were introduced in literature by Italo Calvino in the book Calvino, I., 1988, *Six Memos for the Next Millennium*. Harvard University Press, Cambridge, MA, in this order: Lightness, Quickness, Exactitude, Visibility, Multiplicity, Consistency.

We specify that pre-properties may be not *necessary* for the establishment of properties or quasi-properties, since we cannot postulate any necessary convergence, continuity or homogeneity, while examples of *non-continuity* are given by phase transitions.

Configurations of properties occurring for any reason, like due to environment and occurrence of *defects* due, for instance, to aging, may establish a single or sequences of eventual pre-properties like *symptoms*. They may transform into *properties* or *quasi-properties* if becoming emergent or related to some structures like stabilized malfunctioning.

It seems like a situation where the system *explores possibilities* to be eventually assumed as points of trajectories of its *chaotic version* around attractors. The case may be considered for combinations of evolution and self-organization studied, for instance, by *Stuart A. Kauffman* (Kauffman, 1993). Instabilities of attractors act as *sources* for creating pre-properties to be eventually consolidated. ***It is a kind of creative processes for systems*** (see, for instance, in the case of Neural Networks, Thaler, 2012, 2014).

Lightness[2] *and non-invasivity introduced at* Sect. 2.2 *relate to the need to respect and facilitate this kind of creative process for complex systems respecting their implicit form.*

Pre-properties may be eventually *recognized* by using suitable approaches.

Pre-properties may be understood occurring at the early stage of establishment of processes of emergence. There is increasing research interest on levels of processes of emergence and on the transience between levels; see Chap. 7. We relate to the starting and final transience of a process of emergence when:

- Arising from pre-properties to subsequently become acquired emergent properties.
- Degenerating, i.e. partially loosing coherence and stability becoming firstly quasi-property and then past quasi-property, meaning that the direction of the process is towards degeneration. In this view an illness may be considered as *failed*, i.e. degenerated, recovery process and healing may be considered as degenerated process of falling ill.

However the dynamics may be much more complex than reduced to consolidative transitions *towards* properties or degenerative transitions turning away from properties. How do we eventually recognize and distinguish between the establishing of pre-emergent properties and pre-properties in general? A research approach is given by considering, for instance, their eventual network, meta-structural and ergodic *nature* as mentioned above.

Pre-properties can be explored by the system through assumption of configurations and roles. *Detection of pre-properties seems as detection of unvoiced potentialities or collapsing potentialities.*

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[2] See note [1] above.

An interesting case combining the two features of pre- and emergent properties is given when considering *collective intelligence* (Bostrom, 2014).

In this case the process of emergence is assumed to take place and be in progress by an *established collective behaviour*. The collective behaviour comes *first* being collective intelligence *implicit* potentiality within it, when modalities of collective coherent behaving may be intended as pre-properties of collective intelligence. Such pre-property may be activated, made emergent and collapsed by an external event like the detection of a predator for a flock or swarm. However, collective intelligence may be understood as an implicit pre-property, *potentially* given by multiple coherent structures. Actuation of potentialities is often given by fluctuations and perturbations as for *noise-induced phase transitions* (Horsthemke & Lefever, 2006). As a matter of fact, it has been observed how suitable noise intensities can give rise to *noise-induced phase transitions*, that is, phase transitions towards more ordered states which would be *impossible* in the absence of noisy fluctuations (see Carrillo, Ibañes, García-Ojalvo, Casademunt, & Sancho, 2003; San Miguel & Toral, 2000). It is interesting to note that the formalism used to deal with the effects of noise in spatially extended systems is very similar to that used in QFT (see Fogedby, 1998; Fogedby & Brandenburg, 1999; Mikhailov & Loskutov, 2012; Minati & Pessa, 2006, Chap. 5 and Chap. 6 of this volume).

Another example is given when the system *oscillates* among properties like symmetry, stability and dissipation. Many cases pertain pre-order related to assumptions, for instance, of symmetry.

Another case relates to *pre-disorder* when systems may oscillate between two types of disorder (see, for instance, Blavatska, 2013; Patel & Fredrickson, 2003):

- The *quenched* disorder, in which the parameters of the system are randomly distributed, but this distribution does not evolve with time.
- The *annealed* disorder, in which the parameters of the system are random variables which evolve however in function of the values of the state variables.

Pre-order is related to pre-phase transitions, pre-self-organization and when order or new orders can be acquired.

The *status* of pre-property relates also to *compatibility*.

First of all we may consider the scale, the *granularity*, e.g. temporal, at which we consider a process of emergence. Temporal sequences of a process of emergence at a suitable scale are coherent. However hypothetically there are no *prescriptions* for properties of the process occurring *between* (see Chap. 2, Sect. 7.1) two subsequent sequences when considered at lower scale, i.e. decreasing the microscopic level. The request of compatibility relates to *temporal extremes* where the process can start to lose and then reacquire the original coherence. In this case the process of *reacquisition* of the original emergence at the upper scale could be given by increasing compatibility with the original coherence when such increasing compatibility should be understood as pre-property at the lower scale. A conceptual example is given by considering frames of a movie as a collective behaviour. *Coherent continuity* may occur at a suitable temporal scale, while continuity and/or coherence may not occur at lower temporal or dimensional scale.

All this is an example of the conceptual world of the post-GOFS. Reductionism and GOFS both assume a ***world of skeletons*** *and that everything will be reducible to this level assumed* ***complete and explicit****.*

4.2 Quasi

We are going to use in the following the prefix *quasi*- already considered in a varieties of cases in different disciplines.

We will not present in details the several meanings and usages by limiting ourselves to consider the general *transversal* disciplinary meaning useful to consider in the following a real new generation of systems, i.e. quasi-systems.

It is interesting to consider that in the common language, the meaning of quasi is generally understandable as related to *non-completely* or *not yet* and *in the process of*.

4.2.1 Analogy and Metaphor

We consider in this section some aspects important to be clarified before to deal with the issue of *quasi*, i.e. logical inferences, like deduction, induction and abduction, and the concepts of analogy and metaphor. The process to make *analogies* is not properly a *logical inference*, like deduction, induction and abduction are. The process of *making inferences* may be understood as *generating conclusions* from premises (Pearl, 2000).

4.2.1.1 Deduction

Deduction is a kind of *inference* starting from necessary premises. Premises contain everything necessary to reach conclusions. Therefore, in a valid deduction, the conclusion cannot be false if all premises are true.

In the case of deduction, the most widely used rule is the so-called *modus ponens*.

A very simple example is:

- All the pieces in this box are black – rule (R).
- Those pieces come from this box – case (C).
- Therefore those pieces are black – result (Res).

4.2.1.2 Induction

Induction (Holland, Holyoak, Nisbett, & Thagard, 1986) is an inference, which from a finite number of particular cases leads to another case or to a general conclusion. Because of that, induction has probabilistic nature.

A very simple example is:

- Those pieces come from this box – case (C).
- Those pieces are red – result (Res).
- All the pieces in this box are red – rule (R).

4.2.1.3 Abduction

In the case of abduction a reasoning of this kind is adopted:

- The starting point is a collection of data D.
- The hypothesis H, if true, could explain D.
- No other hypothesis can explain D better than H.
- Then H is probably true.

There is a *hypothesis inventing process* that may be even viewed as a *selection* among the most suitable ones for explaining D.

With abduction, a process of *clustering* is carried out, grouping together variables that are most probably related (or, more precisely, that it is suitable to think they are): *Because B is true probably A is also true, since if A were true the truth of B would be obvious*. *Charles S. Peirce* defines his concept of *abduction* in the following way: ‘Abduction is the process of forming an explanatory hypothesis. It is the only logical operation which introduces any new idea (Peirce, 1998)’.

4.2.1.4 Metaphor

In short there is a metaphor when descriptions of objects or processes are used to describe another different one and one is described in terms of the other (Kovecses, 2010). The metaphor aims to introduce *hypothetical* representative identities.

It is matter to represent *something* not well known in terms of something else better known. The equals, ideals and hypothetical representations introduced by a metaphor can also be very misleading. For example, consider, as it really happened, the electric current as *flow*, the *flow* of time, the *flying* of thought and the *life* of a company. Neither the physical properties of fluid dynamics related to the flows of matter, nor of the flying, nor of the biological properties of living matter are applicable.

The metaphor does not suggest in fact *extensions of the same approach*.

4.2.1.5 Analogy

The process to make analogies may be intended rather as a kind of *incomplete induction* being, for instance, not *only probabilistic* but also related to variable clusters of properties for which to consider probability (Bartha, 2010; Gentner, Holyoak, & Kokinov, 2001).

When considering two entities A and B, an analogy between them is established in the case, for example, in which A possesses all the attributes a_n and B instead possesses attributes a_n, but not $\{a_k\}$, with $1 \leq k < C < n$, where C is the *level* of analogy. An analogy can then relate to the regularity of partial match or matches between properties of processes. It is a matter of using the partial representation of a process to represent another one. Afterwards a simple form of analogy is given by dynamics and shapes as keeping topological properties.

An analogy can then concern the partial correspondence or regularity of correspondences between properties of processes. For example, the dynamics of processes can be described by analytical representations having common properties such as growth, increasing growth and continuity as in the case of logistics.

This can then be detected not by the *whole* dynamics but only for special cases that recur with regularity, such as with periodicity. For eventual representations in phase space, it can instead be considered the *type* of attractors. It is a matter to use the partial representation used to represent a process to represent another one.

A form of simple analogy is then given by the *proportionality* between measures used for processes and shapes.

The *logical power* of analogy stays therefore in detecting partial matches.

We mention for completeness the concept of *analogue computer* operating with *directly measurable quantities* like electrical, pressure and motion, rather than symbolically (Saggio, 2014).

4.2.2 *From Analogy to Quasi*

The concept of quasi that we are considering here may be understood as considering *sequences* of analogies assumed related to the *same* entity or process. The quasi may be introduced also as *continuous analogy*. The concept of quasi intended as continuous analogy may be intended to occur when, in the definition introduced above, k is continuously changing both as value and with regard to properties.

The concept of quasi-property may be in some ways related to the huge category of fuzziness, i.e. *fuzzy sets, fuzzy logic and fuzzy systems* introduced by *Lofti Zadeh* (Klir & Yuan, 1995; Zadeh, Klir, & Yuan, 1996) where a fuzzy property may be understood to occur having different probabilities, levels of intensity or completeness.

We comment that the difference between *quasi* and *fuzzy* relates to the dynamical and ***structural incompleteness*** *of the first, real identity of the quasi, while the fuzzy relates to the well-defined, even probabilistic,* **levels of belonging** *along time.*

This structural incompleteness may be given by *inhomogeneities* of different natures well represented by quasi-properties considered at Sect. 4.4 and the case of Multiple Systems introduced at Sect. 4.5 when multiple belonging and multiple interacting are *variable*, i.e. irregularly interesting different clusters of elements along time and per instant.

The structural incompleteness does not relate to *converging* processes but to keeping such incompleteness as identity, as dynamics allowing, for instance, the changing of degrees of freedom between states as discussed above and sources of equivalences for processes of emergence; see Sects. 3.7 and 3.8.

We consider the *implicit* conceptual framework represented by the usage of the term *quasi* as suitable to apply and depict several of the new aspects of the *perspective* new, post-GOFS systemics considered in the previous chapters such as between dynamical coherence, non-explicit, systems identity, transient and uncertainty. Other aspects are, for instance, quasi-homogeneity, homology, iteration, openness, probabilistic, random, regularity and reversible. The list may include quasi-Turing machines, and we could explore *quasi-meta-structures*.

The concept may be extended, generalized by introducing one of the ***quasiness*** *intended as dynamical stability in possessing quasi-properties introduced later.*

The quasiness is a *generic* property, and eventual general approaches suitable to measure its degrees and compare its levels are difficult to be implemented and perhaps of doubtful effectiveness considering the dynamics that characterizes the property.

The ability to *formalize* is expected in a nonclassical way; see Chap. 5 – the quasiness is the challenge for the new systemics. It is not related to the becoming between states but to the *structural becoming*. Examples of structural becoming allowing quasiness are given by levels of emergence, properties as coherences and meta-structural properties and evolving multiple networks (see Chap. 7).

4.3 Quasi-properties

In this section, we will consider the concept of quasi-property and some cases.

The term is used in cases like *quasi*-classical, concave, ergodic, homogeneous, lattice, Newton methods, particle, periodic, quantum, species and zero.

A typical example is given by quasi-crystals (Janot, 2012; Varn & Crutchfield, 2015) possessing an ordered but not periodic structure. There is not translational symmetry as in crystals.

A non-emergent, i.e. established by functional and structured interactions, or emergent-acquired systemic property may be:

1. Stable and regular.

2. Unstable, having regularities, local and eventually partial.
3. Part of a stable or dynamical mix of stable and unstable properties.

Quasi-properties are intended to occur for cases 2 and 3.

Examples of *systemic* quasi-properties are given by:

- Quasi-openness, when the property is, for instance, temporally *unstable*; *partial*, i.e. dynamically relating to some aspects of the system like energetic, input processing; and *local* like relating to some subsystems or eventual structures only. In the same way, we may consider properties like quasi-order and quasi-autopoietic.
- Quasi-emergence, when there is, for instance, coexistence of emergence and organized systemic properties being the mix and the sequences of any kind. Examples are given by biological collective behaviours where living agents combine emergence and structures and collective behaviours *with leader* as for migrations (Guttal & Couzin, 2010). The same may be considered for quasi-self-organization. Other more generic examples are given by social systems like corporations, families, hospitals and schools continuously combining in different ways and time global structures and local emergences.
- Quasi-coherence, taking place when there is the occurring of multiple non-synchronous coherences and as properties of subsystems.
- Quasi-network, when links among components assumed to become *nodes* are not connecting all the components or links are unstable.
- Metastability where different stabilities are possible, see Sect. 4.4.1.

Besides with regard to the example of *pre-disorder* considered in 4.1, we may have *quasi-disorder* when the *quenched* and *annealed* disorder occur partially, in inhomogeneous way and relating to some aspects of the system only.

Furthermore quasi-scale invariance may relate to phenomena where scale invariance is not *global*, as in case of local scale invariance (LSI), see (Henkel, 2002) and multiple scale invariance in turbulences (Lesne & Laguës, 2011).

We mention that a different meaning occurs for *quasi-analytic class of functions* when if two functions of the class coincide *locally*, e.g. on an interval $[a, b]$ on the real axis, then they are identical. *Local* coincidence means equality of the functions in the interior of entire interval (Beurling, 1989).

An instant of a quasi-property may coincide with an instant of a pre-property.

We may summarize as in Table 4.1.

4.4 Quasi-systems

We may first of all ask ourselves if the status of quasi-system is *coincident*, as necessary and sufficient condition, with the possession or acquisition of quasi-systemic properties. We may tentatively distinguish among some cases. For instance:

Table 4.1 Pre-properties and quasi-properties

Pre-properties	Analogue, compatible, converging, convertible, implicit, necessary, and of increasing strength. Related to space of properties having eventually properties. The concept of pre-property may be intended representing sets of properties visited or acquired by the system over time by keeping levels of coherence while assuming definitive *convergence* to one specifically.
Quasi-properties	Structurally partially possessed by a quasi-system in an eventual inhomogeneous and instable ways. Temporal, unstable, partial, i.e., relating to some aspects of the system, and local, i.e., relating to some subsystems only. Metastability. Structural incompleteness, real identity of the quasi.

An instant of a pre-property may coincide with an instant of a quasi-property and vice versa
They are different for their evolutionary paths: pre-properties are convergent, while quasi-properties are not

- A quasi-system may be given by a system when possessing dynamical structural aspects of instability due, for instance, to local or temporal *inhomogeneity* of its status of system. Correspondingly systemic properties will be local or temporal. For instance, a corporation may act as such, i.e. as a system, only during the working hours, and some departments may act as assembly lines, i.e. as structured sets instead than systems or just as sets depending on the tasks and environmental actions. An electronic system may be constituted of subsystems activated on request otherwise inactive structured sets of components.
- A quasi-system may be given by the *inhomogeneous* possession or emergent acquisition of systemic properties. For instance, an ecosystem may have different *levels of openness* depending on spatial location when some areas may be iced or shielded from light. A system may have openness related to different aspects like be open to energy but not to information and have such openness at different levels along time. A cognitively open system may have limited levels of openness such as ability to adapt but by using a limited selection of cognitive models. A biological system may have *dynamical interacting polipathologies*. A collective system may be able to acquire collective intelligence and assume intelligent behaviour only for specific events.

In the cases above, it is the ***nature of the system*** *making it to possess or acquire regular systemic properties as quasi-properties.*

We mention that forms of *degenerations* of Multiple Systems and Collective Beings may be considered examples of quasi-system when making reference to cases presented at Sect. 4.5.1:

(a) Agents may *simultaneously* belong to different systems.
(b) Agents may *dynamically* give arise to *subsequent* different systems.

The degeneration is intended to occur when agents do not belong anymore to *any* system, for instance, when in a flock a boid *becomes* isolated.

When considering quasi-properties, *it is the* ***nature of the properties*** *making the system as regular or quasi-system.*

Quasi systems ***convert*** *regular systemic properties into quasi-properties.*

Quasi-properties ***convert*** *a regular system into a quasi-system.*

In case of mix of regular and quasi-properties, (a) if possessed by a quasi-system, the quasi-nature of the system remains; (b) if possessed by a regular, i.e. non-quasi-system, its nature may vary depending on the mix.

It is possible to outline that future post-GOFS system research will concentrate on new issues and new concepts such as innovations in the concept of the system itself by considering, for instance:

- *Instable* systems, i.e. not being system all the time.
- *Partial* systemic properties such as local and eventually regularly or not regularly oscillating, when areas of the systems cease to have systemic properties for time periods or they lose their coherence, as because of drawbacks, perturbations and diseases in case of living systems.
- *Multiplicity* and its eventual related properties like varying along time, of systemic properties themselves.

It is matter of abandoning simplified dichotomous visions such as *systems* or *nonsystems*.

It is matter to apply also to systemics the concept of quasi not intended as *state* of incompleteness but as *structural* partiality, transience and multiplicity of properties that can be at different levels of diffusion and temporarily simultaneous or subsequent, similarly to the phase transitions of the first kind, like water ice vapour, where it is possible the coexistence of phases as opposed to those of the second kind such as paramagnetic-magnetic, where contemporary different phases are not possible. Other cases are given by multiple coherences, multiple emergences and dominions as at Chap. 7.

Even in these cases, the ability to detect *partiality* of properties, considerable as quasi, allows to detect the dynamics of properties and the possibility of directing them by identifying and facilitating evolutionary paths otherwise equivalent or identical.

Quasi-systems are understandable as systems ***in continuous structural becoming*** *eventually waiting for events to collapse, i.e. assume converging evolutionary paths and coherences when quasi-systems* ***transform*** *into systems. Conceptually it occurs when quasiness gives way for any reasons to structural stability and homogeneity of properties.*

When dealing with GOFS, the quasi is a limitation signal of incompleteness to be eventually fixed and *completed*. In GOFS the quasi is assumed as freedom where ‘request’ to *complete* in order to reach the expected single finality or equifinality may occur.

In the post-GOFS, the quasi is signal of complexity eventually in progress: it seems a kind of ***necessary condition*** *of continuous structural openness to acquire properties, i.e. complexity*. However, we may consider the quasiness even related to complexity itself in a sort of *levels of quasiness* like for *quasi-emergence*. These kinds of processes may be intended to take place from different points of view. For instance, it is possible to consider processes where a collective system *oscillates* between usual single-structured phases and phases characterized by different coherences not due to single structures. It may be understood as *keeping emergent the same coherence rather applying the same structure*. Quasi-emergence may be also understood to take place when there is simultaneity of structured interactions and self-organization like in institutions and corporations officially ruled by precise official regulations but occurring in reality by a huge variety of *modalitie*s often termed as *informal organization*. In such situations, it applies the term *quasi-emergent* since due to phenomena of different kinds.

Within a biological collective system under attached by a predator, a balance may occur between agents assuming behaviour maintained as collective and agents assuming individual escaping behaviour like for evacuation (see, for instance, Helbing, Farkás, Molnár, & Vicsek, 2002).

Other examples are given by the atmospheric system, ecosystems, social systems and economical systems of suitable dimensions and temporal scale having dynamical structures and properties.

4.4.1 Specific Forms of Quasiness

We list now some cases of kinds of systems having eventual *specific forms of quasiness*.

A first case considers systems far from the equilibrium such as *dissipative structures*. However, even if some analogies are possible between quasi-systems and dissipative structures, the property of quasiness is not necessarily due to dissipation and to keeping far from equilibrium but to structural reasons and dynamical coherences and may apply to a huge amount of properties other than thermodynamic. However, quasiness may be given by the fact that a system can be dissipative in different ways. Such ways and the related quasiness are represented by geometrical *irregularities* of trajectories around attractors and even by the nature of attractors (Mori & Kuramoto, 2011).

A second case relates to the so-called *disordered systems* (Klinger, 2013) where individuality is more important than general laws. Examples are given by (a) glasses where the composing elements are arranged randomly in space as opposed to ordered systems like crystals where the composing elements are arranged in stable patterns and (b) *spin glass*, magnet with so-called *frustrated interactions* displaying stochastic disorder when ferromagnetic and antiferromagnetic bonding is randomly distributed like in chemical glass. Accordingly, suitable approaches to model such systems are named *non-homogeneous*. The approach considered in this case is *non-homogenous* since elements are assumed distinguishable as opposed to the *homogeneous approach* when assuming single elements possessing identical features and then indistinguishable. In this case quasiness is represented by inhomogeneity.

A third case considers *metastability* (see, for instance, Slowik, 2012). The concept of quasi-systems is well represented by metastable systems having *local* *minima* called *metastable equilibrium states*. More properly, considering a system of non-linearly coupled non-linear oscillators metastability is intended as property of the system where there is the simultaneous tendency of components to function autonomously and a tendency to assume a coordinated activity. A classical nontrivial case occurs for phase transitions. For instance, in the *first-order phase transitions* at the onset of the transition, the new phase appears as very small nuclei (for instance, small crystals, fine liquid droplets, small vapour bubbles) which, as the transition advances, undergo a dynamical growth process. However, it could occur that, under suitable conditions (for instance, the absence of external disturbances, very slow heat liberation or absorption, absence of impurities), the phase transition cannot take place and the initial phase continues to survive, even after crossing the critical curve, in a situation which is no longer thermodynamically stable. This situation is named *metastable* when in the presence of suitable disturbances, the metastable initial phase disappears and suddenly a phase transition produces the new stable phase. A *metastable state* is represented by suitable stationary values, and metastable equilibrium states for dissipative structures are also called *far from equilibrium stationary states*. The quasi relates to the fact that the meta-stability is kept and not *solved* by selecting one of the possible phases. The quasi may relate to properties of eventual regular oscillations among metastable phases.

A fourth case relates to emergence when an emergent system is a quasi-system since being in reality considerable as *collection of compatible*, *equivalent*, as of acquired emergent properties, different quasi-systems. This relates to the fact that a specific process of emergence may occur in different ways, establishing a quasi-system acquiring the same emergent properties (and *identity* of the system like being a swarm, an industrial district or a network). As we will see later, this is the case for Quasi-Multiple Systems when coherence of collective behaviours is intended given by coherences among different equivalent emergent multiple systems rather than sequences of structurally fixed, i.e. non-emergent, systems.

4.4.2 Levels of Quasiness

It is possible to consider the level of quasiness of a system as the 'difference' of the system from its non-quasi *completed* version.

It is possible to consider *levels of quasiness* of quasi-systems by using some suitable quantitative approaches. It is possible, for instance, to consider the *percentage* per instant of composing elements (a) involved in specific systemic properties quasi-possessed or quasi-acquired, (b) following some structures and (c) interact in some specific ways. In this way it is possible to also delineate a kind of *history of the quasiness* of a quasi-system in analogy with the *history of usage* of degrees of freedom considered at Sect. 3.7 and as considered by using the mesoscopic general vector as at Sect. 3.8.3.7. The ways of changing of the quasiness of a quasi-system along time may be considered to represent processes of acquisition, starting and even degeneration of self-organization and emergence at suitable scale. The *level of quasiness* may signal and correspond to critical phases of processes of self-organisation and emergence allowing to prevent, for instance, degeneration and disintegration. The availability of suitable data and approaches allows, for instance, detection of *critical points* in collective behaviours by distinguishing *physiological* quasiness when some elements definitively or temporally abandon the collective behaviour and when a process of disintegration is ongoing. Quasiness may assume aspects related to its eventual network representation like for diseases (Ki et al., 2007).

We should ask ourselves which are the eventual *relationships between quasiness and identity* as introduced in Sect. 3.5. Which levels of quasiness are compatible with the keeping of the same identity, and which one can be considered the breaking level? The first cases that come to mind are related to fault-tolerant systems, resilience and *robustness* of processes of synchronizations. Robustness here should be understood as acceptable quasiness keeping identity of the system.

However, the interest here is to consider properties of the changing of *physiological* quasiness as related to the *nature* of the system rather than its robustness. History of the system's quasiness and its structural changing (for instance, from relating percentages of elements to percentages of rules of interaction used, and so on), it will tell about the *structural change of the system* and its coherences rather than about the *change of the same system* as for structural changing; see Chap. 3.

Quasiness relates to ***balances*** *between coherence and incoherence, while levels of quasiness relate to non-perturbing or perturbing effects on such balances.*

Typical examples of such quasi-systems are biological living systems and ecosystems where the non- or low-invasive, light co-management allows the support of systemic identities, like life and health of lakes (e.g. against eutrophication) and mountains. Other well-known examples are given by social systems, e.g. organized criminality, and emergent quasi-systems where the levels of quasiness have cultural, economical, energetic, environmental and political aspects.

We conclude by saying that considering non-quasi systems looks at this point as a matter of ***simplification****. The reason to introduce all the concepts above about the subject of quasiness is to allow systems scientists to better carry out approaches and tools to act on such systems by considering, for instance, lightness as non-invasiveness. In the conceptual framework of the GOFS, these kinds of systems are* ***invisible*** *or reduced to usual systems. This is source of unsuitable, reductionist approaches like in biology when not deal with complex multiplicity of diseases and health* (Cesario et al., 2014) *and social systems.*

4.5 From Collective Beings to Quasi-collective Beings

Instead of Multiple Systems, we may consider multiple quasi-systems when (a) systems in play are quasi-system, their coherence is not homogeneous and variable, and (b) multiple interactions occur irregularly, and some elements may be not involved in the processes of interaction along time.

4.5.1 Multiple Systems and Collective Systems

The concept of *Multiple System* has been introduced in Minati and Pessa (2006, pp. 110–137) as coherent set of systems having components belonging to more than a single system. Similar understanding is considered for multiple networks where same nodes may belong to different simultaneous networks (Nicosia, Bianconi, Latora, & Barthelemy, 2013).

Multiple belonging to different systems is considered given by the occurring of multiple dynamical and context-sensitive combinations of single rules of interactions as introduced in Chap. 3 *generating, in this case, corresponding Multiple Systems*. While in some cases Multiple Systems can be effectively identified, as in the examples below, they can be *supposed* as modelling approach when dealing with collective multiple interactions.

Multiple belonging to different systems is considered ***also*** *given by the occurring of multiple dynamical and* ***contextual multiple contextual roles****.*

The roles, states and actions have simultaneous multiple different *significances*. We consider simultaneous systems or sequences of systems when the same components can correspondingly play, both simultaneously and at different times, several, eventually interchangeable, *unintended multiple* roles and give rise to the emergence of different systems. This is the case when different components may be simultaneously part of different systems when they play *different independent roles*. Examples are given when the reaction of an organ while, considered as component of a living system, may also be a source of information when using diagnostic and regulatory techniques; the output of an electronic subsystem or component may be also a source of information for networking, regulatory and security monitoring system. Another example is given by networked interacting computer systems performing cooperative and shared tasks such as for the Internet. It is also possible to consider the case of the *counterpoint* music in Baroque music (de la Motte, 1981; Howen, 1992) with particular reference to *Canons* and *Fugues*. We consider the *multiple* roles of the same themes. For instance, in a Canon, a theme is *opposed* to itself: each one of the several voices performs a copy of the theme. Furthermore, a theme forms the basis for a Canon, when *each of its notes can take on different roles*, by having more than one single musical meaning in the mind of the listener.

We stress that multiple ***belonging*** *and interchangeable roles are in this case* ***passive*** *for components, while it is* ***active*** *when multiple interacting is selected by components.*

Collective behaviours may be intended as coherent superimpositions of different systems when same elements may simultaneously interact, for instance, by considering their distances, speed and altitude (see Sect. 3.8.2).

An interesting aspect of Multiple Systems relates to take in count *interchangeability* between interacting elements allowing to consider coherence of the emergent behaviour, for instance, as ergodic (Petersen, 1989; Walters, 1982). However, we need to consider also that the *same* system can be *both* ergodic and non-ergodic depending upon the time scale of the observer, as in polymers (Kotelyanskii, Veytsman, & Kumar, 1998).

It is possible to consider the ergodic behaviour of Multiple Systems by referring, for instance, depending to the phenomena under study, to *classes* of distances, speeds, altitudes, directions and prices of interacting elements.

We focus a little below on ergodicity because of its ***clarity*** *on considering the problem rather than for its applicative possibility to real cases.*

Migration of elements in Multiple Systems from one class to another one and simultaneously belonging to more than one is not *active*, but a matter of *belonging*, i.e. interchangeability of roles intended as belonging to classes; see Sect. 3.8.4.2.

Interchangeability of roles within collective behaviours can be considered represented by its ergodicity.

This is, of course, an idealistic simplified situation. We should, rather, consider different more realistic situations.

We may consider cases of *multiple ergodicity* related to the ergodicity of the values adopted by different state variables, e.g. speed, direction and altitude, and by different clusters as stated in Sect. 3.8.4. The degree of ergodicity is given by:

$$E_{\varphi} = 1/\left[1 + \left(X_{\varphi}\% - Y_{\varphi}\%\right)^{2}\right]$$

where we may consider $Y_{\varphi}\%$ as the average percentage of time spent by a single element in state S and $X_{\varphi}\%$ *as* the average percentage of elements lying in the same state over a given observational time and considering a system composed by finite, constant over time number of elements. The state shows ergodicity when $X_{\varphi}\% = Y_{\varphi}\%$ and the degree E_{φ} adopts its maximum value of 1.

This is assumed to occur for the *entire* system and the entire observational time in the assumption of complete ergodicity, while it may occur *dynamically* and per zones for quasi-systems and when ergodicity is not the *primary responsible* for coherence. The approach can be extended by considering *weak ergodicity* (Coppersmith & Wu, 2008).

The *ergodic hypothesis* states that, given an infinite time duration, the trajectory of the point representing the entire system in the phase space will pass through every point (or as *close* as we want to every point in the *quasi-ergodic* hypothesis) lying on the energy hypersurface.

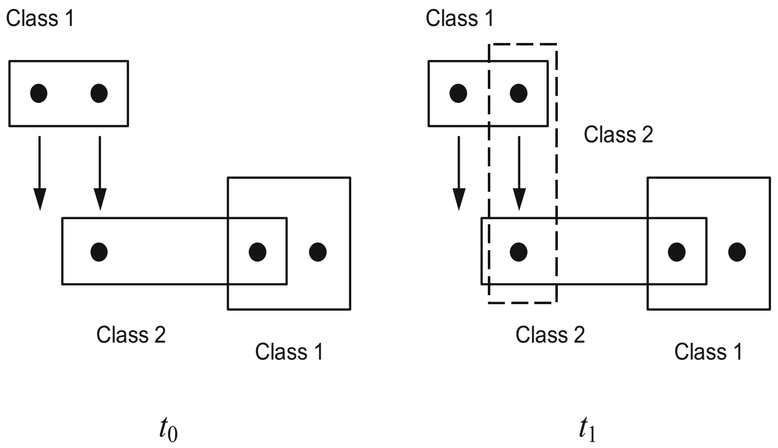

Fig. 4.1 By considering only two classes we have an example of multiple belonging from time t_0 to time t_1

Elements X_i may, for example, be represented as points in an n-dimensional space.

We consider a simplified situation which could occur in a two-dimensional space that could, for instance, be depicted as shown in Fig. 4.1 (Minati & Pessa, 2006, p. 304).

Multiple interactions are assumed to make elements to assume ergodic properties such as related, in this case, to distances. Ergodic is not the ***way*** *to interact but the effects of suitable multiple interactions.*

The *status* of Multiple System can be then considered both as *epiphenomenological* or related to the level of representation assumed by the observer.

Conversely, an *active interchangeability* becomes possible when interacting elements are *autonomous*, i.e. provided with a cognitive system possessing sufficient complexity to remember and respect *behavioural degrees of freedom*, and take decisions depending on the context and environmental conditions.

This is the case of *Collective Beings*, particular Multiple Systems established by agents possessing a (natural or artificial) cognitive system.

It is possible to identify almost two kinds of processes of *emergence of Collective Beings* from agents assumed possessing the *same cognitive system*, typically when belonging to the *same species* as for flocks and human beings:

- In one case agents interact by using the same cognitive model implying multiple roles, such as for collective behaviours.
- In other cases agents interact by simultaneously or dynamically using eventual different cognitive models.

The first case relates to contexts having *fixed behavioural rules* only admitting *parameterization*, while the second relates to contexts having *variables rules*.

Examples of the first case are given by flocks, swarms, herds and school fishes. Examples of the second systems are given by *human social systems* when:

(a) Agents may *simultaneously* belong to different systems (e.g. behave as components of families, working places, traffic system, buyers and mobile telephone networks). *Simultaneously* is related to the agents' behaviour, considering their simultaneous belonging, their roles in other systems. A buyer *while* buying also contributes to establish the system of buyers in the local store, performs a role for its family by selecting a product, performs a behavioural role within the facility and security system of the store and influences the local ecosystem.
(b) Agents may *dynamically* give arise to *subsequent* different systems, like temporal communities (e.g. attendance, lines and on a bus), in different times and without considering multiple belonging.

The collective interactions of Collective Beings allow them to collectively ***react****, i.e. cognitively and collectively make emergent their response behaviour.*

A scheme of Collective Beings is presented in Fig. 4.2 (from Minati & Pessa, 2006, p. 123).

We stress that Multiple Systems are both ***effective systems*** *as in the examples mentioned in the* Sect. 4.5.1 *and ecosystems, and* ***supposed as suitable modelling approach*** *since in several cases Multiple Systems considered above cannot be identified* ***analytically****, i.e. considering all the specific interactions used by agents per instant, because the problem is* ***intractable****, like for general collective behaviours.*

Another possible research approach to model in a more generalized way coherence of Multiple Systems and Collective Beings other than considering ergodicity and *level of ergodicity* is given when considering meta-structures and meta-structural properties as introduced above. However, as stated in Minati and Licata (2012), *any ergodic Multiple System possesses meta-structural properties* (see Sect. 3.7), while *any collective behaviour* may be intended to *possess meta-structural but not necessarily ergodic properties.*

Other representations and models not based on ergodicity are, of course, available. It is possible, for instance, considering scale invariance (Cavagna et al., 2010), network representations with related properties, models of artificial life (Bonabeau & Theraulaz, 1994), methods of theoretical physics in order to describe the emergence of collective behaviours as flocks (Darling, 1938), swarms (Bonabeau, Theraulaz, & Deneubourg, 1996; Lindauer, 1961; Millonas 1992, 1994), fish schools (Breder, 1954; Echelle & Kornfield, 1984), herds and ant colonies (Deneubourg & Goss, 1989; Deneubourg et al., 1991; Deneubourg, Aron, Goss, & Pasteels, 1990; Deneubourg, Goss, Franks, & Pasteels, 1989; Deneubourg, Goss, Pasteels, Fresneau, & Lachaud, 1987; Deneubourg, Pasteels, & Verhaeghe, 1983; Franks, Gomez, Goss, & Deneubourg, 1991; Goss, Beckers, Deneubourg, Aron, & Pasteels, 1990; Holldobler & Wilson, 1990; Millonas, 1992, 1994) and several other approaches like the ones based on partial differential equations. A general overview is available in Vicsek and Zafeiris (2012).

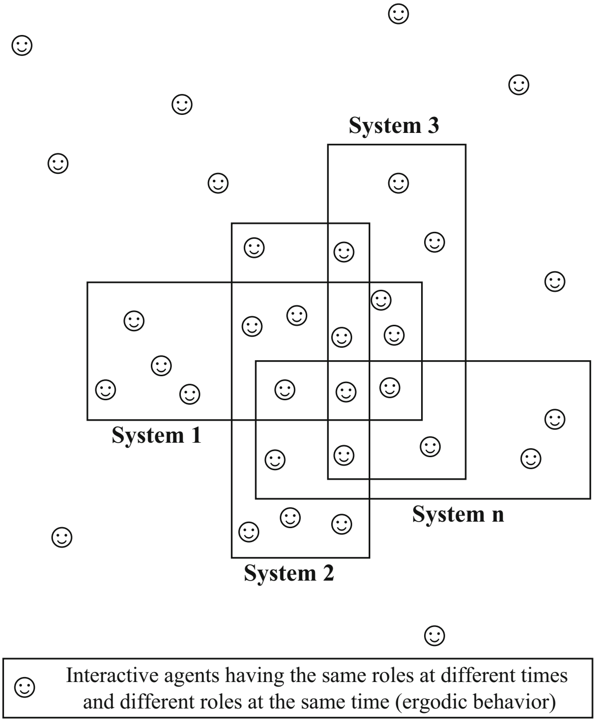

Fig. 4.2 Illustration of the concept of Collective Being

Several approaches are available to model and simulate collective behaviour like in (Bajec, Zimic, & Mraz, 2005, 2007; Couzin, 2009; Cucker & Smale, 2007; Cziròk, Barabasi, & Vicsek, 1999; Huepe & Aldana, 2011; Huth & Wissel, 1992; Quinn, Metoyer, & Hunter-Zaworski, 2003; Reynolds, 1987, 2006).

4.5.2 Interchangeability as Strategy

Dealing with the generic *defence* purpose, collective behaviour (see, for instance, Sumpter, 2010) can be understood as the implementation of the strategy of making roles and positions *equivalent* for the threat through interchangeability between interacting agents which take on the *same roles at different times and different roles at the same time* like in ergodic behaviour and for Multiple Systems and Collective Beings considered in the previous section.

Each component should be *equivalent* to each predator or external threat. The purpose is to divide the single probability of being the object of an attack or an external threat so that individuals have *minimized* the possibility to be involved (Krause & Ruxton, 2002; Pulliam, 1973).

Hypothetically, the larger the collective behaviour is, the minimum the probability for the individual to receive an external attack (for studies related to *density*, see, for instance, Ballarini et al., 2008).

On the other side, collective behaviours and their size increasing may *facilitate* the task to predators not interested in a single specific prey – the predator is not assumed to *select*. This is the case for *large* flocks.

Moreover, the larger is the flock, the more boids may detect the presence of threat. In the same way, when a group of boids is eating, the possibility to detect a threat compared to the one possible for a single-eating boid is higher (Anderson, 1980; Hemelrijk & Hildenbrandt, 2011; Pulliam & Caraco, 1984).

However, we must note that some competition may *noise* the group behaviour like competing for food or *polarizing*, i.e. degree of global ordering, when the flock detect food (see, for instance, Viscido, Parrish, & Grunbaum, 2004).

Collective behaviour may also allow assumption of *collective intelligent actions* allowing, for instance, the so-called *predator confusion* (Handegard et al., 2012; Jeschke & Tollrian, 2005, 2007; Krakauer, 1995; Olson, Hintze, Dyer, Knoesterm, & Adami, 2013; Tunstrøm et al., 2013; Vabo & Nottestad, 1997).

In case of collective behaviour, the possibility of *repeating* an *attacking* collective action, e.g. to sting or peck, or implement a *defence* collective strategy, e.g. herrings, reflect the light giving the predator the impression of being in front of a large being that is in reality collective. *High frequency of weak actions substitutes impossible strong single actions, moreover with the advantage of flexibility to adapt.*

Such flexibility is based on conceptual interchangeability.

4.5.3 Quasi-multiple Systems and Quasi-collective Beings

We mentioned in Sect. 4.5.1 how Multiple Systems relate to both effective systems and *supposed* as suitable modelling approach.

The concept of quasi allows more realistic modelling avoiding formal and rigid assumptions of general representations by using rule-based approach considered having general validity unless, eventually, context-dependent parameterizations.

The concept of quasi applies to Multiple System and Collective Beings when they are based on Quasi-Multiple Systems. Furthermore, multiple interactions may be quasi, i.e. occurring in partial, non-regular way when some of them may do not occur at all.

By considering the modelling based on ergodicity, we deal, for instance, with *multiple ergodicities* interesting different systems of the Multiple System or Collective Beings.

In these cases we deal with sequences of different *local* ergodicities changing over time and related, for instance, to specific interactions.

In this case *coherence among different ergodic multiple systems* may be modelled by using different approaches like considering synchronizations and networks.

A specific collective behaviour may be modelled as *resulting* from varieties of multiple, simultaneous *crossing* (*on* same agents) of multiple systems conceptually corresponding to the scenario depicted in Sect. 3.8.2.

A Quasi-Multiple System ***differs*** *from a specific Multiple System since it is composed by a variety of* ***compatible possible multiple quasi-systems****. This is the* ***light*** *version of the Multiple Systems.*

This is the case when systems establishing a multiple system are emergent (or eventual suitable dynamic combinations of equivalent, compatible, emergent and non-emergent systems) as at Sect. 4.4.1. In this case multiple interactions between same elements establish not only different systems as in the original definition of Multiple System but different emergent systems. In the latter case, *emergent systems are cases of a quasi-system* being in reality considerable as *collection of possible, compatible*, *equivalent* systems constituted by same elements.

Interchangeability, assumed for granted when considering ergodic models, is limited and *fuzzy* in these cases since equivalence relates to acquired emergent properties *only*.

Different *combinations* of such (emergent in this case) quasi-systems establishing Quasi-Multiple Systems may occur, *besides their coherence* considered later as given by properties of their single specific meta-structural or network properties, having the effect to optimise robustness, sensibility to environmental conditions and ability to reconfigure and to adapt.

We consider now *how to model such process of combination.*

We will consider in the following the level of quasiness of emergent systems, intended as Quasi-Systems for the reasons introduced above since they may emerge in a variety of equivalent ways, as given by their properties characterizing the varieties of equivalent different *ways* to emerge (coherent sequences of configurations of a flock are not unique, being different instantaneous configurations possible, compatible and equivalent for the global coherence).

Coefficients of scale invariance, network and meta-structural properties are considered to represent processes of emergence of collective behaviour. *Actually there are* ***different ways*** *and configurations by which* ***same property*** *of this kind may be respected.* Such different ways represent the quasiness of the emergent system, its being Quasi-System.

We may consider the conceptual correspondence with the approaches introduced in Sect. 3.8.4.

However the case under study here does not relate to the specific collective behaviour of a specific emergent system but to the collective behaviour of correspondent emergent systems, intended to *combine* in a Multiple System.

Approaches considered in Sect. 3.8.4 like the mesoscopic dynamics, see Sect. 3.8.4.7, and structural regimes of validity, see Sect. 3.8.5, are not considered here for *agents of the general collective behaviour* under study but for *single emergent systems having specific meta-structural or network properties*.

Because of that, the focus shifts here from mesoscopic properties of agents and meta-structural properties of mesoscopic variables to *properties of sets or sequences of meta-structural properties*. In conceptual analogy with the approaches introduced in Sects. 3.8.4 and 3.8.4.7, we consider here meta-structural properties rather than mesoscopic properties, *focusing on systems rather than on agents*.

At this regard it is possible to consider a collective behaviour as given by the behaviour and properties of a Quasi-Multiple System.

When considering the collective behaviour given by agents interacting in different ways as in Multiple Systems, we may apply the approaches introduced in Sect. 3.8.4 considering agents, mesoscopic properties and following meta-structural properties.

When considering the collective behaviour given by multiple single collective behaviours each establishing Quasi-Systems then combined in Quasi-Multiple System, we should consider the *properties of the single, emergent Quasi-Systems, like meta-structural and network intended as levels of quasiness. The reason by which we consider levels of quasiness of emergent systems as given by properties stating the coherence of the systems, e.g. coefficients of scale invariance, network and meta-structural properties, is that such properties may be respected by different, instantaneous systems playing equivalent, compatible roles in the process of emergence, which is quasiness.*

The general approach considered here focuses on ***levels of quasiness*** *and their properties, like periodicity, synchronization, correlation and properties of values assumed by the* ***meta-structural general vector*** *along time*:

$$\mathrm{MST}_{h,sn}(t_i) = \left[p_{h,1}(t_i), p_{h,2}(t_i), \ldots, p_{h,sn}(t_i)\right]$$

where

- h identifies one of the h meta-structural properties[3] possessed by the collective behaviour along the time of study.
- sn identifies one of the total number[4] of emergent quasi-systems established along the time of study.
- $p_{h,sn}$ takes the value 1 if the system sn possesses the meta-structural property h at time t_i or the value 0 if it does not.

The same concepts and approaches proposed above for Quasi-Multiple Systems applies when considering *Quasi-Collective Beings*, where Collective beings are

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[3] Same meta-structural property will be considered to give eventual rise to different meta-structural properties depending on different parametrical values.

[4] Since the multiplicity of emergent quasi-systems is here only *supposed* as approach and analytically unrecognisable in collective behaviours, their number should be also supposed as given by the number of meta-structural properties valid per instant and along time, however, considered *coincident* when differentiated only by parametrical values.

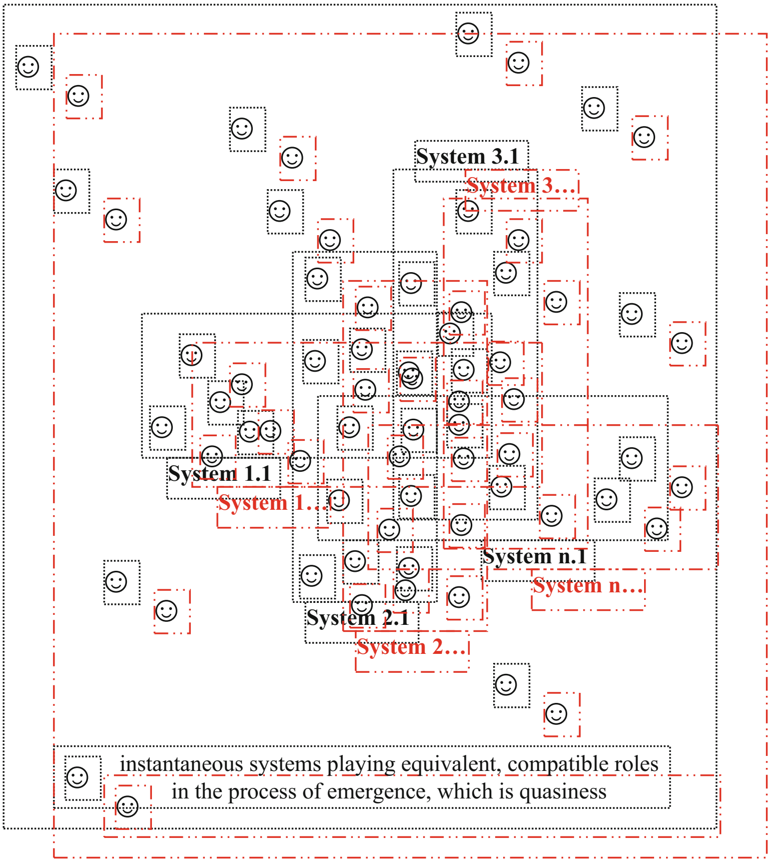

Fig. 4.3 Illustration of the concept of Quasi-collective Being

particular Multiple Systems established by agents possessing a (natural or artificial) cognitive system as introduced in Sect. 4.5.1.

We will not elaborate here the correspondence between the two cases. However we would like to mention how Quasi-Collective Beings are suitable to deal with collective and multiple behaviours of social systems.

Levels of quasiness, intended as properties that may be respected by different, instantaneous systems playing equivalent, compatible roles in the process of emergence, represent in quasi-analytical forms what is usually ***approximated*** *as statistical, probabilistic or generic freedom given by arbitrariness or relativity. This opens the possibility to use new approaches to orient and induce social emergence, with unfortunate possibility of* ***manipulation****, which in other forms there have always been, but also the possibility to* ***understand*** *them when in progress.* An illustration is available in Fig. 4.3.

The concepts introduced above should be considered typical of the post-GOFS as dealing with coherence, combinations (crossing and superimpositions), *compatibility, equivalence, emergence (as ubiquitous), lightness, multiplicity, non-causality, non-invasiveness, non-prescrivability, potentiality, quasiness and simultaneity.*

Suitable modelling should consider new approaches of formalization as in Chap. 5.

4.6 System Propagation

This is a daring tentative to conceptually introduce the hypothesis that the *status of systemic* intended as related to properties eventually of different levels possessed or acquired by any entity or *process* be not anymore considered as *only* and *mandatorily* given by active roles due, for instance, to *interactions* of any kind.

A first example is given by the establishment of *synchronicity* without explicit exchange of matter-energy like for remote synchronization (see p. 271), quantum phenomena and entanglement. Another example is given by network representations (see Chap. 8) where links represent relations among nodes that can be in their turn phenomena and systemic properties are represented by network properties like topologies, dynamics and emergence.

We are elaborating the suitability to consider the status of systemic as given, under suitable conditions, by properties, for instance, of the *hosting space* when a typical example is given by ecosystems.

The hosting space may in its turn have non-active and/or active properties as geometrical and as *environmental* and due to *fields* adding in active ways properties to *internal* elements, for instance, by supplying appropriated energy. We consider eventual properties of the hosting space such as geometrical and topological for networks.

The distinctions introduced above, i.e. between hosting space, environment and field, are a *simplification* introduced to fix the ideas, while real cases are given by different levels of their eventual dynamical combinations.

Propagation (Levis, Johnson, & Teixeira, 2010) and diffusion (Vrentas & Vrentas, 2013) are well-studied phenomena in different disciplines like physics, e.g. acoustic, electromagnetic, nanostructural, optical and seismic phenomena; chemistry, epidemics in medicine and sociology. Approaches to influence generic collective behaviours are allowed by the existence of *propagation rules* for propagating patterns of activities through the network of connections. This is possible by influencing the propagation of information, by modifying, confusing and applying *long-range interactions* (see, for instance, Barrè, Dauxois, & Ruffo, 2001).

The general idea is that forms of *status of being systemic*, like attitude to acquire systemic properties and assume a systemic behaviour, can *propagate*, could be *diffused* within the environment and hosting space, *emanated*, *induced* or even *transmitted* by systemic entities to other nonsystemic entities.

We consider the opportunity to introduce the subject by distinguishing between *propagation* of nonautonomous or autonomous systemic properties, i.e. possessed or acquired by systems provided or non-provided with cognitive system.

However, this eventual distinction is another simplification since processes of propagation, emanation, induction and transmission of forms of being systemic may overlap and simultaneously relate to different aspects of both nonautonomous and autonomous systems.

We will name, for short, the *status of being systemic* as *systemicity* having meaning different from the one of *being systematic*, i.e. methodical, repetitive and ordered.

We will try to tentatively consider structural properties of the hosting space as ***source or generator of systemicity*** (the conceptual inspiration is given by quantum entanglement) *when a* ***less*** *totalizing and invasive view is given by properties of the non-separable* ***environment****. We will consider the eventual* ***propagation*** *of systemicity.*

4.6.1 The Case of Nonautonomous Systems

A first example we mention is synchronicity. This relates, for instance, to dynamic clustering when synchronization is the source of their coherence (see, for instance, Boccaletti, 2008; Boccaletti, Kurths, Osipov, Valladares, & Zhouc, 2002; Ciszak, Euzzor, Geltrude, Arecchi, & Meucci, 2013; Mikhailov & Calenbuhr, 2002).

This may relate, for instance, to signals, energy availability and environment properties.

Another example occurs with order parameters as considered in Sect. 2.4 when dealing with the slaving principle used by synergetics.

The validity of a *network or meta-structural regime* is a further example of environmental-spatial systemic propagation when the *simple belonging*, e.g. *immersion into* and interaction within a systemic network or meta-structural environment-space, induces the acquisition of systemic behaviour transmitted through unavoidable interaction with entities previously possessing such network or meta-structural properties.

This is when elements of collective behaviours do not only interact but also propagate and diffuse in some ways properties of the interacting neighbour, i.e. by allowing forms of transitiveness.

When considering the collective behaviour established by nonautonomous elements, i.e. assumed not provided with cognitive system, we may take in count cases such as cellular automata, the climate system, protein chains and their folding, cell and bacterial colonies, objects on vibrating surfaces that tend to take consistent variations, autonomous lamps networks that tend to take consistent changes (Minati, de Candia, & Scarpetta, 2016) and the Internet (traffic signals).

As we mentioned above, geometrical properties such as symmetry and fractality may be responsible for acquisition of systemicity (Resconi & Licata, 2014) as well environmental with reference, for instance, to energy-light availability, information availability and possible distortion and noises.

Besides, another inspiring case, if not specifying the approach tout-court, is the vacuum curvature in QFT. As mentioned above and elaborated, Chap. 6 expressly dedicates to *theoretical systemics and quantum field theory*; thanks to the entanglement, no classical interactions are required to make entities interdependent. This relates to the unavoidable pervasiveness of the quantum vacuum or vacuums given by a variety of possible states of vacuum.

For instance, in the quantum vacuum, each perturbation causes the emergence of collective *long-range* excitations named Nambu-Goldstone bosons (NGBs) – see Chap. 6 – which coordinates the behaviour of individual components of the system, so as to keep *general coherence*.

Moreover the NGBs can interact between them, giving rise to the appearance of macroscopic entities (the so-called quantum objects), which in turn modify the behaviour of the entire system from which they originated.

4.6.2 The Case of Autonomous Systems

When considering the collective behaviour established by autonomous elements, i.e. assumed provided with *sufficiently complex* cognitive system, we may take in to account cases such as flocks, industrial clusters, industrial districts networks, markets and social systems such as cities, companies and families and individual living systems as human beings and animals.

At this regard in order to modify the behaviour of their possible collective behaviour and emergent acquired properties, it is possible to consider the approach based on *inserting* a collective behaviour *inside* the collective behaviour to be modified. We may call the inserted collective behaviour as perturbative collective behaviour (PCB) as introduced in Sect. 3.8.4. The PCB is not intended to *slave* (see Sect. 3.8.4.3) the previous one by looking to *substitute* its behaviour to the previous one. The purpose is to suitably influence in order to introduce emergence of a modified collective behaviour. Suitable strategies should be considered for such introduction. For instance, we may consider aspects such as:

- The (fixed or variable) number of agents establishing the PCB with regard to the number of agents establishing the collective behaviour to modify, i.e. which percentage?
- The *topology* and *distribution* (e.g. at borders, at the centre, regularly diluted, etc. and having suitable sequences and variations in time) of the PCB related to properties of the collective behaviour to modify.
- The difference between cases (a) when agents of the PCB are the *same* of the collective behaviour to modify and *mutating* their behaviour, i.e. their role and (b) when agents of the PCB are *new ones* emerging/materializing from the environment like fluctuations.

- The eventual *feedback* between the PCB and the collective behaviour to modify allowing the first one to change in number, topology and diffusion, allowing some kinds of *learning* when regulating depends on the expected modification to be induced.

The approach is even suitable for computational, simulated phenomena of emergence from nonautonomous systems and to be eventually considered for real cases. The approach can be considered when properties and effects of the PCB are not cognitively processed but reduced to suitable noises.

Furthermore we may then consider, *cognitive environments* settled by cultures, ideologies, religions, languages and cognitive models when hosting collective behaviours and phenomena of emergence established by agents, typically human beings possessing *same* cognitive system and *generating* cognitive models. The case does not apply to agents provided with *fixed*, nonevolutionary cognitive models like for simple animals having low cognitive abilities, e.g. learning, memory and representation.

Examples of the setting of *cognitive environments*, specifically related to *autonomous systems* when focusing on their cognitive processing, may be:

- The spreading out and usage of *analogies* – see Sect. 4.2 – and *metaphors* occurring when applying linguistic expressions proper to a phenomenon to other ones, e.g. the flux of time or the life of a company, in any kind of social interactions. When relating to systemic properties, this induces to practice cognitive correspondences helpful to assume levels of systems thinking.
- The usage of models based on requiring a specific property, like when a model of an artificial system *requires* a designer. If the same model is used, transposed to model natural systems, *then* the designer is required. An example is given by the solar system requiring *then* a designer (the solar systems is a system so it is assumed appropriate to ask *who* is the designer) unless one accepts the notion of self-organization.
- The *language* (Ellis & Larsen-Freeman, 2010) used. As considered in the literature, languages specify and limit our cognitive power and our designing space and represent and induce processes, contradictions and potentialities (Carroll, Levinson, & Lee, 2012; Sapir, 1929). It is possible to say that *we are our languages*. At this regard, *Lev Semyonovich Vygotskij* (1896–1934) wrote: ‘Thought is not merely expressed in words; it comes into existence through them’. (Vygotskij, 1986, p. 218). We need new words to establish a language able to *say* new concepts. Furthermore *Ludwig Josef Johann Wittgenstein* (1889–1951) wrote: ‘... to imagine a language means to imagine a form of life’ (Wittgenstein, 1953, Part 1, §19). However, it is not only a matter of words but rather of representation and of semantics by using modalities. *Systems thinking* is based on representing multiple correspondences, dynamics and coherences suitably represented by languages. For instance, *usage and focus* on linguistic expressions like control, decide, equilibrate, foresee, optimize, posses, regulate, separate, stabilize and solve will *facilitate* if not *induce* GOFS thinking. Other approaches are the ones inducing *familiarity* with ways of thinking, diffused by

> huge varieties of cases like advertising; editorial products like newspapers, magazines and books; games and videogames; lifestyles; movies; tools, products and ways to use *propagating* concepts like ‘the more is better’; and the concepts of functioning, planning and deciding, regulating and repairing and organizing and solving, assumed to apply to everything. This does not only open in general the doors to manipulation, but even worse it is a kind of *self-manipulation* limiting the cognitive evolutionary and emergent possibilities of social systems and forcing them to collapse into crystallized states than assuming new collective cognitive ability to make emergent *new social phases*, corresponding to new ways of thinking. At this regard we mention the following expression controversially attributed to Joseph Goebbels, Adolf Hitler’s Propaganda Minister in Nazi Germany: ‘If you tell a lie big enough and keep repeating it, people will eventually come to believe it’.

When considering social systems where autonomous agents are able to process information by using variable cognitive models, we may take in count the following examples.

The first example occurs when structural properties facilitate or even induce to act systemically, i.e. to interact in such ways suitable to establish systems. At this regard, it is possible to consider suitably *structured environments* able to induce systemic behaviour and acquisition of emergent properties by agents acting within and with such structures. With reference to human systems, it is the case for *architectural constraints* (see Chap. 10) able to induce acquisition of emergent properties by inhabitant agents. Any parent knows the influence of the decision to put their children to sleep in separate or single rooms. The subject concerning architectural constraints has different applicative significances regarding, for instance, the *induction* or *disrupt* of the coherence of behaviours related to a variety of kinds, like criminality, formation of traffic, hospitalization, safety at work, way to dwell and way to visit a location, as dealt with by a huge bibliography, like The Behavioural Design Lab, Alexander (1979), Eisenman and Lacan (2006), Fairweather and McConville (2000), Federal Facilities Council (2002), Geddes (1915), Hillier and Leaman (1974), Marshall (2009), Minati and Collen (2009), and Sundstrom, Bell, Busby, and Asmus (1996).

Another related interesting example takes place when interacting *within networks*; see, for instance, Motter and Albert (2012), Valente (2012).

A final example takes place when considering *virtual structures* given by the *way to respect* degrees of freedom as real structures. It relates, as introduced above, to modalities to respect and use degrees of freedom. While such ways and modalities are considered to establish *histories of usages* and related *profiles*, e.g. markets profiling users and buyers, it is a kind of virtual, *dual* structure. In this case the dual structure may be, for instance, physical, economical, juridical, linguistic and musical.

With regard to different well-known aspects of *diffusion* studied in physics like for substances, gases, reaction-diffusion systems and dissipation through diffusion, and in social science, we would like to consider here the concept of diffusion related to behaviour as a special form of process of acquisition of collective behaviour. We should take in count the *diffusion* or spread out of a specific behaviour through processes of *positive feedback* phenomena; like when in stock exchange, the more stakeholders sell, the more they sell.

However, we may refer to behaviours induced by specific suitable, in time and quantity, micro-behaviours like the *collective escaping* of birds from the ground when some of them escape and reach a critical point in quantity or synchronization. This is also the case of emergency for crowd, queues or collective escaping from context where the reason to escape is relegated in a reduced area like partial structural failure and partial flooding.

We conclude this section mentioning that the implicit propagation and diffusion discussed above should also be considered within a more theoretical framework allowing, for instance, to consider ***levels*** *of propagation and diffusion when* ***dynamics of levels*** *and their properties may constitute another hierarchically higher aspect like* ***ways to propagate*** *and* ***diffuse****. While the first level introduced above is not incompatible with GOFS, if not when dealing with collective, emergent aspects, the dealing with eventual further higher levels and long-range aspects is suitable for the post-GOFS.*

4.7 Quasi-dynamic Coherence

We already discussed the concept of *dynamical coherence* at Sect. 3.2.4.

While the case of dynamical coherence relates to multiple coherences, quasi-dynamic coherence, in correspondence with quasiness introduced above, relates to multiple *partial*, subsequent or even simultaneous different coherences.

Partiality may relate to local inhomogeneous assumption of coherences, temporal sequences of coherences, non-regular sequences of coherences and different *levels* of coherences.

The general property of quasi-dynamic coherence could be interesting during *transience* when *establishing and acquiring* coherences, losing coherences during processes of *degeneration* and when an unstable mix takes place setting a metastable situation as pre-property to be eventually suitably collapsed.

Quasi-dynamic coherence should be intended as the name of the *place* where the game of assuming coherences is open. It is the name of incomplete, irregular and potential coherences in progress waiting to be *confirmed*, i.e. to become convergent *pre-coherence*, in a space of eventual temporal equivalences.

Metaphorically we may say that *it is matter of analogies between analogies.*

The setting of quasi-dynamic coherence could be intended as a way to introduce *possible future properties of the becoming.*

This is the case when considering validity of multiple, partial network or meta-structural regimes.

Real applications seem suitable for non-yet collective behaviours, as for populations of elements collectively interacting but do not establishing a collective behaviour *yet*, e.g. the Brownian motion and crowd.

Processes of quasi-dynamic coherence establish the *place* where metastable interaction is open to a variety of possibilities, and we should have suitable approaches to orient and facilitate emergence of the desired behaviour.

Quasi-dynamic coherence may keep as such indefinitely or eventually turn into pre-coherence, i.e. when quasi-dynamic coherent configurations become ***convergent*** *to a specific, stable or instable, coherence.*

An important step should be the ability to transform an established coherence into quasi-coherence and then quasi-dynamic coherence (dismount an established coherence) in order to *reopen* the game and make the system to select new levels of coherences. This is crucial, for instance, for biological dynamics when *illnesses* could be interpreted as unwilled, pathological coherence or incoherencies, social systems and probably for cognitive processes.

Like first-order cybernetics was conceptually related to ***play a game****, i.e. apply a specific rule-based coherence; the second-order cybernetics was related to change coherence, i.e. invent a new game; here the point is to set* ***how*** *to play by setting new environmental scenarios and ways to use and invent new possible rules.*

We may say that quasi-dynamic coherence may break an establishing coherence keeping coherence as general framework and be ***incubator*** *where different coherences are attempted, metaphorically* ***proposed*** *and from where an emergent different coherence may emerge.*

4.8 The Cytoskeleton as Quasi-system

With reference to the active behaviour of the cytoskeleton (Jülicher, Kruse, Prost, & Joanny, 2007), theoretical aspects of the framework introduced in Sect. 3.3 and related to modelling, we consider the following other aspects useful to show the suitability to consider the cytoskeleton and the model considered as example of quasi-system.

Based on the research of on the quantum processes that take place in microtubules (see, for reviews, Craddock & Tuszynski, 2010; Tuszynski et al., 2005), the activity of each microtubule was described by a quantum Markov process constant over time (see on these processes Mülken & Blumen, 2011), governed by interactions with the output of microtubules spatially close but in which the output of the signal produced by the microtubule considered takes place in a time that depends on the length of the microtubule same. This length is considered to be variable, as it occurs in real microtubules, and described by laws of variation already identified in the literature (see Baulin, Marques, & Thalmann, 2007; Deymier, Yang, & Hoying, 2005).

In addition to these interactions, unlike other models, it is also added to the interaction between microtubules and the intracellular fluid in which they are immersed. Actually, the latter is responsible for the formation in the liquid of coherent domains that can act as ‘temporary memory’ of information conveyed by the microtubules. Because of this, the liquid is represented as a system of interacting spin (representing the electric dipoles contained therein), with interactions between the nearest neighbours. As they have not been taken into account, the molecules of tubulin remained in the cytoskeleton after the disintegration of a single microtubule, since that recent models (see Glade, 2012) have shown that this fact is of secondary importance for the dynamic evolution of the system of microtubules.

4.9 Further Remarks

We mention how the problems and approaches mentioned in this chapter may be considered relating to a classical conceptual framework, the one of *uncertainty*; see Sect. 1.3.9 and 2.5.

On one side it is assumed in the literature that the regularities in nature occur represented as *statistical trends*.

Moreover, the concepts elaborated in this chapter, like pre-properties, quasi, quasiness, quasi-dynamic coherence, quasi- properties, quasi-systems and system propagation are intended to *specify* uncertainty, to be *cases* of uncertainty when uncertainty relates to the multiplicity and levels of coherence of phenomena of collective interaction.

Uncertainty of coherence represents its *open valence*. Can we *generalize* the study of uncertainty when related to such phenomena of collective interaction?

Can the *structural* quasiness of Quasi-Collective Beings be the suitable place to study such eventual forms of generalization?

Can properties of levels of coherences of sequences of collective interactions be described by a single general theory able to deal, for instance, with super-coherences and super-analogies?

It looks as a chapter of the post-GOFS.

Box 4.1: Order Parameter

When complex systems undergo phase transitions, a special type of ordering occurs at the microscopic level. Instead of addressing each of very large number of atoms of a complex system, Haken (1988) has shown, mathematically, that it is possible to address their fundamental *modes* by means of *order parameters*. The very important mathematical result obtained by using this approach consists in drastically lowering the number of degrees of freedom to only a few parameters. Haken also showed how *order parameters* guide complex processes in self-organizing systems.

(continued)

Box 4.1 (continued)

When an *order parameter* guides a process, it is said to *slave* the other parameters, and this slaving principle is the key to understanding self-organizing systems. Complex systems organize and generate themselves at far-from-equilibrium conditions:

> ‘In general just a few collective modes become unstable and serve as ‘order parameters’ which describe the macroscopic pattern. At the same time the macroscopic variables, i.e., the order parameters, govern the behaviour of the microscopic parts by the ‘slaving principle’. In this way, the occurrence of order parameters and their ability to enslave allows the system to find its own structure’ (Graham & Haken, 1969, p. 13).

> ‘In general, the behaviour of the total system is governed by only a few order parameters that prescribe the newly evolving order of the system’ (Haken, 1987), p. 425.

In Sects. 3.8.4.3, 3.8.4.5 and 5.3.3, we considered as order parameter a suitable Perturbative Collective Behaviour (PCB) to be inserted *within* another collective behaviour in order to *induce* desired changes.

Box 4.2: Ergodicity

The terms *ergodenhypothese* and *Ergode* appeared in papers published by Boltzmann in 1871 (Boltzmann, 1871) and 1884 (Boltzmann 1884a, 1884b).

The theory is behind classical statistical mechanics.

The *ergodic hypothesis* states that, given an infinite time duration, the trajectory of the point representing the entire system in the phase space will pass through every point (or as *close* as you want to every point, in the *quasi-ergodic* hypothesis) lying on the energy hypersurface. The relationship, or *trade-off*, between time and space comes from the fact that an average value, for the location of the point representing the system, determined by following its successive positions over time, will be the same when the average value is calculated over an ensemble of different points, representing different systems, at a single instant of time, provided they lie on the same energy hypersurface.

Sampling at a single time instant across an ensemble of different copies of the same system is equivalent to sampling through time for a single system: that is the notion contained in the ergodic hypothesis.

The *Gibbs Postulate* about *time evolution and ergodicity* introduced by the theoretical physicist J. W. Gibbs (1839–1903), states that, *in the phase space*,

(continued)

Box 4.2 (continued)

all states in the microcanonical ensemble are equivalent, in the sense that they have the same probability of occurrence.

The assumption behind the Gibbs postulate is that after a long time, every system will ‘forget’ its initial conditions. In other words, the *probability of each microstate does not depend upon initial conditions.*

Let us assume system monitoring involves a single, particular, behavioural feature F, which will be assumed to be associated with a finite number of different possible states F_i. For each of these states, let us assume that our monitoring (over a given observational time) of a system, containing a finite (and constant over time) number of elements, gave the average percentage of time spent by a single element in state F_i as $y\%_i$ and the average percentage of elements lying in the same state as $x\%_i$.

The state shows ergodicity when $x\%_i = y\%_i$.

Referring to population dynamics, it means the *if* $\boldsymbol{x}$*% of the population is in a particular state* **S** *at* ***any*** *moment in time, and* ***all*** *subpopulations spend* $\boldsymbol{y}$ *% of time in that state, the system is ergodic when* $\boldsymbol{x\% = y\%}$ (Cornfeld & Fomin 1982; Minati & Pessa, 2006)

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Chapter 5
New Formalization?

Contents

This chapter is dedicated to elaborate about eventual *formalizations* suitable for the post-GOFS. We discuss about the meaning of formalization to consider if the classical understanding is still suitable, looking for validations like theorems and formulations. We will reconsider comments already introduced in Sect. 1.3 about *explicit formalization*. Shall we consider new approach alternatives to classical formalizations? Which approaches to consider?

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5.1 Formalist *or* Constructivist?

In mathematics and logics, there is a huge variety of consolidated classical approaches dealing with formalism and axiomatization. Examples of historical fundamental contributions are the ones of *Alfred North Whitehead* (1861–1947), *Bertrand Arthur William Russell* (1872–1970) as in Whitehead and Russell (1910, 1912, 1913) and *David Hilbert* (1862–1943), as in Hilbert (2013) having then to deal, for instance, with different challenges like the:

- Gödel's two incompleteness theorems (Gödel, 1931).
- Uncertainty principles in science in the absence of commutativity allowing for generalizations (see, for instance, Brody & Hughston, 1997; Minati & Pessa, 2006, pp. 55–64) like for constructivism (Von Glasersfeld, 1991a, 1991b).

We will deal with related concepts as the uncertainty principles, the theory of cognitive operators and the issues of formalism and constructivism as discussed in Minati and Pessa (2006, pp. 55–60).

5.1.1 Uncertainty Principles

The quest for uncertainty principles in science (and their discovery in specific domains) arose as a result of the need for dealing with systems in which the act itself of observing or of monitoring was interfering with the activity of the systems themselves. This interference, as is well known, was observed very early in the history of physics, when researchers began investigating phenomena on an atomic scale.

In order to set a framework for understanding the role played by the different uncertainty principles so far introduced, it is convenient to start from the pioneering intuition of *Heinz von Foerster* (Von Foerster, 1981) while trying to build a general theory of the behaviour of a complex system whose subsystems are an *observed system* (a sort of environment) and an *observing system* (the observer or, in other contexts, the scientist). Such a system can be depicted as in Fig. 5.1.

As we can see from the figure, the observed system initially inputs its state φ to the observing system (here the mathematical nature of φ does not matter: it may be a number, a function, a functional, etc., according to the theoretical framework adopted). The latter, in turn, perturbs the observed system, owing to the act of observation itself, and the perturbation can be described as the action of an operator R which, acting on φ, gives rise to a new state of the observed system $R\varphi$. Such a change implies that, as a consequence of the observation, the input to the observing system is no longer φ, but $R\varphi$. As the latter continues to make observations, it will in turn transform this input to $RR\varphi$. If we continue further along this road, after n environment-observer interactions, the state of the environment itself will be $R^n\varphi$, where the symbol R^n denotes the *n-th* iteration of applying the operator R. Generally

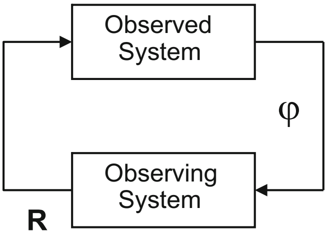

Fig. 5.1 Observed and observing systems

speaking, $R^n\varphi$ will be very different from φ, so that this argument seems to leave no hope, for the observing system, of detecting some stable feature of its environment.

However, there is the possibility to introduce an environmental state φ^* fulfilling the relationship:

$$R\varphi^* = \varphi^*$$

where, in mathematical terms, φ^* is called a *fixed point* of the operator R. It is now easy to see that if the environment falls into the state φ^*, then it will remain indefinitely in this state, despite the perturbations induced by the observer. The latter, in turn, will detect that the environment is in the *invariant state* φ^*.

The proposal of von Foerster gives rise to a number of difficult conceptual problems, listed as follows:

(a) The argument of von Foerster is useful if we assume that the form of the operator R is such that, when starting the process of mutual interaction between observer and environment from an initial environmental state φ_0, different from φ^*, the iterated application of R gives rise (eventually, after an infinite number of steps) to the state φ^*. In mathematical terms, an operator endowed with such a property is called a *contractive operator* (Berinde, 2007). But what are the necessary conditions for R to be contractive? And what happens if R has a multiplicity of different fixed points?

(b) Can such an argument always be translated into a mathematical form? In other words, how is it possible to define in a formalized way the operator R and the state φ? Or, conversely, when is it not possible to introduce such a definition?

(c) The operator R could have a form such that its fixed point is trivial. In this case, even if R were to be contractive, the behaviour of the whole observer-environment system would fall into triviality, and the whole theory would become useless. A simple example of such a situation is given by the case in which the environmental state is described by a real number x and the action of the operator R consists simply in the multiplication of this number by a given constant k, assumed to be different from zero. In this case the fixed point x^* is defined by the condition $k\,x^* = x^*$ whose only solution is the trivial one, that is, $x^* = 0$!

Although problems (a) and (b) are still waiting for a solution, problem (c) can be circumvented by relaxing the requirement of the fixed point and by substituting it with a wider one:

$$R\varphi^* = \lambda\varphi^*$$

with the further condition that φ^* be non-trivial. In mathematical terms, the number λ is called an *eigenvalue* of the operator R, whereas the terminology adopted for φ^* depends on the mathematical context used to describe the latter. For instance, if φ^* is a vector, one speaks of *eigenvector*; on the contrary, if φ^* is a function, it is called an *eigenfunction* and so on. In general, we will refer to φ^* as an *eigenstate*.

A suggestive interpretation of this relationship associates φ^* with an *observable quantity* of the environment, λ the *result of an observation* and R the *observing action*. Starting from this interpretation, we can search for a framework for discussing the roles played by the various uncertainty principles used in science.

5.1.2 Theory of Cognitive Operators

We consider the use of some interesting arguments (and related definitions) put forward by *Olaf Dietterich* within the context of his *Theory of Cognitive Operators* (for a summary, see Diettrich, 2001, 2004, 2006). The main hypothesis adopted by Dietterich is the existence of *phylogenetically* acquired mental operators (a subclass of possible Rs), which are responsible for our perceptual capacities (as well as for the related motorial ones) in everyday experience. We refer to these operators as 'primitive operators'. Problems arise, according to Dietterich, when designing a procedure for performing a scientific experiment (e.g. in physics) or when we design a procedure for performing a 'mental experiment' on abstract entities, defined within an abstract theory. In this case, we are faced with the possibility of a contradiction between our traditional world picture, in turn based on the eigenvalues of our inborn primitive mental operators (we will denote such a world picture as 'classical world picture'), and the world picture resulting from the new operators associated with our physical or mental experiments. In order to discuss what could occur, we will introduce a suitable notation, based on the one already used above. More precisely, let us denote with P a generic primitive operator and with φ a generic eigenstate of P. A classical world picture will then be associated with the condition:

$$P\varphi = \lambda\varphi.$$

Let us now introduce a generic operator, associated with our physical experiment (or our 'mental experiment') denoted with O. By applying this operator to both members of the above relationship, we obtain:

$$O\,P\varphi = \lambda\,O\,\varphi.$$

Two possible cases can then arise:

1. Operators O and P are mutually *commuting*, that is, they satisfy the condition $O\ P = P\ O$.
2. Operators O and P are not commutative, i.e. O P ≠ P O. In the former case, we can rewrite the above relationship in the form:

$$P\ O\varphi = \lambda\,O\,\varphi.$$

This new relationship tells us that $O\varphi$ is still an eigenstate of our primitive operator P. This observation allows an interesting interpretation: $O\varphi$ denotes the result of the application of our experimental scientific device to the environment, in turn related to a particular world picture arising from the action of the device itself, and the fact that it continues to be an eigenstate of P means that the world picture arising from our experimental apparatus *does not contradict* our classical world picture, as represented by P.

In other words, if the operators associated to our scientific measurements commute with our primitive cognitive operators, we will obtain a world picture which can still be expressed in terms of our everyday experiences. Such a new picture will, in a sense, be an *extension* of our classical world view (in this case Dietterich speaks of *quantitative extension*), but it will be fully compatible with it and understandable by resorting to the classical view. A typical case of such a situation is offered by classical mechanics which, as a matter of fact, represents nothing but an extension and a formalization of our everyday experience of the motion of bodies.

An entirely different situation occurs when the operators O and P do not commute. In this case, which Dietterich refers to as *qualitative extension*, the world picture arising from our scientific measures no longer agrees with our classical world picture and cannot be explained within the classical context. A typical (and celebrated) case is given by quantum mechanics. This case is of a particular historical and conceptual importance as, within the formalism of this theory, it is possible, probably for the first time, to connect the lack of commutativity with the appearance of uncertainty principles dealing with physical quantities which, at first sight, could seem entirely understandable in classical terms. It will be interesting to present here the reason for the occurrence of uncertainty principles in the absence of commutativity. It must first be mentioned that the set of possible experimental devices, or measuring apparatuses, giving rise to world pictures differing from the classical one is, in principle, unlimited. In mathematical terms, this amounts to saying that the set of the operators non-commuting with P is *infinite*. Such a circumstance entails that not only each operator, not commuting with P, will be associated with a non-classical world view, but that there will be infinity non-classical world views, each differing from the others. This is due to the fact that different non-classical operators can also be mutually non-commutative. Now, if a given observable quantity α is an eigenstate of a given non-classical operator A and another observable quantity β is an eigenstate of another non-classical operator B, with A and B not commuting, automatically there will be an uncertainty principle connecting our uncertainty about the measurement of α with our uncertainty about the measurement of β. Further, the mathematical machinery of quantum theory leads us to the conclusion that such an uncertainty principle will have, in the simplest cases, the form $\Delta\alpha \, \Delta\beta \geq k$ where k is a suitable constant.

5.1.3 Formalization

An entirely analogous argument could be made for the 'mental experiments' which, in turn, are connected to mathematical activity.

At this point we must consider that there are currently two main views about the nature of mathematics: the *formalist* one, exemplified by the so-called Hilbert's program (Simpson, 1988) and by the so-called Bourbaki program relying on abstract definitions and axioms (http://www.bourbaki.ens.fr/Ouvrages.html, http://www.bourbaki.ens.fr/), and the *constructivist* one considered in Sect. 5.1.4. In the formalist view, mathematical entities are intended within an abstract world, where they are endowed with a sort of 'objective existence', possible by the absence of contradictions. Within such a platonic world, mathematicians can only 'discover' entities which exist, beyond space and time, independently from their searching.

The formalist view assumes the objective existence of one, and only one, mathematical world, which, per se, should be described by only one omnicomprehensive theory, the only one true. For the formalist, the fact that such a theory is still lacking is due only to the insufficient development of mathematics; in any case, such a theory *already exists*, and it is only waiting to be discovered.

As it is well known from the history of mathematics, the formalist program, aiming at a complete axiomatization of all mathematics, and to a general control over all mathematical formalisms, through a super-discipline named metamathematics, ran into failure, owing to theorems such as the celebrated Gödel incompleteness theorems. The need to deal with uncertainty principles made in evidence the *closure nature* of this approach.

The *closure* of classical approaches is given by a variety of aspects already mentioned in Chap. 1 such as completeness, computable uncertainty (see Sect. 2.5), lack of free variables, lack of structural dynamics (see Sect. 3.2.4), possibility to solve and being true *or* false. Dynamic multiplicity, dynamic coherences, dynamic superimpositions and incompatibilities are not allowed, and their eventual representations could be not explicit, but occurring by using intermediate approaches, classically statistical.

5.1.4 Constructivism

This approach was after others trying to go beyond the formalization of *Hilbert's program* like the introduction of *intuitionistic logics* encompassing principles of logical reasoning used by *Luitzen Egbertus Jan Brouwer* (1881–1966). Brouwer developed his intuitionistic mathematics by considering, for instance, rejection of *tertium non datur*, introducing an intuitionistic number theory, an intuitionistic first-order predicate logic, and translating classical into intuitionistic logic (Brouwer, 1913, 1927; Heyting, 1975; Van Dalen, 1981; Van Stigt, 1990).

We limit ourselves here to mention some examples of *constructive mathematics* (see, for instance, Longo, 2003) like introducing new definitions of cardinality, axiom of choice, measure theory (see, for instance, Bishop, 1967) and the *non-standard analysis* introduced in Robinson (1996).

Paul Valery wrote 'Mathematics is the science of acts without things - and through this, of things one can define by acts' (Valery, 1935).

The *constructivist* approach for mathematics, like for physics and other sciences, is considered a human construction, produced in certain ways as a consequence of given particular goals, natural and artificial tools and environmental features.

Mathematics is intendedly built for human needs, and, as such, it is grounded on our primary perceptual, motorial and cognitive capacities.

It is thus obvious that the formalist program is in total disagreement with the systemic view. The latter, therefore, is more compatible with the constructivist approach, and it is useful to recall that most researchers holding a systemic view are strongly influenced by the philosophical aspects of constructivism, known as *radical constructivism* (see Von Glasersfeld, 1995).

If we adopt a constructivist view, then this implies that even basic mathematical constructs are based on primitive cognitive operators, as for physical ones. We can, thus, introduce the notion of a *classical* mathematics, that is, mathematics whose cognitive operators commute with the primitive cognitive operators. Classical mathematics gives rise to a quantitative extension of the classical view related to operations of everyday experience, such as counting, adding, manipulating objects, measuring lengths and so on. As a matter of fact, the constructs of classical mathematics can always be understood in terms of intuitive, and elementary, operations such as those quoted above. Perhaps this circumstance could explain what Wigner calls 'the unreasonable effectiveness of mathematics' in describing the natural world (Longo, 2005; Wigner, 1960). Going beyond classical mathematics, it is, however, possible to construct even *non-classical* mathematics (which, as a matter of fact, has been built). The latter, based on cognitive operators which do not commute with the primitive ones, gives rise to constructs which cannot be fully understood in terms of elementary operations in everyday life. In any case, owing to the unlimited number of different possible operators which do not fulfil the commutative property, we should expect the appearance, even within non-classical mathematics, of uncertainty principles. And, in fact, one such principle has effectively been introduced: the Gödel incompleteness theorems already cited above! In short, we can interpret the content of these theorems as asserting that no axiomatic system (beyond a given degree of complexity) can exhaust the possibilities offered by a non-classical mathematical world, owing to the presence within it of formal expressions which, in a sense, are unreachable by starting only from axioms, and equipped only with logical inference rules. Thus, we could assert that, to a certain degree, the uncertainty principles introduced in physics (such as the celebrated Heisenberg one) and the Gödel theorems in mathematics are but different sides of the same coin, related to different domains of application of the cognitive operators or to different, but strongly related, cognitive activities of the same observer.

We may conclude this Section mentioning that a generic understanding of constructivism as *cultural* approach may be phrased as the search for the *more effective* way to consider something rather to search for what it *really* is, object or process it is. We mention that the second case is just a particular case of the first constructivist understanding.

5.1.5 ***Formalism*** **and** ***Constructivism***

Within the conceptual framework assumed in this book, we consider here the *alternative* between the two approaches as a matter of simplification.

The entire discussion will focus on *modalities*, i.e. local, dynamic research strategies based on multiplicity to deal with complexity of processes of emergence. We will consider ideal and non-ideal models (see Sect. 5.2); their usages in a DYSAM-like way introduced above (Minati & Pessa, 2006, 64–75, Appendix 1, point 6); data-driven and a posteriori approaches when the idea *to zip* the essential characteristics of change into a set of ideal equations is unsuitable; and temporary, simultaneous objectivistic *and* non-objectivistic approaches not ideologically divided but eventually used *on demand* within a *logically open approach* (see Sect. 2.7).

However the crucial point is to consider and decide what we are looking for and what we expect from representations and formalizations. We will consider in the following three fundamental aspects of the post-GOFS systems making classical formalizations often unsuitable, such as non-invasiveness, non-prescribability and non-causality, and their conceptual impact on modelling and simulations in the general conceptual framework of ‘softness’ intended as given by *multidimensional, non-contradiction-free formalizations*.

5.2 Beyond *Non-explicit* Models: Ideal – Non-ideal?

The subject relates to the general conceptual frameworks adopted to study emergence.

Two main kinds of frameworks should be considered:

- One relating to the role played by *general principles* and *assumptions*.
- The other one relating to the role of homogeneity of individual elements or agents component of the system under study.

With reference to the first case, we will consider a rough approximation which allows distinction between *ideal* and *non-ideal* models of emergence (Pessa, 2000, 2006).

With reference to the second case, we will consider the distinction between *homogeneity-based* and *heterogeneity-based* models of emergence. Heterogeneity-based models of emergence are, of course, much more difficult to deal with than homogeneity-based ones when considered in a classical way.

5.2.1 General Principles: Ideal Models

A model of emergence can be qualified as *ideal* if it is characterized by a top-down structure, based on general principles assumed to be universally (or at least largely) valid, covering the widest possible spectrum of phenomena. This feature allows the deduction of particular consequences and forecasting only if suitable mathematical tools are available.

There is the epistemological assumption of the possibility *to zip* the essential characteristics of the phenomena under study into a set of ideal equations. This very relates to formalism since this implies that the search for these tools becomes the main concern for the researcher trying to build an ideal model of emergence. Usually such a search is difficult, requiring a high level of mathematical competence; in most cases the tools required by the researcher simply do not exist, and one is aware, from the beginning, that the model of emergence taken in consideration will be only a very rough approximation with respect to the initial requirements. However, when an ideal model of emergence produces a result, one can be sure that this is not a consequence of some ad hoc assumption or of some mathematical trick, but *derives*, having deductive nature, in a logical way from ‘first principles’. In some cases this allows for the *control* of emergence phenomena foreseen by the model, as it is always possible to understand, in mathematical terms, how to act upon the system described by the model to produce or to eliminate such phenomena. For this reason, many researchers (particularly physicists) think that ideal models of emergence are the most reliable.

However ideal models of emergence, owing to their very nature, tend to neglect the description and the role of the environment in which a system is embedded. Indeed, a model which claims to be universal should, in principle, be applied to the entire Universe due to their idealistic, context-independent nature. Typical examples of this kind are the ones given by quantum field theory (Huang, 1998; Itzykson & Zuber, 1986; Kiselev, Shnir, & Tregubovich, 2000; Lahiri & Pal, 2001; Maggiore, 2005; Peskin & Schroeder, 1995; Stone, 2000; Umezawa, 1993; Weinberg, 1995, 1996) and as in Licata (2010) and Pessa (2008).

Their eventual openness is ideal, formal and being in reality based on logical closure.

5.2.2 General Principles: Non-ideal Models

Non-ideal models of emergence are characterized essentially by the *difficulty in controlling* the process of emergence itself. In other words, when these models exhibit emergent behaviours (most frequently by resorting to very simple algorithms), they cannot be forecast, nor can the mechanisms for producing or eliminating a given behaviour be identified. This occurs because most models of this kind are a mixture of general principles and of specific choices, which give rise to a mathematical structure so complicated as to make it very difficult to foresee its operational features. In these cases, often the only way to obtain information about model behaviour is by using suitable computer simulations. Among the specific choices mentioned above, the most popular ones concern the form of the model equations and/or suitable boundary conditions. An obvious advantage of these models is their simplicity: even a person with a modest mathematical competence can understand the model laws, run a computer simulation of its behaviour and interpret its outcome. For this reason these models are very popular within the scientific community and used in many different domains. These include agent-based models, artificial and biological neural networks, cellular automata, artificial life, dissipative structures and so on (see Table 5.1).

The openness is logical since based on structural dynamics like for sub-symbolic techniques, such as neural networks able to learn from a training set. *This is the logical openness of constructivism.*

Table 5.1 A general classification scheme for models of emergence

	Ideal models	Non-ideal models
Homogeneity-based models	Spontaneous symmetry breaking in quantum field theory	Cellular automata
	Noise-induced phase transitions	
	Chaos	Dissipative structures
Heterogeneity-based models	Multiple systems and collective beings (multiple roles, interchangeability, ergodic-like)?	Agent-based models
		Artificial life
		Quasi multiple systems? Quasi collective beings?
	Network science (ideal scale-free networks)	Immune networks
	Spin glasses	Neural networks
		Meta-structures?
		Interaction between collective behaviours?

5.2.3 Homogeneity- and Heterogeneity-Based Models

Let us turn, at this point, to the distinction between 'homogeneity-based' and 'heterogeneity-based' models of emergence. As considered above emergence is connected, among other things, to the existence of different *observational* or *descriptional* levels, the 'lowest' of which is generally assumed to be the 'base' level, in which the system under study is described as an interacting assembly of *components*. The behaviours emergent at the 'higher' levels are produced by interactions between these components and top-down and bottom-up levels of emergence as in Chap. 7. But which conceptual frameworks should be adopted to describe the components in their turn eventually emerging from other levels of emergence, eventually simultaneous and superimposed?

According to *homogeneity-based models* of emergence, we should neglect any differences between components and treat them all being equivalent to one another. For centuries this was the approach followed by physicists and mathematicians, as it led to simpler and more tractable models. On the other hand, it has the flaw of being unable to account for emergence in biological systems (and a fortiori in cognitive, social and economic ones), which derives precisely from the differences between individual components. Thus biologically oriented researchers tend to adopt heterogeneity-based models of emergence, in which each component is endowed with a particular 'individuality' and the features of resulting emergent behaviours rely heavily upon the interactions between the various individualities.

Of course, *heterogeneity-based models* of emergence are far and away more difficult to deal with than homogeneity-based ones.

Using the two dimensions introduced above, together with their associated bipolar distinctions, one can propose a classification scheme for possible models of emergence, useful both for fitting existing models and for suggesting new possibilities.

Alternative modelling is given, for instance, by considering populations of interacting agents having different *evolutionary* abilities, e.g. to interact, learn and generate new behavioural rules, we mention the so-called Rogers' paradox related to social learning and introduced in Rogers (1988). The paradox regards coexistence of social (learning from others) and individual learning (learning on one's own) within processes of cultural evolution, where the latter form of learning is typically more costly. The paradox pointed out by Rogers (1988) relates to the fact that in a dichotomous frameworks of social and individual learning, the evolution of social learning does not increase the average level of adaptation of the population compared to the situation exclusively with individual learners (Kobayashi & Ohtsuki, 2014; Rendell, Fogarty, & Laland, 2010). The study of effects on general coherence given by the introduction of PCB will consider such paradox when social learning could be considered as collective reactions to the inserted PCB (see Sects. 4.6.1 and 5.3.3).

Another is based on considering emergence from interaction of *learning agents*, i.e. agents able to *decide* their behaviours by using some *cognitive processing* and not only by applying always the same rules. An attempt to model such behaviour occurring when rules of interaction change is given by the meta-structures (see Sects 3.8.4.5 and 4.5).

On the basis of the aspects considered above, it is possible to propose a classification scheme for models of emergence as in Table 5.1.

The scheme relates to different kinds of models of emergence. The question marks denote models which are not fully developed and currently under study.

After this short introduction to the subject, we consider the idea to go *beyond non-explicit models* as given by the fact that the non-explicitness is not given only by the non-formalist, computational nature of the model, such as when based on CA and ANN and when varying weights and level, but by the *dynamical changing of the models themselves*.

It reminds DYSAM; however we do not refer to sequences of models, but, rather, to the different natures of models, *models in progress*, when it is their structural change that models the complexity of the phenomenon.

This relates to modelling *quasi-systems* when *locally* change nature and properties. The history of the sequences of models and of their natures, and properties of such sequences as well, represents the complexity of the systems analogously to the degrees of freedom considered above in Sect 3.7.

5.3 Models

This section is dedicated to outline perspective approaches to model emergent collective systems whose emergence should possess properties such as the ones introduced above and eventually mixed with classical ones:

1. Properties of the *between* degrees of freedom
2. Coherence and multiple coherences[1]
3. Irreversibility
4. Non-separability
5. Non-causality
6. Non-invasiveness
7. Non-prescribability
8. Pre-properties
9. Quasiness
10. Quasi-properties
11. Quasi-dynamic coherence
12. Quasi-systems
13. Regimes of validity
14. System propagation

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[1] Where coherence is considered as *evolutionary dynamical structural property* and as *stable mode* of change, while equilibrium is intended as maintaining of properties

The approach considered here is conceptually based on *usages* in a DYSAM-like way of ideal and non-ideal models having them homogeneity or heterogeneity nature in correspondence with quasiness and emergent acquisitions of properties. This is as for complex systems like:

- Biological systems (Singh & Dhar, 2015) having phenomena of multiple natures, e.g. chemical, physical, quantum and classical and neurological.
- Social systems (Helbing, Yu, & Rauhut, 2011; Minati, 2012; Moeller, 2011; Sawyer, 2005) having phenomena of multiple natures, e.g. communications, defence, economical combining industrial and post-industrial natures, energetic, housing, multilingualism, political, population dynamics, safety, sanitary and transportation.
- Emergent collective systems as Multiple Systems, particularly Collective Beings (see Sect. 4.5), where cognitive and virtual roles are ubiquitous as considered and modelled in different disciplinary cases and studies (see, for instance, Artikis, Picard, & Vercouter, 2009; Hemelrijk, 2005; Sumpter, 2010). First of all we stress how *decisions* made by a Collective Being, such as to *assume a specific behaviour*, intended as suitably studied by using *a specific model* over time, never result from a single computational process. Decisions come from emergent computation (Minati & Pessa, 2006, p. 118) like for process of swarm intelligence (see, for instance, Bonabeau, Dorigo, & Theraulaz, 1999; Dehuri, Jagadev, & Panda, 2015; Yang, Cui, Xiao, Gandomi, & Karamanoglu, 2013). *The change from a configuration to the following one occurs as 'implicit selection' among a variety of possible* ***equivalent ones***; see Sect. 4.5.3 on Quasi-Multiple Systems and Quasi-Collective Beings. We remind that a Collective Being is intended as a Multiple System coherently *oscillating* among different systemic aspects, having components simultaneously or dynamically belonging to different systems and which can be suitably modelled with DYSAM-like approaches. We consider how *decisions* within a Collective Being arise from emergent processes and emergent computation. For example, we may consider that the *abandonment* of the collective behaviour, like by a bird *abandoning* the flock, may be given, for instance, by trivial *reduction* of cohesive forces or by a situation where two interacting agents *contemporarily* take on an *incompatible* behaviour such as to cause local *disaggregation*. *However, focus can be on the* ***rest*** *of the collective behaviour loosing (as implicit* ***decision****?) the ability to* ***keep*** *an agent involved*. However in the collective behaviour of a Collective Being, there is *room*, for instance, for different agent directions, altitude, speeds and topological positions while keeping the *identity* of the collective behaviour (coherent multiple coherences) as perceived by the observer and eventually given by its scale invariance. That is because of a large variety of *equivalent* paths, behaviours and configurations between degrees of freedom and real world of equivalences allowed. The behaviour of Collective Beings emerges from continuous balancing and interactions between individual behaviours, in such a way as to keep the advantages of acting collectively, that is, to keep coherence and multiple coherences

corresponding to the Collective Being's *identity*. This is its meta-stability about multiple coherences.

- Another case relates to order-disorder transitions when very complicated transient dynamics occur and where, for instance, classical and quantum aspects mix (Gauger, Rieper, Morton, Benjamin, & Vedral, 2011; Rieper, 2011; Sewell, 1986).

With reference to the theory of cognitive operators introduced in Sect. 5.1.2, we consider here the general cases when in

$$O\,P\varphi = \lambda O\,\varphi$$

the operators O and P are not ***commutative***, i.e. $O\,P \neq P\,O$, and the fact that the set of the operators non-commuting with P is *infinite*.

We consider here the property to be commutative as conceptually equivalent to the ***property of coherence*** *when operators are considered coherent if phenomenologically related to what the observer considers the* ***same*** *phenomenon. Considering models rather than operators, non-equivalent models are considered modelling different aspects of the same phenomenon. This is the case of DYSAM discussed in* **Sect**. 5.3.2.

Coherence is in this case experimental, a fact, and focus is on usages of multiple ***non-equivalent*** *models dealing, for instance, among others, with the 14 properties listed above in the conceptual framework of* ***non-completeness*****,** as introduced in the previous chapters and particularly in Chap. 4.

Models are expected to display, for instance, some network, structural and meta-structural invariance useful to establish a kind of *computational lab* where to study network, structural and meta-structural effects of collective behaviours, while the classical in silico is intended to *reproduce* in vitro properties.

In the conceptual framework of the constructivist approach introduced above, we will consider DYSAM based on considering *evolutionary libraries* of models to suitably deal with the process of acquisition of subsequent properties typically occurring within processes of emergence and for systems as for the four cases considered above.

5.3.1 Representations

As discussed above (see Sect. 3.8.3), we consider here representations of the *middle way*, as mesoscopic and networked variables, by:

- Simplifying and ignoring details or individualities;
- Assuming concepts such as completeness, determinism and causality;

the least possible.

We deal with ***properties of representations*** *without assuming they should represent properties of* ***real, in vitro*** *processes.*

The representations considered here are networks and meta-structures when variables, properties and relations or links are *uncompleted enough* to call for dynamical combinations with other models.

We mention how *multiple simultaneous meta-structural-models* may apply in case of non-homogeneous collective systems.

A trivial case occurs when the collective behaviour is given by a superimposition of two or more autonomous collective behaviours. In such a case, non-homogeneous elements appear as environmental constraints and perturbations to the other ones as for the case of *Perturbative Collective Behaviour* (PCB) considered in Sect. 4.6.1. In this case *behaviours are meta-structurally separated.* The general meta-structural properties may be given by suitable *combinations* of single ones.

A non-trivial case occurs when non-homogeneous elements interact both within their possible *class* of homogeneity and with some or all the other ones. A simple case occurs by considering flocks of preys and predators. In these cases there is a non-linear combination of behaviours to be considered for a multiple simultaneous meta-structural model and representation.

This representation should be able to combine eventual separated meta-structural models by introducing an upper level of meta-structural coherence as in Sect. 3.4.

Can we expect new properties, convergence and limits to such eventual sequences of levels of meta-structural coherence? This is one of the new challenges for the post-GOFS.

Network models (Lewis, 2009) can represent the properties listed above as network properties like for social systems (Valente, 2012) and for models of collective behaviour (Huepe, Zschaler, Do, & Gross, 2011).

However, we mention how in this conceptual framework when dealing with properties of representations there are different *levels of non-linearity* like considering networks and then their properties such as topological and topological correlation (see, for an introduction, Bucknum & Castro, 2008); neural networks and their architectures, layers and weights; and meta-structures.

Those representations, of high level in their non-linearity, introduce possibilities in *representing qualitative* aspects when given by properties like in neurology (Caeyenberghs, Leemans, Leunissen, Michiels, & Swinnen, 2013), pathologies and health *unsuitably* represented by variables and indexes.

5.3.2 DYSAM

After the general references presented in the previous chapters, we present here the conceptual framework and some more precise aspects.

The concept of DYSAM has been introduced in Minati & Pessa, (2006, pp. 64–70).

The first aspect of the general conceptual framework is given by the classical well-known *Bayesian method* (Bayes, 1763), named after the reverend *Thomas Bayes (1702–1761)*, used and applied in a huge variety of disciplines and cases (see, for instance, Carlin & Louis, 2008). Among other variations we mention the ones introduced in Arecchi (2014, 2016) and related to *subsequent applications* of Bayes inferences and the *inverse Bayes*.

Other aspects to be considered as constituting the general framework of DYSAM are, for instance:

- *Machine learning*, based on a large number of techniques like neural networks and genetic algorithms. Since one of the purposes of *machine learning* is to make decisions, Bayesian statistics are often used (Barber, 2012; Bishop, 2007; Marsland, 2014; Shalev-Shwartz & Ben-David, 2014).
- *Ensemble Learning*, whose basic idea is to combine an uncorrelated collection of learning systems all trained in the same task. In general, this approach is based upon controlling the ensemble performance by stabilizing the solution through the reduction of dependence on the training set and the optimization algorithms used by the members of the ensemble (Zhang & Ma, 2014).
- *Evolutionary game theory*, being this theory based on the **von** *Neumann* 'minimax theorem' stated in 1928. The consequences and the applications of this theorem have been initially studied in the book written jointly by von Neumann and Oskar Morgenstern in 1944, *Theory of Games and Economic Behavior* (Sigmund, 2010, 2011a, 2011b; Von Neumann & Morgenstern, 2007). The theory has been subsequently studied and applied in several disciplinary contests (Vincent & Brown, 2012) as for the well-known problem named the *prisoner's dilemma* (O'Connor, 2013), originally formulated in 1950 by the mathematician Albert W. Tucker and the *evolutionary stable strategies* (Otumba, 2011).

DYSAM was introduced as given by:

- Suitable level of representations to be adopted, e.g. micro- or macroscopic.
- An eventually evolving set of, eventually interconnected, models available to the researcher, where interconnection may be given by usage of the same variables.
- An eventually evolving strategy allowing the researcher to decide the most suitable combinations of models to be applied.

The usage of DYSAM is requested in cases like when:

- A system can be described only through a number of different partial representations (here the concept of 'representation' is assumed to be defined in a well-specified disciplinary way). In physics such a case, for instance, occurs when speaking of corpuscular and wave representations of atomic phenomena or when speaking of the different, not unitarily equivalent, representations of a quantum matter field (which can be thought of as different matter 'phases'). However it applies in general such as considering, for instance, biological and psychological, economical and social and structural and aesthetical aspects. This is the typical case for Multiple Systems and emergent systems acquiring different properties.

- A system allowing for a number of different equilibrium behaviours, which have the same probability. Such a case occurs in spontaneous symmetry breaking phenomena well known in physics and used in models of intrinsic emergence (Cruchtfield, 1994; Pessa, 1998; Umezawa, 1993). A similar circumstance, however, also characterizes the behaviour of neural networks, cellular automata and artificial life systems.
- A system whose models must allow for the introduction of noise or fuzziness, related to individual and unforeseeable phenomena, as is the case for biological, socio-economic or cognitive systems as considered above.
- A system whose models must necessarily incorporate a model of the observer of that system or a model of the model builder.

DYSAM is structurally appropriated to deal with generic quasiness, particularly for modelling quasiness of quasi-properties and quasi-systems.

DYSAM can be concretely implemented in a virtually unlimited number of different ways such as methodological and computational.

We refer in the following to previous elaborations related to DYSAM introduced in Minati and Pessa, (2006, pp. 76–84).

They relate to assume the case when the models available to the observer can be represented through particular kinds of *neural networks* networking models:

On intuitive grounds, one would expect that, in situations in which the environment behaves in a simple and predictable way, the behaviour of the model should differ from a DYSAM-like one. These situations occur when the number of possible different input patterns is very small or, more frequently, when their probability of occurrence is described by a distribution which is sharply 'peaked' over a small number of patterns. Besides, the law of association between input patterns and correct categories should not change with time. In such situations, the input patterns are always more or less the same and the model does nothing but to learn the statistical structure of a fairly simple environment. No DYSAM strategy is required, except in the initial phases, because a single network (that is a single model) is sufficient to capture the environmental regularities. In the opposite situation, however, in which the probability distribution for the occurrence of input patterns tends to be nearly flat, a DYSAM-like behaviour should develop, and such an effect should increase in the presence of a variation with time of the law connecting the input patterns with the correct categories. (Minati & Pessa, 2006, pp. 78–79).

We stress that the still GOFS ***nature*** *of DYSAM is given by the fact that coherence between models is* ***phenomenological,*** *i.e. it is given by the complex coherent phenomenon to be modelled rather than* ***represented****, for instance, by eventual properties of networks of models.*

As mentioned above we should consider here a ***constructivist DYSAM****, given of suitable mix of ideal and non-ideal models.*

The sequence of models is given by the phenomenological emergence of the phenomenon under study.

We consider here ***a posteriori*** *Collective and Quasi-Collective Beings when DYSAM is given by non-ideal models but of data-driven, structurally adaptive models without usage of microscopic statistics or macroscopic indexes and variables* (Minati & Licata, 2013).

An interesting possible variation occurs when the models considered are networks or meta-structures and when input units are meta-structural values and represented as nodes through particular kinds of *neural networks*.

We stress that while DYSAM has the purpose to **select or create** *a suitable usage of models suitable to deal with emergent acquired properties, an eventual* ***meta-structural DYSAM*** *has the purpose to outline and suggest features and properties of an eventual general upper meta-structural level. These upper* ***meta-structural*** *levels could correspond to* **categories of collective coherent systems.**

At this regard we consider DYSAM as possible **network**(s) *of different, eventually homogeneous, non-homogeneous models, like based on chaos and attractors, correlations, meta-structures, networks, scale invariance and power laws and topological properties.*

5.3.3 Simulations

A great number of papers and tools have appeared in the literature regarding modelling and simulation of dynamic systems (see, for instance, Sokolowski & Banks, 2009; Terano, Kita, Kaneda, Arai, & Deguchi, 2005) and the development of mathematical models and simulations in the field of artificial life (Adamatzky & Komosinski, 2010; Chalup, Blair, & Randall, 2015; Komosinski & Adamatzky, 2014; Kyung-Joong & Sung-Bae, 2006; Takashi, Li, & Aihara, 2014); in synthetic biology, the 'techno-science' of artificial life (Forster, Liljeruhm, & Gullberg, 2014; Kaebnick & Murray, 2013); and in social science (Gilbert & Troitzsch, 2005).

We limit ourselves to outline in this section some eventual aspects for new post-GOFS simulations tacking count of the comments introduced above.

In this case also we would like to start from principles and approaches already considered for DYSAM.

It should be noted that DYSAM exploits the parallel processing (even though it is *simulated* in a sequential way) of different models related to the same level of description, so as to take into account different results *simultaneously*. The goal is not restricted to compare *only* effectiveness and suitability, but to carry out a learning, evolutionary, emergent system of approaches which are able to use in the *locally best* way the resources available.

Thus, DYSAM is not a single, procedural, rule-based methodology, but a systemic general model, a *meta-model* (i.e. a model of models), used to carry out single, contextual methodologies. In this case simulation does not relate to the simulation of the phenomenon under study, but the usage of models looking forward for effectiveness of the collective modelling.

In a networked or meta-structured space, *free behaviours* occurring by respecting constraints can occur in any way, but they will acquire some specific network or meta-structural properties, pre-properties making the system collapsing on equivalent configurations notwithstanding eventual fluctuations.

A technical issue relates to the possibilities to use simulations allowing the automatic search for the *fitting* of mesoscopic variables and meta-structural properties with phenomenological ones, for instance, due to clustering, scalarity and statistical properties.

An interesting case considered above relates the approach to simulate multiple coherences and even to experiment possible ways to influence emergent collective behaviour through *insertion* of suitable *Perturbative Collective Behaviour* (PCB) to interact with (see Sects. 4.6.1 and 5.3.3). The latter idea relates to the following cases typically asking for DYSAM approaches when, for instance:

- Two autonomous collective behaviours assume some *merging*. In this case elements of the two collective behaviours consider the others as moving obstacles and behave by maintaining the prescribed degrees of freedom. One collective behaviour *looks* as *interference* to the other one.
- Two autonomous collective behaviours assume some *merging*. However one may be insensitive to the presence of the other one and maintaining its behaviour. It is to the other one to avoid collisions and maintain degrees of freedom.
- Two autonomous collective behaviours assume some *merging*. In this case agents are provided with some *learning* abilities allowing them to anticipate some behavioural features of the other. It is possible to distinguish between the cases when only agents of one collective behaviour possess this property or both, possibly with fixed or variable time.
- The case can be complicated when considering more than two collective behaviours eventually subsequent and possessing variable number of agents and properties.

This approach is currently under study in the meta-structure project (Minati & Licata, 2015).

We mention how some properties, approaches and models used to study nanotechnologies (see, for instance, Bensaude-Vincent, 2009; Kulkarni, 2014) and the *doping* of the silicon (Siffert & Krimmel, 2010) may be considered in this research.

5.4 Three Aspects

In this section we focus on 3 particular aspects of the 14 listed above in Sect. 5.3, i.e. non-invasiveness, non-prescribability and non-causality.

These three aspects are considered to specially represent the need for new modelling (Minati, 2016) based on approaches considered at the Sect. 5.3.

5.4.1 Non-invasiveness

We already mentioned above the systemic meaning of the subject. We will explore here its autonomous, i.e. non-reducible to *negation* of invasiveness, theoretical meaning and its representability suitable for eventual formalizations and modelling.

The concept of non-invasiveness is not only irreducible to negation of invasiveness, but it is constituted by different aspects and gradualness. For instance, instead of speaking of non-invasiveness tout court, we consider approaches having *low intensity* in their invasiveness, where *lowness* relates to general parameters of the phenomenon under study. We may consider the *non-explicit* aspects of non-invasiveness when modifying actions and intervention are not *directly* on aspects or variables of interest, but rather on other aspects or variables having eventually composed, dynamical *non-linear* relationships with the ones of interest. This is, in short, related to actions on complex systems discussed until now.

We intend here the concept of *invasiveness* as related to characteristics of approaches used in various disciplines like medicine for a large variety of cases and illnesses (see, for instance, Miller, 2013; Werner & Davis, 2014), ecology (Kohli, Jose, & Singh, 2008) and having generic meaning in economics when dealing with the introduction of new products and services.

Unlike the related concept of *diffusion* – intended as ‘passive’, i.e. due to eventual *combinations* between properties of the hosting environment and *invaders*, like in ecosystems, chemistry and medicine (see, for instance, Friedl, Locker, Sahai, & Segall, 2012) – we consider invasiveness here as active, concerning phenomena when *external* interventions are based on *inserting*, for instance, new entities and processes assumed to (a) perform roles that the system is not anymore able to do or that it never did or (b) substitute and replace entities and procedures when, for instance, assumed not anymore suitable.

In medicine it may relate, for instance, to pacemakers, transplants, transfusions and in social systems replacement of currency, taxations, language and imposition of religion.

Invasiveness is based on considering systems mostly intended as *devices* to be repaired or requiring maintenance or having the identity (see Sect. 3.5) to be substituted or changed. It is matter of generalized, eventually gradual changes.

Even in military and political strategies, peacekeeping may be considered as an approach of this kind (Bellamy, Williams, & Griffin, 2010).

The theoretical framework of invasiveness may be understood to correspond to the ones used for allowing and maintaining functions and functioning in engineering and medicine, as well as to insert devices able to detect properties and eventually influence them.

Moreover the term *invasiveness* can be even *inadequate* when dealing with systems having, or considered as such, emergent acquired properties rather than functional only, i.e. *decidable*. Invasiveness *inside* a process of emergence may be intended as eventually composed, for instance, of:

- Low-intensive and non-explicit actions (we discussed in Sect. 3.7 possible influential actions on processes of emergence like on available energy, environment and the degrees of freedom).
- Insertion of a PCB as in Sects. 4.5.1 and 5.3.3.

In this case the problems and purposes to deal with are not anymore coincident or reducible to performing *roles* in a more suitable way or to substitute and replace.

Considering processes of emergence, invasiveness should be intended as desegregation of emergence unless a process of substitution having same emergent nature is possible.

The subject is indeed completely different when dealing with quasi-systems, quasi-properties and emerging acquired properties and related emergent systems.

At this point our interest focuses on the fact that quasi- or non-invasiveness are properties of interventions suitable to appropriately modify emergent acquired properties.

We may say that the point consists of approaches to deal with *properties of properties*, i.e. modalities and processes of acquisition, change and keeping on one side, and stability, evolution on the other side, of properties. This relates, for instance, to availability to assume property (like pre-property); behavioural aspects rather than behaviour; changing pattern by keeping, for instance, similarities; style as modality to act; tendencies like to expand or reduce and to be regular or not; and valences like tendency to assume kinds of change. That is quasiness.

Several approaches introduced in the literature are considerable to represent such processes and possibly *induce* 'indirect' variations in a non-invasive way. We may consider interventions having medium- and long-range temporal and spatial effects, like (1) in public economics as taxations, printing of paper money and purchase of government bonds to intervene on liquidity and inflation (see, for instance, Stiglitz & Rosengard, 2015); (2) in biology and medicine when chemical interventions, e.g. though drugs, may slow down, accelerate or initiate huge processes of different kind rather than *substitute and replace* (among countless contributions available in literature, we mention in neurology Ibarra & Martiñón, 2009; Wasserfall & Herzog, 2009); and (3) in sociology and cognitive science studying induction of behaviour in humans as cooperation in social systems (among countless contributions available in literature, we mention Bowles & Gintis, 2013; Germar, Schlemmer, Krug, Voss, & Mojzisch, 2014 in social psychology). The list may continue regarding several other disciplinary contexts.

We want to outline in the follow general characteristics of non-invasive approaches based on generic *softness* of non-invasiveness.

It means the property to proportionally, continuously adapt to and use the general *parametrical* characteristics of the system under consideration in order to induce variations. *Soft approaches* have properties based on *properly feeding* systems with inputs, perturbations, environmental changes and eventual structural and parametrical changes *appropriated* to the system, e.g. *low* in reference to current parameters. The appropriateness relates to *adapt* interventions in terms, for instance, of proportionality of the intensity and timing, of renouncing to substitute or to force roles and reactions but, rather suggest, induce the system to assume them. *Suitable knowledge of the system not related to its functioning, suitable for non-soft approaches, but, rather, to its emergence, is required.*

In those cases the softness does not only assure proportionality, but, rather, it is supposed to destabilize equivalences and orient or compete with fluctuations.

We may consider the example given by the difference between acting on structures and on networks or meta-structures.

Issues for *soft approaches*, allowing non-invasiveness, relate, for instance, to *network* and *meta-structural interventions*.

We should note that they have different levels of *non-linearity* since dealing with networks we may act, for instance, on their topology or scale invariance. While dealing with meta-structures, we may have *two levels of non-linearity* as given, for instance, by:

- Processes of clustering, mesoscopic variables and their values.
- Meta-structural properties as properties of mesoscopic variables.

We stress how such interventions may be metaphorically understood as *suggestions* to the system and that this approach could also be considered 'respectful' with the system. The *effectiveness* of this approach is given by avoiding the forcing often one-dimensional, irrespective to the general systemic context and its dynamics. It is a matter of an effective respectfulness able to preserve or induce change, not substitute, the identity of the system. It applies to complex systems and particularly to systems having different levels of complexity like for living systems and dealing with medical interventions.

At this regard we may consider a kind of eventual *invasiveness of emergence* occurring in sets of interacting elements without coherence and without establishing emergence. This relates to different levels of well-studied order-disorder transitions and the strategy to suitably *perturb* a process of emergence by acting, for instance, on degrees of freedom and their usages and by *inserting* a suitable PCB, when examples are soft coherent combinations of changes of economical parameters for social systems, drugs and medical and psychological interventions for patients and ecosystems like to prevent destructive imbalances.

5.4.2 Non-prescribability

The general subject of this point relates to the impossibility to *explicitly* prescribe properties and behaviours to emergent variables and properties of complex systems.

Examples of *explicit prescriptions* intended here are (a) *direct* parametrical changes of values possessed by the variable(s) of interest, (b) changes of rules of interaction among components of the system, (c) insertion of new elements and (d) generic intensive, i.e. *high intensity*, invasiveness (see also non-invasiveness in Sect. 5.4.1).

We mention how this topic is related to the previous one of non-invasiveness since *non-invasiveness cannot be explicitly prescribed*. Actually non-invasiveness can be only conceptually prescribed as generic property of properties possessed by any kind of intervention.

The case we consider here is related to properties of complex systems and related emergent variables. Emergent properties of complex systems and values assumed by acquired emergent variables cannot be *directly* changed, e.g. *regulated* by an *external* intervention, but eventually influenced in such a way to possibly *converge* to the desired change. For instance, changes of properties of collective behaviours like the altitude or direction of flocks and swarms, the flux of traffic, the use of credit by businesses, the morphology of towns and the landscape cannot be explicitly, i.e. symbolically, prescribed.

Processes of emergence of complex systems are eventually *distorted* or *destroyed* by explicit interventions, as *catastrophic perturbations*. For instance:

1. *Direct dispensing* of chemicals to living systems may be an ineffective strategy, e.g. calcium in case of osteoporosis rather than drugs acting on internal biochemical processes allowing the available calcium to be *absorbed* by bones.
2. In economics *injections* of monetary liquidity may be ineffective in the absence of interventions on availability of credits and suitable taxation.
3. *Non-adaptive* traffic lightings to optimize the flux.

Furthermore prescribability is made almost impossible by the non-linear nature of complex systems.

However it is possible to *prescribe* (a) eventual *necessary conditions* in the absence of which processes of emergence cannot take place like minimums and maximums of parametrical values and (b) general changes likely related to environmental conditions, degrees of freedom and network or meta-structural properties having in their turn second-level, non-linear effects on the corresponding complex processes.

The non-prescribability means that it is not possible to give *orders* to complex systems, if not *suggestions* by using non-invasiveness. Actually, *invasive actions* relate to symbolically *prescribe*, i.e. substitute, remove, modify or introduce structures, i.e. *decide*.

By dealing with systems, we face the *alternative* between to prescribe and not when considering their emergent or non-emergent nature. However the situation is different for quasi-systems dynamically eventually combining the different aspects.

The subject relates the crucial problem of the availabilities of approaches suitable to (a) facilitate and induce emergence of collective coherent properties in populations of elements only collectively interacting and (b) act on collective emergent phenomena with the purpose of *change*, *vary*, *establish*, *maintain or avoid* emergent properties. Suitable combinations of approaches are necessary to deal with quasi-systems.

As mentioned above we figure out some possible approaches to *prescribe* meta-structural properties by referring to concepts introduced in Sect. 3.7.

For instance, by changing the *degrees of usage* by interacting agents of the degrees of freedom in such a way as to *induce*, *vary* or *prescribe* meta-structural or network properties to collective interacting agents. The approach may be merely phenomenological establishing some *categories* or *libraries* of approaches.

A second possible approach considers *environmental properties* establishing dynamical non-homogeneous environments, *coherently* influencing and eventually distorting, for instance, energy and information exchanges.

A third possible approach considers the eventual influencing of structural regimes of validity and their sequences.

A fourth possible approach considers the eventual influencing of the mesoscopic general vector.

A fifth possible approach considers the eventual *adequate* introduction, e.g. with regard to the number of agents and their distribution, *into* the collective behaviour to be varied, of agents which artificially already interact according to the meta-structural property to be prescribed, as with PCBs.

5.4.3 Non-causality and Causalities

As it is well known, there is a clear distinction between correlation and causality, for instance, since *correlation does not imply causation* and *correlation does not prove causation*. It is matter of inductive thinking based on probabilistic evaluations (Pearl, 2009).

In a causal, *non-anticipative* system, the output depends on past and current inputs, but not on future inputs. Examples are given by analogue circuits and any memory-less system.

We remind that an *anticipatory system* (Rosen, 1985) is intended as a system '... containing a predictive model of itself and/or of its environment, which allows it to change its state at an instant in accord with the model's prediction pertaining to a later instant'. Formally, an anticipatory system is a system X whose dynamical evolution is governed by the equation: $X(t + 1) = F(X(t), X^*(t + 1))$ where $X^*(t + 1)$ is X's anticipation of what its state will be at time $(t + 1)$.

The concept of causality has been the object of study and research since long time, in philosophy and scientific disciplines (see, for instance, Illari & Russo, 2014; Mumford & Anjum, 2013; Pearl, 2009).

The simpler concept of *causality* is given when assuming that the output at any time depends only on past and present values and when certain terms are intended as *causes* and other terms as *effects*.

A classical example occurs in classical Newtonian mechanics where a cause may be given by a force acting on a body and an effect by the consequent acceleration as by Newton's second law.

In the general theory of relativity, *differently*, acceleration, being not a generally relativistic vector, is not considered as an effect. General relativistic effects comparable to those of Newtonian mechanics are the deviations from geodesic motion in curved space-time.

Before to consider more cases, we mention that the subject was discussed by von Bertalanffy discussing possible *equivalence* between equifinality and causality (Von Bertalanffy, 1968, pp. 40; 136, 148–49).

von Bertalanffy discussed three kinds of finalities associated, respectively, with the following situations:

- The dynamical evolution of a system reaches a stationary state asymptotically over time.
- The dynamical evolution never reaches this state.
- The dynamical evolution is characterized by periodic oscillations.

In the first case, variations in the values of the state variables may be expressed as a function of their distance from the stationary state. System changes may be described as if they depended on a future final state. Such a circumstance could be related to a teleological view expressed, for instance, by *minimum or maximum principles* (of a local or global nature). von Bertalanffy noticed how this form of description is nothing but a *different expression of causality*: the final state simply corresponds to a limiting condition of the differential equations governing the dynamical evolution. Such a condition, however, could also be considered as describing a particular kind of finality, i.e. the so-called equifinality. This is a characteristic of dynamical systems able to reach the same final state independently of initial conditions and input, like the trivial case of the pendulum.

It is important to realize that causality cannot be considered *in general*, but as related to specific cases such as dealing with linearity, non-linearity, networks and specific models.

Dealing with the linearity of structural equations, a *causal model* can be considered as an abstract model that describes the eventual causal structural *mechanisms* of a system.

A causal model can be defined as an ordered triplet $\langle U,V,E \rangle$, where:

- U is a set of *exogenous variables* whose values are determined by factors *outside the model.*
- V is a set of *endogenous variables* whose values are determined by factors *within* the model.
- E is a set of *structural equations* that express the value of each endogenous variable as function of the values of the other variables in U and V (Pearl, 2009).

Forms of *non-causality* intended here as non-reducible to *linear* cases mentioned above relate, for instance, to situations when the system is *out of phase* with the driving input force as when the system is subject to an oscillatory force possessing a frequency much higher than the highest resonant frequency of the system. In this case there will be no sufficient time for the system to react before the force has switched its direction. This will *destroy* causality.

Other forms of such non-causality occur for:

- System of causal systems, such as *collective systems of causal systems* where local causalities *evanish* in a variety of interactions like for the second cybernetics (Maruyama, 1963).
- Quasi-systems where causality becomes a quasi-property.

Different concepts of causality intended here as non-linear causality should be considered when dealing with the complexity of non-linear systems (Coffman, 2011) such as:

- Top-down causation rather than the classical bottom up, as in networks and collective systems (see Sect. 7.1.1 for *bottom-up and up-down emergence* and related references; see, for instance, Auletta, Ellis, & Jaeger, 2008 Lloret-Climent & Nescolarde-Selva, 2014).
- Non-linear causation as in neural networks (see, for instance, Blum, 2014; Wang & Ma, 2010).
- Meaning of causation in entangled quantum systems (see, for instance, Blute, Ivanov, & Panangaden, 2003; Bohm, 1957; Kent, 2005).
- Causation as transfer of information (see, for instance, Collier, 2011).

At this regard several definitions of causality are possible as in Kleinberg (2012).

As it is possible to have different forms and levels of causality, e.g. linear, non-linear, multidimensional, first- and second-order causality (http://second-order/second-order%20causality.pdf Web Resources) and the so-called Granger causality[2] (Ancona, Marinazzo, & Stramaglia, 2004; Chen, Rangarajan, Feng, & Ding, 2004; Granger, 1969, 1980), it is also possible to have a variety of forms of non-causality. *At this regard we considered phenomena of emergence of collective behaviours not reducible to sequences of cause-effect, when emergence is continuously locally decided by breaking equivalences in different ways and by keeping global coherence.*

We may state that causality is conceptually substituted by approaches to induce and maintain coherences.

In this way the interest focuses, for instance, on network, meta-structural, topological and quantum properties.

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[2] A signal X_1 is considered to *G-cause* a signal X_2 when past values of X_1 contain information that helps predict X_2 beyond the information contained in past values of X_2. The mathematical formulation is based on linear regression modelling of stochastic processes.

5.5 Further Remarks

The discussion and elaboration relate to the need to have suitable strategies to *combine* and *use* different, multiple approaches introduced in order to get the advantages classically given by formalizations when it is not possible to zip the essential characteristics of complex systems into sets of ideal equations.

As it is well known, the interest to formalize processes is to reach a *symbolic* representation such as to allow the study and research of implicit or non-evident properties in the corresponding phenomenon. We discussed the issue in Sect. 1.3.4 distinguishing between explicit and non-explicit formalizations. Research focuses on properties of representations.

It is interesting to remind that the approaches may consider representations having non-*linear* connections with microscopic entities like for *macroscopic indexes*, e.g. temperature and molecular behaviour, and for mesoscopic variables introduced above.

The subject of this chapter focuses on multiple combined, e.g. networked, usages of formalizations, constructivist approaches, tools and methodologies to correspondingly deal with multiplicity of structural dynamics of processes of emergence, like for the 14 properties listed in Sect. 5.3 where the *transversal general invariants* are given by properties of structural dynamics and dynamical coherences.

The usual alternative between symbolic and non-symbolic is difficult to apply since the nature of the properties to be represented and eventually formalized is multiple such as the fourteen considered and for quasi-systems.

The point relates to the ability to *reproduce* systemic autonomy of complexity rather than to symbolically or sub-symbolically represent it.

We considered the still GOFS nature of DYSAM, while we should consider here a *constructivist DYSAM*, given of suitable mix, network of ideal and non-ideal models.

This reminds the possible *meta-structural DYSAM* formalizing upper meta-structural levels representing *categories of collective coherent systems as by using regimes of validity*.

However this seems to have predominant *phenomenological nature*. Can we *theoretically* study the *nature* of such usages and have prospectively models of usages of models, i.e. give theoretical *thickness*? That is not to reach *improbable* higher levels of formalizations, but to set eventual *correspondences* among phenomenological properties of complex and emergent phenomena and the multidimensional usages of approaches and models. Can we find some invariants – the correspondences? Is it the supposed *General System* – singular – *Theory*, i.e. *theory of* the *general system*, introduced by von Bertalanffy (Von Bertalanffy, 1968)?

Box 5.1: Bifurcation

How does the behaviour of a given dynamical system change when we change the values of its parameters? In attempting to answer this question, the most widely studied phenomenon is *bifurcation*. This term denotes a change in the number or type of attractors as a consequence of changes in parameter values (for a general treatment of this subject, see Iooss & Joseph, 2012). In most simple cases (i.e. those dealing with a single parameter), a bifurcation takes place when the value of a parameter, the so-called bifurcation (or *critical*) parameter, crosses a *critical value*, which thus appears as a separator between two structurally different states of affairs: one with values of the bifurcation parameter less than the critical value and the other with values greater than the critical value. This suggests not only that models admitting bifurcation phenomena are the best suited to describe self-organizing systems, but induces one to postulate a close analogy between bifurcation phenomena and *phase transitions* in physical systems. Namely, the two different states of affairs, before and after critical value, can be considered as being analogous to different *phases* of matter, the critical value itself being viewed as the *critical point* of a phase transition. However such an analogy breaks down when we take into account the fact that the values of dependent variables undergo unavoidable fluctuations, due both to the limited sensitivity of our measuring instruments and to the coupling between the system and a noisy environment. Despite this, most researchers, from Prigogine onward (Nicolis & Prigogine, 1977), upheld the validity of such an analogy.

Mathematicians also introduced another classification of bifurcations into two categories: *local* and *global* (see Ott, 2002). A local bifurcation gives rise to changes in attractor structure only within a small neighbourhood of phase space of the system under study. On the contrary, a global bifurcation results from a connection between distant attractors and gives rise to sudden structural changes over large domains of phase space. The different categories of bifurcations sketched above are the object of intense study by mathematicians. A general theory of bifurcation, however, covering all possible phenomenology is still lacking. Although for particular kinds of bifurcation well-known algorithms exist (implemented even through computer programs for symbolic manipulation) which allow to forecast their phenomenology in a detailed way, in other cases we are still forced to resort to numerical simulations. Mathematicians and theoretical physicists (see the literature cited above) have, however, shown how nonlinear systems can always be described by suitable *canonical forms*, which are valid near bifurcation points (Kelso, 1995).

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Chapter 6
Theoretical Systemics and Quantum Field Theory

Contents

> *I think I can safely say that nobody understands quantum mechanics…"* Richard Feynman, in *The Character of Physical Law*; MIT Press, Cambridge, Ma, 1967.

This chapter introduces some considerations about the systemic valence of quantum field theory (hereafter shortly denoted as QFT). At first sight these considerations could seem out of place within a book dealing with systemics, as usually people regard QFT as a strictly physical theory, concerning elementary particles or microscopic features of matter. This viewpoint is, however, incorrect, as QFT constitutes the widest conceptual framework so far introduced by the human mind to describe all possible physical phenomena. This circumstance authorizes to consider QFT as an important example of a *General System Theory*. Thus, it appears as impossible to embark on a discussion about systemic features while ignoring the contributions of QFT.

It is, however, to be remarked that the lack of knowledge regarding QFT, characterizing a large number of scholars outside the community of theoretical physicists, is partly due to the complexity of the history of development of QFT (though particular aspects of this history are taken into consideration in many books on QFT, the number of specific references is far smaller: they begin with a short paper by Weinberg (1977), followed by a more extended one by Darrigol (1984); more complete books are the ones of Cao (1997), Pais (1986) and Schweber (1994); some of the most important papers are reprinted in Schwinger (2012)). Namely, the first attempts to build QFT were devoted to account for the interactions between

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radiation and matter, which were impossible to describe within the context of ordinary quantum mechanics. These phenomena were the most easily accessible through the experimental technology available in the first half of the twentieth century. Their study required the introduction of a quantized theory of the electromagnetic field, called ‘Quantum Electrodynamics’, which became the first successful example of a QFT.

Around the 1940s the jump of the technology, due to introduction of synchrotrons, accelerators and other instruments used in nuclear physics, allowed to perform new experiments concerning an ever-growing number of different elementary particles. Such a circumstance shifted the interest of theoretical physicists towards the possible applications of QFT to describe other kinds of interactions (such as strong and weak ones), different from the electromagnetic ones. This trend was dominated by the need for explaining and forecasting the results of experiments characterized by an ever-growing technical complexity. All that produced a sort of neglect of the fundamental conceptual problems of QFT and of its intrinsic systemic potentiality. This explains why the almost contemporary development of systemic approach occurred without relationships with QFT.

This situation began to change in the 1960s, owing to a number of different factors, including the introduction of the renormalization program for taming the infinities present in QFT computations; the application of QFT to condensed matter physics, evidencing a wider range of possible uses of QFT outside the particle physics; and the theorems by Haag and Hepp on the existence within QFT of different – but not unitarily equivalent – representations of the same canonical commutation relations. These advances opened the way to possible applications of QFT not only to microscopic but also to macroscopic quantum phenomena. Therefore, it began legitimate to consider QFT as a candidate for building a *Theory of Whole*, a fact which attracted the interest in QFT not only of physicists but also of philosophers, computer scientists, biologists, complexity scholars and even psychologists. This interest increased in the last hears owing also to the recent advances in the theory of *quantum computing*, motivated by the technological attempts to build a *quantum computer*. Namely, even if most achievements in this domain regarded standard quantum mechanics and not QFT, they were useful to deepen our knowledge of the conceptual basis of QFT itself. Within this chapter we will try to explain up to which extent this interest is justified in the context of post-GOFS Systemics.

6.1 Embedded Systemic Principles: The Need for the Introduction of a Quantum Approach

The mathematical details of QFT as well as its conceptual and philosophical foundations are described in a large number of textbooks (a surely incomplete list includes Araki, 1999; Duncan, 2012; Huang, 1998; Itzykson & Zuber, 1986; Kiselev, Shnir, & Tregubovich, 2000; Lahiri & Pal, 2001; Maggiore, 2005;

Mandl & Shaw, 2010; Peskin & Schroeder, 1995; Schwartz, 2014; Srednicki, 2007; Stone, 2000; Umezawa, 1993; Weinberg, 1995, 1996, 2000; a short discussion of QFT is contained in the Sect. 5.3 of Minati & Pessa, 2006). However, a formal definition of what distinguishes QFT from other physical theories is still lacking. Perhaps, it would be more correct to say that QFT is a general conceptual framework adopted by a number of specific theories, each one of which represents a particular implementation of QFT. This framework is characterized by a number of principles expressing the embedded systemic nature of all QFT-like theories.

In this regard it is to be remarked that the mathematical implementations of these principles are so far affected by a number of unsolved problems, dealt with by people working on the *Philosophical Foundations of QFT* (among the books on this subject, we can quote Auyang, 1995; Cao, 2010; Kuhlmann, Lyre, & Wayne, 2002; Ruetsche, 2011; Teller, 1995). This situation authorizes to think of actual QFT like a sort of incomplete and ever-growing building, supporting many successful achievements owing to a mixture of mathematics, tricks and questionable suppositions. Nevertheless, a discussion of the aforementioned principles helps to understand why the best way so far followed to build a truly general systems theory is so difficult to cover. In the following we present a tentative list of these principles.

Since the middle of the past century, there has been a growing interest in the quantum-like approaches, concerning mostly their simplest implementation, that is, *quantum mechanics* (QM). This interest is essentially due to the fact that QM allows (and predicts) some phenomena of long-range coherence which are forbidden by the traditional physical theories based on deterministic laws. Among these phenomena, we can quote the occurrence of macroscopic states endowed with *collective coherence* (e.g. in a ferromagnet or a superconductor), the *Bose-Einstein condensation*, the *entanglement*, the *overcoming of an energy barrier* even in absence of the necessary energy supply and the *teleportation*. We will now spend some words about the entanglement for two main reasons: (1) it constitutes the most genuine quantum effect, to which all other quantum phenomena can, in a way or in another, be reduced; (2) it allows to deeply understand why the QFT constitutes the better and powerful implementation of a quantum approach, if compared with traditional QM.

In order to make clearer our arguments, we will shortly recall some basic concepts of standard Quantum Mechanics (QM). To start, we remember that, analogously to classical physics, also in QM the concept of *state* has a paramount importance. A state is characterized by the possible values assumed by a number of suitable *state variables*. The fact that the number of available possibilities can in some cases be finite and in other infinite justifies the choice of representing states as *vectors* belonging to suitable vector spaces. Usually these latter are *Hilbert spaces*, that is vector spaces over the set of complex numbers. The smallest nontrivial Hilbert space is two-dimensional and describes vectors with only two components. It is used to describe *quantum bits*, or *qubits*, that is quantum systems allowing only two possible measurement outputs, often called 0 and 1. As it is well known from the elementary theory of n-dimensional vector spaces, in order to describe vectors in a numerical fashion, we need to introduce (in an arbitrary way) a set of n basis vectors, each of unit length and reciprocally orthogonal, in such a way as to express each vector in terms of its projections on the basis vectors. Here, in order to shorten our symbolic representations, we will make use of the *Dirac bra-ket notation* in which a single ordinary vector is globally denoted through a *ket symbol* like, for instance, $|A\rangle$, which denotes the vector A without taking care of the values of its components. The usual convention interprets a ket as a column vector, while the *bra symbol* denotes the transpose of the same vector, given by a row vector. By using these symbols, we can, for instance, introduce a particular basis for the two-dimensional Hilbert space, often called *computational basis*, given by two vectors $|0\rangle$ and $|1\rangle$, explicitly given by:

$$|0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \quad |1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

A generic vector $|\psi\rangle$ can then be represented under the form:

$$|\psi\rangle = \begin{pmatrix} \alpha \\ \beta \end{pmatrix} = \alpha|0\rangle + \beta|1\rangle = \alpha\begin{pmatrix} 1 \\ 0 \end{pmatrix} + \beta\begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

where α and β are complex numbers. If, according to the postulates of QM, we interpret the squares of the coefficients α and β as the probabilities of obtaining, after a measure on the system described by this vector, respectively, the outputs 0 and 1, then we have that, in order to fulfil the probability rules, these coefficients must obey the constraint.

$$\alpha^2 + \beta^2 = 1$$

These mathematical formulae give a description of a qubit. Specific choices of the values of coefficients α and β correspond to particular qubits. Among them the most famous one is the choice $\alpha = \beta = \frac{1}{\sqrt{2}}$, defining the so-called *cat state*, that is a qubit in which a measurement has equal probabilities (exactly $\frac{1}{2}$) of obtaining the outputs 0 or 1 (as well known the name of this state is related to the celebrated 'cat' thought experiment introduced in 1935 by Erwin Schrödinger; see Schrödinger, 1935a).

It is important to remark that any qubit can be obtained through a linear superposition of the two states $|0\rangle$ and $|1\rangle$, in conformity with general principle, holding in quantum mechanics, according to which every linear superposition of pure quantum states gives rise to a new pure quantum state. Here the attribute 'pure' characterizes mathematically all vectors of a suitable Hilbert space which are solutions of the Schrödinger equation holding within this space or which are eigenstates of suitable quantum measurement operators. If we use a computational basis within a generic Hilbert space, the simplest examples of pure states coincide with the basic combinations of possible measurement outputs within this space. In this regard, let us consider a more complex quantum system made by two qubits. The possible combinations of the possible measurement outputs are obviously 4, as each qubit has two possible outputs, denoted by 0 and 1. The list of these 4 combinations is (1) 0 on the first qubit and 0 on the second qubit, together denoted as $|00\rangle$; (2) 0 on the first qubit and 1 on the second qubit, together denoted as $|01\rangle$; (3) 1 on the first qubit and 0 on the second qubit, together denoted as $|10\rangle$; and (4) 1 on the first qubit and 1 on the second qubit, together denoted as $|11\rangle$. We can use the four vectors $|00\rangle$, $|01\rangle$, $|10\rangle$ and $|11\rangle$ as the computational basis for a four-dimensional Hilbert space. A generic vector $|G\rangle$ of this space has a form of the kind: $|G\rangle = \alpha|00\rangle + \beta|01\rangle + \gamma|10\rangle + \lambda|11\rangle$, fulfilling the condition:

$$|\alpha|^2 + |\beta|^2 + |\gamma|^2 + |\lambda|^2 = 1$$

It is, now, natural to ask ourselves whether a generic vector can be related to the qubits previously introduced. To answer this question, we need to resort to a new concept, the one of *tensor product between two vectors*. More precisely, given two vectors A and B, defined in terms of their components as in the following:

$$A = \begin{vmatrix} a_1 \\ a_2 \\ \dots \\ a_n \end{vmatrix} \qquad B = \begin{vmatrix} b_1 \\ b_2 \\ \dots \\ b_n \end{vmatrix}$$

we will define the tensor product of A and B, denoted as $A \bigotimes B$, through a new vector, build according to the rule:

$$A \bigotimes B = \begin{vmatrix} a_1 \begin{vmatrix} b_1 \\ b_2 \\ \dots \\ b_n \end{vmatrix} \\ a_2 \begin{vmatrix} b_1 \\ b_2 \\ \dots \\ b_n \end{vmatrix} \\ \dots \\ a_n \begin{vmatrix} b_1 \\ b_2 \\ \dots \\ b_n \end{vmatrix} \end{vmatrix}$$

For instance, in the case of two-component vectors, if we have:

$$A = \begin{vmatrix} a_1 \\ a_2 \end{vmatrix} \qquad B = \begin{vmatrix} b_1 \\ b_2 \end{vmatrix}$$

we immediately obtain:

$$A \bigotimes B = \begin{vmatrix} a_1 b_1 \\ a_1 b_2 \\ a_2 b_1 \\ a_2 b_2 \end{vmatrix}$$

This example shows how the tensor product allows to transform two-dimensional vectors into four-dimensional vectors, creating a sort of relationship between two-dimensional and four-dimensional Hilbert spaces. As qubits are typically two-dimensional objects, it is spontaneous to ask if four-dimensional vectors can be expressed in terms of qubits, that is, if given a generic $|G\rangle$, we can always write:

$$|G\rangle = |A\rangle \bigotimes |B\rangle$$

where the two-dimensional vectors code two qubits. It is easy to show that in some cases the answer is affirmative. If the computational basis vectors of the four-dimensional Hilbert space are chosen in such a way as to have:

$$|00\rangle = \begin{vmatrix} 1 \\ 0 \\ 0 \\ 0 \end{vmatrix} \qquad |01\rangle = \begin{vmatrix} 0 \\ 1 \\ 0 \\ 0 \end{vmatrix} \qquad |10\rangle = \begin{vmatrix} 0 \\ 0 \\ 1 \\ 0 \end{vmatrix} \qquad |11\ \rangle = \begin{vmatrix} 0 \\ 0 \\ 0 \\ 1 \end{vmatrix}$$

it is immediate to see that, for example, $|01\rangle = |0\rangle \bigotimes |1\rangle$, where the two vectors are coded through the two-dimensional computational basis convention. However, it can easily be shown that there are cases in which we have four-dimensional vectors which cannot be expressed through a tensor product of two qubits, that is, of two bidimensional vectors. When this occurs? If we look at the previous formula giving a four-dimensional vector built from the tensor product of two bidimensional vectors, it is immediate to see that the ordinary product of the first by fourth component is exactly equal to the product of second by third components. This equality gives the criterion allowing to decide whether a generic four-dimensional vector can or cannot be written as a tensor product of two bidimensional vectors. Among the most celebrated examples of the states which cannot be written in this way, one is given by the state $|G\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$. It is immediate to see that it is given, in terms of components (neglecting the coefficient $\frac{1}{\sqrt{2}}$, inserted only to normalize the state), by:

$$|00\rangle + |11\rangle = \begin{vmatrix} 1 \\ 0 \\ 0 \\ 1 \end{vmatrix}$$

Here the product of the first by fourth component gives 1, while the product of the second by third component gives 0. Therefore this state, belonging to the category of the so-called *Bell states* (in honour of the physicist John Bell), cannot be obtained through a tensor product of two qubits. States of this kind are called *entangled*. This attribute, first introduced by Schrödinger in 1935 (see Schrödinger, 1935b, the first paper on this subject), denotes the most characteristic and paradoxical aspect of quantum theory.

In order to become aware of this circumstance, let us first remark that a system described by a four-dimensional Hilbert space is a *bipartite system*. This means that it must be considered as constituted by two different components, each one of which can be separately studied through suitable measure operations. For instance, it is possible to detect that the first component is in the state $|0\rangle$ or that the second component is in the state $|1\rangle$. However, it must be remembered that the state of the whole system consists in the simultaneous states of both components. Let us, then, consider a bipartite system in the particular Bell state previously described. If, for example, we detect that the first component is in the state $|0\rangle$, then the only possibility allowed to the whole system is that this latter is in the state $|00\rangle$, as it is evident by looking at the previous definition of this Bell state. As a consequence, we must acknowledge that a measurement of the state of the second component will necessarily give as a result $|0\rangle$. This is equivalent to recognize that the result of a measurement of the state of the second component is not independent from the result of the measurement of the state made on the first component. The two measures, in other terms, are interrelated. But this interrelation is very different from a classical interrelation, due to the fact that there is a physical interaction between the two components, transmitted through local signals from a component to the other. Namely, if we put the two components of the same system on different and very far locations, separated in such a way as to make impossible the transmission of a local signal from one location to the other, and we suppose that the whole system is in the previous Bell state, the correlation between a measure on the first component and the one on the second component will continue to hold (of course, this conclusion has been confirmed by a large number of experiments; for reviews on this hot topic see Gühne & Tóth, 2009; Horodecki, Horodecki, Horodecki, & Horodecki, 2009; Pan et al., 2012; among the useful books we quote Chandra & Ghosh, 2013; Jaeger, 2009; Nielsen & Chuang, 2010; Silverman, 2008). In short, this correlation is of *non-local* nature.

This result is surely paradoxical as it contradicts the well-known principles of relativity theory, forbidding any form of local signal transmission at a faster-than-light velocity. It is, however, to be remarked that the paradox is only apparent because the non-local correlation predicted by quantum theory cannot be used to transmit information. Rather, the result derives from the fact that, once we gave rise, in one or other fashion, to a system *behaving as such*, that is in which the components form an inseparable unity, this circumstance itself automatically produces the non-local correlation. The latter, therefore, is nothing but a consequence of the fact that a (quantum) system *is a system*. The problem, if any, consists rather in how to generate a true system with inseparable components. In this regard there is a number of different techniques, most of which used in different experimental contexts (for a first review it is useful to consult the references quoted immediately above).

Anyway, the theoretical and experimental advances in this domain evidenced that the quantum entanglement, rather than being an isolated phenomenon, is ubiquitous in almost the majority of physical world.

The previous considerations induce to ask ourselves how they could be applied to QFT. In this case the components of the systems are *fields*, that is, entities occupying whole space-time regions, described by infinite numbers of degrees of freedom. While in traditional quantum mechanics we have at disposal a number of quantitative measures which can be used to detect the presence of entanglement (the most known being the *entanglement entropy*), in the context of QFT, the definition itself of entanglement is problematic. In this regard we can resort to two different approaches: the *algebraic quantum field theory* (AQFT) and the use of lattice models of quantum fields complemented by some results of *conformal field theory* (CFT). The AQFT (fundamental references are Haag, 1996; Halvorson, 2006; Horuzhy, 1988), deriving from the 'axiomatic approach' to QFT, is based on an abstract mathematical representation of the quantities used within QFT and of their relationships. Without entering into useless details, we limit ourselves to say that this approach relies on a suitable association between specific-bounded open subsets of the four-dimensional Minkowski space-time, commonly used in relativity theory, and sets of operators acting on Hilbert spaces. As these operators can be related through suitable algebraic operations, these sets support specific forms of algebras (technically called C^**-algebras*). The operators represent the *observable* quantities as well as the operations allowable on them within the specific chosen subset. Besides, each operator algebra is associated to a further linear functional which maps every subset of operators to a specific expectation. The latter, commonly represented as a vector in the Hilbert space, gives the *physical state* obtained through the actions of the considered operators. Within this framework, the set of all possible operator algebras and their relationships (the so-called net) associated to the different subsets of Minkowski space-time characterizes a specific *physical field*.

Within this approach it is possible to describe the physics of QFT in terms of relationships between abstract algebras and introduce a (likewise abstract) characterization of entanglement within QFT. In this context it has been possible to show (the fundamental paper is Clifton & Halvorson, 2001) that within QFT the entanglement is far more ubiquitous and strong than in quantum mechanics, characterizing in an unavoidable way even all possible vacuum states. In any case, these results, even if generally accepted, should be taken with some caution. Namely, the AQFT has serious limitations (for instance, it cannot take into consideration interacting fields), which induced some philosophers to propose the abandonment of it (see, for instance, Wallace, 2011).

Taking now into consideration the second approach, previously quoted, to the study of entanglement in QFT – the one based on lattice models complemented by some results of CFT – we first remark that the study of systems' time evolution in QFT is far more difficult than in Quantum Mechanics. Namely, in the latter case one can resort to descriptions based on wave functions, whose space-time dependence is ruled by Schrödinger equations, including easily understandable representations of observable quantities. Nothing similar is, on the contrary, present in QFT where the observables correspond to abstract operators devoid of any direct connection with the probabilities of obtaining specific system outputs. In such a situation, it is easy to understand that the best way to obtain information about the occurrence (and the evolution) of features like the entanglement consists in performing computer simulations of discretized systems, such as the ones located on suitable lattices, which can approximate the continuous QFT systems. Then, suitable limit operations, eventually supported also by data analysis techniques, can help to obtain results holding for QFT systems, which could be impossible to gather in other ways. Moreover, the community of theoretical physicists is accustomed from long time to the use of these methods, initially used in many-body physics.

We present here a short list of the results so far obtained from this approach, all expressed in terms of entanglement entropy (a more exhaustive list can be found in Eisert, Cramer, & Plenio, 2010). To start, we take into consideration a quantum lattice system containing a number L of d-dimensional constituents, dividing it into two subsystems, one containing I constituents and the other $O = L - I$ constituents. Then, the expected entanglement entropy $E[S]$ is given by (see, e.g. Sen, 1996):

$$E[S] = (I)\log_2(d) - \frac{d^{(I-O)}}{2\log_2(2)}$$

It is easy to see that, in the cases in which the difference $I - O$ is vanishing or very small, the expected entanglement entropy grows linearly with the number of constituents and, when this number tends to infinity, (as it would occur in the case of QFT systems), exhibits a divergent trend. This circumstance yet gives an argument supporting the opinion that in QFT the entanglement is far stronger and diffuse than in Quantum-Mechanical systems.

Another interesting result regards a set of parallel harmonic chains of quantum oscillators with finite-range couplings within the same chain and collective couplings between parallel neighbouring chains. If we introduce a partition of the whole system into two subsystems, one including a compact block made by a rectangle of harmonic oscillators whose horizontal side has a length l_x and the vertical side a length l_y (both lengths are measured in term of the number of oscillators) and the other including all the residual oscillators, then it can be shown (see Unanyan, Fleischhauer, & Bruss, 2007) that the asymptotic value of entanglement entropy S is given by:

$$S \approx \frac{l_x}{2} \ln\left(l_y\right)$$

We end this short list of findings by mentioning a result concerning arbitrary lattices of whatever dimensionality, supporting quantum systems ruled by Hamiltonians allowing a finite energy gap between the vacuum and the first excited state and characterized by a potential energy not so much different from the one typical of harmonic oscillators (in technical terms, these models are called *quasifree*).

This result (see, e.g. Cramer, Eisert, Plenio, & Dreissig, 2006; Eisert et al., 2010) states that in all these cases the entanglement entropy of vacuum states fulfils the inequality:

$$S \leq \xi \, surf(I)$$

where I denotes one of the two subsystems chosen to measure the amount of entanglement and the symbol $surf(I)$ denotes the area of the surface enclosing the region where I is located, while ξ is a suitable constant. The importance of this result stems from the fact that, contrarily to the previous findings evidencing a logarithmic growth of entanglement entropy, in these cases the latter depends on an area. This seems to support the so-called *holographic principle* (see, e.g. Bousso, 2002), borrowed from black hole physics and conjecturing that the information contained into a volume of space can be represented by a theory which deals with the boundary of that region (for instance, based on its area).

As some of the previously quoted results seems to depend on the dimensionality and/or the size of the systems under study, it seems useful, in order to gather a size-dimension-independent information about entanglement phenomena, to resort to a quantum field theory invariant under scale transformations. Mathematically the scale transformation is a subset of the so-called *conformal transformations*. Therefore, the QFT theories invariant under conformal transformations are collectively known as *conformal field theory* (CFT). The latter (see, for a textbook, Blumenhagen & Plauschinn, 2009; Schottenloher, 2008 an excellent introduction is the one by Ginsparg, 1990) still is plagued by some problem, the most important of which is the fact that so far a complete development of CFT has concerned only low-dimensionality systems, that is, one-dimensional and two-dimensional ones. Besides, as CFT deals only with scale invariant systems, it cannot contain a preferred length scale and, as a consequence, cannot include a mass or a Compton wavelength. However, there are in physics situations in which we are in situations similar to the ones dealt with by CFT, as occurs, for instance, when we are in proximity of the critical point of a phase transition. This fact allowed some researchers to exploit the possibilities offered by CFT to study entanglement in some specific QFT models. The most important findings (see, for instance, Swingle, 2012; Swingle & Senthil, 2012) consist in the acknowledgement that, while strong entanglement is ubiquitous in QFT, the dependence of entanglement entropy on the system features is often disagreeing with holographic principle. In most models this disagreement is produced by the low-energy contributions, which favour form of dependence of logarithmic kind.

As a conclusion we can assert that both theoretical arguments and computer simulations (as well as laboratory experiments) evidenced that QFT is characterized by an entanglement far stronger than the one characterizing standard quantum mechanics. This circumstance allows to consider QFT as the best framework in which to describe and study the formation and survival of *systems as such*. The only problem to be solved concerns the translation of the complicated mathematics of QFT, designed to deal with specific physical systems, into the domain of economic and social sciences, a task which appears so far very difficult to perform.

6.2 Embedded Systemic Principles: The Introduction of Fields as Autonomous Entities

As well known, the traditional definition of a system identifies it with a set of *elements* and a set of *relationships* between these elements (Hall & Fagen, 1956). Such a simple definition is, however, useless when the number of elements is very great (tending to infinity) or the individuation of elements becomes almost impossible. In all these cases, very common in our daily experience, it is more convenient to introduce the concept of *field*, defined as a mathematical entity (a number, a vector, a tensor, etc.) whose characteristics are functions of *configurational variables*, such as the spatial and/or temporal variables. Very often the latter are assumed as susceptible to assume values within a continuum. Thus the mathematics of continua, well developed since Newton times, can help to deal with fields in a fruitful way. In physics this approach has been first introduced by identifying fields with *fields of forces*, whose values depend on spatio-temporal coordinates.

While at the beginning of the history of physics, the concept of field was used mainly to help in describing the effect of forces produced by suitable material *sources*, the discovery of electromagnetism allowed to consider transmutations of a kind of field into another kind of field (like occurring in the production of a magnetic field in the presence of the current generated by an electric field) as well as propagations of fields from a point to another (like in the case of electromagnetic waves). This circumstance suggested the opportunity of introducing the fields as the primary entities of physics, instead of the sources. The latter could be considered as nothing but equivalent to specific spatial (or spatio-temporal) domains characterized by very strong concentrations of field intensities. Such a conception was adopted chiefly by Maxwell (see, in this regard, Cao, 1997; Hunt, 1991; McMullin, 2002), and its introduction started a still animated debate about the primacy of field or sources (actually identified with elementary particles) in constructing physical theories.

From a systemic point of view, the interpretation of the mathematical formalism of QFT has given rise to two different – and contrasting – viewpoints:

1. The so-called *Duality Thesis* (see, e.g. Peskin & Schroeder, 1995; Teller, 1995; a deep discussion is contained in Bain, 2000), according to which the particle and field pictures represent two different but equivalent aspects of the same physical system, because to every particle there corresponds a field and to every field there corresponds a particle (the so-called field quantum).
2. The concept of particle cannot be used to interpret QFT and, as such, is useless (see Arageorgis, Earman, & Ruetsche, 2003; Fraser, 2008; Halvorson & Clifton, 2002; Malament, 1996); a variant of such a viewpoint allows the use of the concept of particle as a sort of 'practical tool' within effective theory formulations of QFT (for discussions, see Bain, 2011; Pessa, 2011).

Without entering here into technical discussions about the formalism of QFT, we limit ourselves that while the Duality Thesis is widely used in most interpretations of theories based on QFT (e.g. the standard model of elementary particle interactions), it is refused by most philosophers (and by some physicists) owing to a number of theorems asserting that within QFT: it is impossible to introduce local number operators, counting the number of quanta within a specific-bounded region of space-time, as the count operation produces automatically effects on the whole space-time structure (*Reeh-Schlieder theorem*); it is impossible to introduce a *unique* total number operator, because the results of the count operation depend on the adopted representation of possible quantum states (*Unruh effect*); in the presence of interactions, it is impossible even to define the concept itself of total number operator, that is, every global count is impossible (*Haag's theorem*).

An immediate consequence of these results is that if we adopt a systemic approach based on QFT, we are automatically supposing that the systems under consideration are better described as if they were fields (interacting or not), while the introduction of the concept of element (in physics we could speak of particles or sources) is viewed as unnecessary or useless or even, in the best cases, as a sort of imprecise simplification useful only to shorten the used conceptual arguments. We also remark that, while the concept of field is most often related to a description based on continuum mathematics, this is not a compulsory logical requirement, as we can introduce fields described in a discretized way. Without entering here into a discussion about the relationships between continuous and discrete models, we limit ourselves to say that their choice is often a matter of mathematical convenience.

It is to be remarked that, notwithstanding the privileged nature of the field interpretation of QFT formalism, even this interpretation has been criticized by many physicists and philosophers (see, for an exhaustive review, Kuhlmann, 2015). The main reason for this criticism is due to the fact that within QFT the fields are described by space-time dependent operators. These latter, however, do not allow a direct correspondence between the operators themselves and physical properties associated with specific space-time points. Namely, the computations performed within QFT framework are used essentially to obtain general solutions of the field equations, allowing to gather information, at most, about field possible global configurations. In this regard, many scholars object that this sort of knowledge is not enough to characterize it as deriving from a field interpretation of QFT. Among the proposals made to answer this objection, the most actual is based on the concept of the so-called *wave functionals* (see, for instance, Lupher, 2010). In short terms, a wave functional is a mathematical construct $\psi[\varphi(x)]$ which maps numerical functions $\varphi(x)$, describing specific configurations of a classical field, to probability amplitudes, in such a way that $|\psi[\varphi(x)]|^2$ is the probability that a measure performed on a quantum field system gives as outcome the configuration $\varphi(x)$. Such an interpretation encounters a number of difficulties, a first one being that in most cases the users of QFT are rarely interested in field configurations and a second one being that the explicit construction of the wave function is strongly dependent on the interpretation used when dealing with quantum probabilities (e.g. of the implementation of the wave functional approach in the case of adherence to Bohm interpretation of quantum mechanics, see Colin & Struyve, 2007; Dürr, Goldstein, Norsen, Struyve, & Zanghì, 2014; Struyve, 2010, 2011). Further objections have been carefully discussed by Baker (2009), but we avoid here their analysis, as they concern an aspect of QFT which will be dealt with later in this chapter. In any case, despite the diatribes regarding the correct interpretations of concepts like 'particle' or 'field', we must acknowledge that they are endowed with a practical valence, allowing their use in a number of different situations. Of course, we must also be aware that there are situations in which their common use is forbidden or, at least, subject to suitable restrictions.

6.3 Embedded Systemic Principles: The Use of Maximization or Minimization Principles

As it is well known from any textbook about QFT, most models of quantum fields have been introduced by starting from classical field theory and then operating on it through a conceptual process called 'quantization'. This procedure, even if useful from a practical point of view, favours the survival, within QFT, of most concepts borrowed from the old theory of classical fields. In this regard it is to be remembered that since the eighteenth century the latter was formulated in such a way as to allow the derivation of all its consequences from a single *stationarity principle*. It consists in the *Hamilton Principle* (often called *Least Action Principle*) and is formulated in terms of a function of the fields under consideration and of their derivatives, usually denominated *Lagrangian density* (or, more simply, *Lagrangian*). In the case of a single scalar field $\varphi(x)$ within a four-dimensional Minkowskian space-time, the Lagrangian density is a function of $\varphi(x)$ and of its partial derivatives $\partial_\mu \varphi$. Within the trivial context of a single particle the Lagrangian is nothing but the difference between the kinetic energy and the potential energy of the particle. A four-dimensional integration of Lagrangian density over a suitable space-time domain gives a functional S (i.e. an operator transforming functions into numbers) called *action*:

$$S = \int d^4x \, L\big(\varphi(x), \partial_\mu \varphi(x)\big)$$

The Hamilton Principle then consists in asserting that all allowed evolution of the fields are those making stationary the functional S, that is corresponding to zero variations of it. As mathematically proved in every textbook on analytical mechanics, this principle entails that the Lagrangian must fulfil the Euler-Lagrange equations:

$$\frac{\delta L}{\delta \varphi} - \partial_\mu \left(\frac{\delta L}{\delta \, \partial_\mu \varphi} \right) = 0$$

These equations constitute a possible form of the motion equation for the field under consideration. Without entering into more details, it suffices to mention that, by introducing a pair of suitable *canonical variables*, the first one being coincident with φ and the other defined by:

$$\dot{\varphi} = \frac{\partial \varphi}{\partial x_0}, \quad \Pi(x) = \frac{\delta L}{\delta \dot{\varphi}}$$

it is possible to introduce the so-called *Hamiltonian density* (or, shortly, the *Hamiltonian*) through the *Legendre transformation*:

$$H = \Pi(x)\, \dot{\varphi}\,(x) - L$$

Some mathematics allows to prove that the Euler-Lagrange equations can now be transformed into the *Hamilton equations of motion* (well known from mechanics):

$$\dot{\varphi} = \frac{\delta H}{\delta \Pi}, \quad \dot{\Pi} = -\frac{\delta H}{\delta \varphi}$$

It is to be remarked that the canonical variables are analogous to the well-known variables q and p used in traditional mechanics. Without taking into consideration the multi-dimensional case, we will limit ourselves to mention that the canonical variables previously defined satisfy the following identities:

$$\{\varphi, \varphi\} = 0, \quad \{\Pi, \Pi\} = 0, \quad \{\varphi, \Pi\} = 1$$

Here the generic symbolic expression $\{f, g\}$, called *Poisson bracket*, is defined by:

$$\{f, g\} = \frac{\partial f}{\partial \varphi}\frac{\partial g}{\partial \Pi} - \frac{\partial f}{\partial \Pi}\frac{\partial g}{\partial \varphi}$$

Before translating all this classical framework to QFT, we must underline that, whatever can be our opinion about the appropriateness of maximum or minimum principles when describing complex systems, undoubtedly the approach used by classical field theory is advantageous. Namely, by starting from a single stationarity principle, it allows to derive all field dynamics up to the finest details. It is, of course, true that this requires some mathematical work but, once granted the correctness of mathematical deductions, any failure of the theory must be attributed only to the kind of the adopted stationarity principle. And it is far easier to change a single principle than a lot of specific hypotheses. The fundamental problem with this approach is, instead, that it can be applied only in a limited number of cases. This circumstance limited in a consistent way on the development, not only of classical field theory but also of QFT. As a consequence most theoretical physicists have been forced to focus their attention on a limited number of tractable models (to be considered as 'archetypes'), trying to find equivalences (exact or approximate) between them and other less tractable models. Unfortunately it is very difficult to find Hamiltonians for most systems, even if described through mathematical equations! Apart from some partial successes obtained in special cases (among which we can quote the case of Lotka-Volterra-like models; see, e.g. Duarte, Fernandes, & Oliva, 1998), this enterprise achieved best results in two domains: the one of stochastic models and the one of network evolution. In the case of stochastic models, there are even two different definitions of Hamiltonian: one holding in the case of Markov processes, in which the Hamiltonian is identified with the probability transition matrix (see, e.g. Baez & Fong, 2013), and the other related to Fokker-Planck equation describing time evolution of probability in the presence of random noise, in which the Hamiltonian is a given, in the case of a small noise amplitude, by a specific part of the equation itself, just called 'Fokker-Planck Hamiltonian' (see, e.g. Graham, Roekaerts, & Tél, 1985; Graham & Tél, 1984). Concerning the network evolution, some models of network growth have been recently described by introducing suitable Hamiltonians (see, e.g. Zuev, Papadopoulos, & Krioukov, 2016).

We can, now, focus ourselves on the so-called *canonical quantization* (often incorrectly called *second quantization*), that is on the translation of the previous classical approach to QFT. It consists in the substitution of classical fields with *quantum operators* fulfilling suitable *commutation relationships*. This procedure is not free from difficulties and ambiguities and can be described in easily understandable terms only if we deal with simple models. Among these latter the one traditionally considered as the easier to analyse is the model of a *single scalar field* in absence of interactions. Its equation of motion coincides with the well-known Klein-Gordon equation which, in the case in which we have only two independent variables, x and t, can be written as:

$$\frac{\partial^2 \varphi}{\partial t^2} - \frac{\partial^2 \varphi}{\partial x^2} + m^2 \varphi = 0$$

Here, in order to save space and number of symbols, we eliminated all physical constants, like light velocity in vacuum and Planck's constant, by adopting measurement units in which all these constants have a value equal to 1. The parameter denoted by m can then be interpreted as the mass of the field quantum.

Without entering in further details about the physical interpretation of this equation, we begin by observing that this equation is exactly identical with the Euler-Lagrange equation obtained from the following Lagrangian:

$$L = \frac{1}{2}\left(\frac{\partial \varphi}{\partial t}\right)^2 - \frac{1}{2}\left(\frac{\partial \varphi}{\partial x}\right)^2 - \frac{1}{2} m^2 \varphi^2$$

Besides, the canonical momentum Π derived from this Lagrangian is given by:

$$\Pi = \frac{\delta L}{\delta\left(\frac{\partial\varphi}{\partial t}\right)} = \frac{\partial\varphi}{\partial t}$$

This result allows a computation of the Hamiltonian of scalar field theory through the Legendre transformation quoted above. Some trivial algebraic manipulations give:

$$H = \frac{1}{2}\Pi^2 + \frac{1}{2}\left(\frac{\partial\varphi}{\partial x}\right)^2 + \frac{1}{2}m^2\varphi^2$$

All previous computations have been classical. Now we can proceed with the quantization procedure. In this regard, it is more convenient to avoid the direct use of spatial coordinate x (it is to be remembered that often the fields are contained within infinite volumes and, mainly, the momentum variables, being directly related to energies, are far more important than spatial ones). Thus, we perform a Fourier transform of the previous canonical coordinates φ and Π. This operation is not always trivial and often requires some mathematical tricks, such as working within a very large, but finite, spatial volume with periodic boundary conditions, so as to deal with a finite, even if very large, number of oscillatory modes allowed within it, and then, after all required algebraic manipulations have been performed, going to an infinite volume limit. In any case, without entering into mathematical subtleties, we content ourselves of shortly representing the Fourier transform as:

$$\varphi_k = \int \varphi(x)\, \mathrm{e}^{-ikx}\, dx, \quad \Pi_k = \int \Pi(x)\, \mathrm{e}^{-ikx}\, dx$$

Here the integration limits are not specified (but, for instance, can coincide with the finite volume quoted above), while the suffixes k denote the momentum indices of the oscillatory modes.

Before going further, however, we must remember that the procedure used to quantize the fields has been conceived, since the early times of QFT, as a sort of generalization of the procedure already used to build the traditional Quantum Mechanics of particles, in turn firmly grounded on classical analytical mechanics of Lagrange and Hamilton. In particular, two main aspects of Quantum Mechanics have a relevant importance in the building of the actual QFT: the conceptual prominence of harmonic oscillator model (already existing within the classical Physics) and the fact that the operators chosen to represent the physical quantities must be Hermitian. As regards the latter circumstance, we remind that, from a strictly mathematical point of view, an operator is Hermitian when it is equal to its *Hermitian conjugate* (often called *adjoint*). In the most general sense, this attribute denotes the new operator acting on the old through two successive operations: taking the transpose and then performing a complex conjugation. In most cases, if an operator is denoted by the symbol A, its Hermitian conjugate is denoted by $A^\dagger$. Therefore, the operator A is Hermitian if A is equal to $A^\dagger$. The importance of

Hermitian operators stems from the fact that their eigenvalues, representing the possible outcomes of measurement operations, are real numbers. Without entering into details about the mathematical operations needed to compute the Hermitian conjugate, we limit ourselves to mention the following simple results:

h.1: The Hermitian conjugate of the operator of multiplication by x is the operator itself.
h.2: The Hermitian conjugate of the operator of multiplication by the imaginary number i is given by the operator of multiplication by $-i$.
h.3: The Hermitian conjugate of the operator d/dx is the operator $-d/dx$.

As regards the quantities φ_k and Π_k previously obtained through the Fourier transform, it is possible to show that they satisfy the following rules:

$$\varphi_{-k} = \varphi_k^\dagger, \; \Pi_{-k} = \Pi_k^\dagger$$

We also need to add some words about the prominence of harmonic oscillator model, whose classical one-dimensional version is described by the well-known differential equation:

$$m\frac{d^2x}{dt^2} = -kx$$

Not only the solution of this equation is given by a simple harmonic motion, but also the equation itself can be used as first-order approximation of a number of different models. Besides, the Fourier theorems state that all evolutionary phenomena can be represented through suitable linear combinations of different harmonic motions. The importance of this model further grows in quantum mechanics, first of all because it is one of the few quantum models which can be exactly solved, and, in the second place, its N-dimensional version allows a *degeneration* of the energy levels (i.e. the existence of many different states having the same energy). But a deeper reason for the interest in quantum harmonic oscillator is related to well-known duality between particles and waves introduced by De Broglie many years ago. Namely, the latter associates to each particle a wave (the so-called De Broglie wave) which, like any traditional wave, propagates in space. What has this picture to do with the quantum harmonic oscillator? Well, it is possible to show that a packet obtained by superposing different harmonic oscillators (supposed to produce a Gaussian-like distribution of their features) behaves in a fashion similar to the one of traditional waves, propagating in space with a suitable decrease of initial amplitude with time, but with an almost particle-like behaviour, as in most conditions the time needed to reach an appreciable decrease is of the order of cosmic times (see, for instance, Burkhardt & Leventhal, 2008, pp. 96–109). It is thus possible to use assemblies of quantum oscillators to represent particles, at least in an approximate way.

Coming again to our problem of the quantization of scalar field model, we can now observe that some simple computations allow to represent the previous

Hamiltonian in terms of the Fourier transforms of canonical coordinates, thus obtaining the formula:

$$H = \frac{1}{2} \sum_{k=-\infty}^{\infty} \left(\Pi_k \Pi_k^\dagger + \omega_k^2 \varphi_k \varphi_k^\dagger \right)$$

where $\omega_k = \sqrt{k^2 + m^2}$. A look at the theory of N-dimensional quantum harmonic oscillators shows that the latter Hamiltonian just describes an infinite sum of classical harmonic oscillators (reciprocally noninteracting). We can now perform the quantization of this model, transforming the classical quantities φ_k and Π_k into operators. Then we require that these operators must fulfil commutation rules having the same form of the ones holding in Quantum Mechanics for the operators representing the quantities x and p. In this regard, we remind that these commutation rules are nothing but a suitable operatorial generalization of the ones holding for the Poisson brackets between x and p, used in classical mechanics. More precisely, they have the form (putting the Planck's constant equal to 1 and denoting the quantum operators with the same symbols used for the classical quantities):

$$[x, x] = 0, \quad [p, p] = 0, \quad [x, p] = i$$

As a consequence our QFT operators must fulfil the following commutation rules:

$$\left[\varphi_k, \varphi_k^\dagger\right] = 0, \quad \left[\Pi_k, \Pi_k^\dagger\right] = 0, \quad \left[\varphi_k, \Pi_k^\dagger\right] = i$$

Here, in principle, our quantization procedure could be considered as ended. However, for practical reasons, it is not convenient to use directly the QFT operators introduced above. Namely, following a suggestion coming initially from the classical theory of harmonic oscillator and then adopted within the quantum version of this theory, it is better to work with new operators defined as follows:

$$a_k = \frac{1}{\sqrt{2\omega_k}} \left(\omega_k \varphi_k + i\Pi_k \right), \quad a_k^\dagger = \frac{1}{\sqrt{2\omega_k}} \left(\omega_k \varphi_k^\dagger - i\Pi_k^\dagger \right)$$

It is possible to show that each one of these operators (which are not Hermitian) is the Hermitian conjugate of the other. Moreover, they fulfil the following commutation rules:

$$[a_k, a_k] = \left[a_k^\dagger, a_k^\dagger\right] = 0, \quad \left[a_k, a_k^\dagger\right] = 1$$

Within the context of the classical harmonic oscillator model, the numerical quantities corresponding to these operators are referred to as *normal modes*. When dealing with the quantum-mechanical version of the model, they are called *ladder operators*. However, as it is possible to show that, when acting on energy eigenstates of the quantum harmonic oscillator, the action of the operator $a^{\dagger}$ is equivalent to increase the energy of the oscillator of a single quantum of energy, while the action of the operator a is equivalent to lower the energy of a single quantum (neglecting suitable proportionality factors), the operator $a^{\dagger}$ is more commonly called *creation operator*, while a is called *annihilation* (or *destruction*) *operator*. This nomenclature is kept unchanged in QFT, with the difference that the terms of 'creation' and 'annihilation' are referred to 'field quanta' or 'field modes'. However, despite the lack of rigour of this terminology, often, mainly when dealing with systems of particles, it is common to speak of creation and annihilation operators acting on 'particles'.

The field state $|0\rangle$ satisfying, for all values of k, the condition $a_k|0\rangle = 0$ is called *vacuum state*. A field state containing n field quanta with momentum k can be built by applying n times the creation operator to the vacuum state. All single field states built in this way are Hilbert spaces, and the full collection of all possible Hilbert spaces which can be obtained from all possible combinations of actions of creation operator on the vacuum state is called *Fock space*. Besides, the previous formulae allow to rewrite the Hamiltonian operator introduced above in terms of operators of creation and annihilation. By adopting suitable conventions, the computation gives the result:

$$H = \sum_{k=-\infty}^{\infty} \omega_k a_k^{\dagger} a_k$$

Usually the operator $a_k^{\dagger} a_k$ is called *number operator*, and its eigenvalues give the numbers of field quanta (or particles) with momentum k present in the state under consideration. The quoted conventions allow to obtain the important consequence:

$$H|0\rangle = 0$$

which is sometimes adopted as basic definition of the vacuum state.

Without adding further mathematical details about QFT (which would fill a full library of textbooks), the previous exposition has been made to allow an understanding of the basic attitude of most users of QFT which, after starting from a specific Hamiltonian expressed mainly in terms of suitable combinations of creation and annihilation operators, become mad by manipulating a lot of mathematics (today happily coded in advance and even available on computers) to obtain the probabilities of reactions between particles or their cross sections. This happened when QFT was introduced and continues to occur still today. But, even if the intellectual path from a single stationarity principle to the numerical predictions of the outputs of single experiments performed through sophisticated technologies is fascinating, many conceptual problems remain open. Can the whole machinery previously introduced be used in other domains, outside particle physics or even outside physics? Can it be used in order to build a new form of systems theory? Can it be used to deal with complexity? Following this chapter, we will present some arguments supporting affirmative answers to these questions.

6.4 Embedded Systemic Principles: The Existence of Nonequivalent Representations

As evidenced in the previous subsections, QFT (as well as classical mechanics) makes an extensive use of Hamilton Principle and of the associated Hamilton equations. The latter are formulated in terms of the so-called *canonical variables* (which generalize in a suitable way the coordinates and momenta used in elementary physics), in turn fulfilling the *Canonical Commutation Relations* (CCR), already mentioned before. For commodity of the reader, we recall here their form in terms of QFT field operators and putting the Planck's constant equal to 1, given, in the scalar field case, by:

$$\left[\varphi_k, \varphi_k^\dagger\right] = 0, \quad \left[\Pi_k, \Pi_k^\dagger\right] = 0, \quad \left[\varphi_k, \Pi_k^\dagger\right] = i$$

It is to be underlined, in this regard, that, while the CCR are not a specific tool introduced to describe the dynamical evolution of a system in QFT (depending on Hamilton equations), they are however indispensable to compute in a concrete way the details of this evolution. This goal, of course, can be achieved only if the CCR are expressed in terms of operators acting on a suitable Hilbert space. The specific form of this expression is called a *representation* (of CCR).

The concept has been already introduced many years ago in QM and, in this context, it has been characterized by the celebrated *Von Neumann's* (or *Stone-Von Neumann*) *Theorem* (see Stone, 1930; Von Neumann, 1931). The latter asserts that in QM all possible representations are *unitarily equivalent*, that is, given two whatever different representations, it is always possible to find a unitary operator transforming one representation in the other. Here the attribute 'unitary' means that the adjoint of the operator is equal to its inverse. It is to be remembered that the concept of unitary equivalence captures one specific aspects of physical equivalence: the relationships between the quantum states, which are kept invariant in the two unitarily equivalent representations. Instead, the concept itself does not necessarily imply the equivalence between the operators in the two representations nor the equivalence between the two different transition probabilities associated with them (see, in this regard, Baker & Halvorson, 2013).

As regards QFT, the main result is that, contrarily to QM, von Neumann's theorem no longer holds. A theorem, often called *Haag's theorem* (see the original paper by Haag, 1955; a more recent and complete discussion can be found in Earman & Fraser, 2006), asserts the existence, within QFT, of unitarily nonequivalent representations. For a number of years, this theorem has been neglected by most theoretical physicists, but in most recent times, the study of nonequivalent representations gained an ever-growing attention owing to their use in the description of symmetry breaking phenomena, a topic very important not only in the context of elementary particle physics but also in the one of condensed matter physics. In this regard we remember that, in agreement with the general approach first proposed many years ago by L.D.Landau (see for a more detailed information Minati & Pessa, 2006, Sect. 5.2; Cracknell, Lorenc, & Przystawa, 1976; Tolédano & Tolédano, 1987), the specific phase characterizing any given system can be defined in terms of its *symmetry* with respect to suitable transformations. This symmetry can regard the system model equations (typically expressed in terms of suitable Lagrange functions) as well as the energy values of its allowable states (among which the *vacuum* states deserve the highest importance) and characterizes its *invariance* properties. If we restrict ourselves only to take into account the Lagrangians and the vacuum states and we take into consideration only continuous symmetry transformations, then we can deal with three different possibilities:

(α) Both the Lagrangian and the vacuum state energy are invariant with respect to the considered symmetry transformation; in this case the latter is called an *exact symmetry* for the system.

(β) Both the Lagrangian and the vacuum state energy are not invariant with respect to the considered symmetry transformation; in this case we deal with an *explicit symmetry breaking*.

(γ) The Lagrangian is invariant with respect to the considered symmetry transformation, but the vacuum state energy is not invariant; in this case we have a *spontaneous symmetry breaking*.

The latter case deserves a particular importance for the description of different kinds of phase transitions, starting from the well-known cases of ferromagnetism or of superconductivity. Here, it is important to underline that its description is strictly connected to the presence of nonequivalent representations, a circumstance, as we will see, implying unexpected phenomenal features. In order to evidence the latter in the following, we will shortly discuss a well-known model of phase transition, suggested by the original Landau theory and described by a Lagrangian having the form:

$$L_1 = \left(\partial_\mu \varphi^*\right)\left(\partial_\mu \varphi\right) + m^2 \varphi^* \varphi - \frac{1}{4} f \left(\varphi^* \varphi\right)^2$$

Here φ is a complex scalar field, and m^2 and f are positive parameters, while the star denotes the complex conjugation. To derive some consequences from this Lagrangian, we must first obtain a specific expression for the energy of the system under description. This can be done by resorting again to the methods of analytical mechanics shortly recalled in the previous subsection when dealing with the case of the scalar field. These methods allow to obtain that the Hamiltonian corresponding to the previous Lagrangian has a form given by:

$$H = (\partial_0 \varphi^*)(\partial_0 \varphi) + (\partial_i \varphi^*)(\partial_i \varphi) - m^2 \varphi^* \varphi + \frac{1}{4} f (\varphi^* \varphi)^2$$

where the indices i denote the spatial coordinates x_1, x_2, x_3 while the index 0 denotes the time coordinate. We remember that this expression of the Hamiltonian (as well as the one of the corresponding Lagrangian) is nothing but a synthetic expression to design a *space-time density*, because only the integral of this expression on a suitable space-time region allows to obtain a physically meaningful quantity, which in the case of the Hamiltonian describes the total amount of energy present in the region under consideration. This implies that in order to find the condition corresponding to the minimum value of energy, it suffices to impose that the value of H be minimum in that region. By using trivial methods of elementary differential calculus, it is easy to obtain that this minimum corresponds to the vanishing, in the expression for H, of partial derivatives with respect to the variables φ and φ^*. This condition leads to the following two equations:

$$-m^2 \varphi^* + \frac{f}{2} (\varphi^*)^2 \varphi = 0, \quad - m^2 \varphi + \frac{f}{2} (\varphi^*) \varphi^2 = 0$$

If we identify the minimum energy state with the *vacuum state*, we obtain that the latter is given by the solutions of both equations, obeying the condition:

$$\varphi^* \varphi = \frac{2m^2}{f}$$

which describes a circle of radius $R = \frac{\sqrt{2}m}{\sqrt{f}}$ on the plane with coordinates φ and φ^*, centred on its origin. In other terms, we have an infinite number of different possible vacua, each corresponding to a possible point on this circle. This situation is usually described by saying that we are in the presence of an infinite *vacuum degeneration*.

It is, of course, spontaneous to ask ourselves whether we can introduce a transformation, acting on the field values, allowing to move from one of these vacuum values to another. The answer is positive, because a rotation around the origin of the φ, φ^* plane can easily perform this task. The latter can be written, by resorting to elementary complex numbers theory, under the form:

$$\varphi \to \varphi' = \mathrm{e}^{-ig\alpha}\varphi, \quad \varphi^* \to (\varphi^*)' = \mathrm{e}^{ig\alpha}\varphi^*,$$

where g is a suitable constant parameter and α a rotation angle (which could be finite as well as infinitesimal). It is very easy to verify that the Lagrangian L_1 is invariant with respect to this transformation, which is called by mathematician as *Global* U_1 (to be more correct, this is the name of the algebraic group whose elements are constituted by this kind of transformations). Thus, while the dynamical equations of the theory (i.e. the Lagrangian) are invariant with respect to U_1, the vacuum states are by definition not invariant.

But, is this loss of invariance only an apparent fact? Could it be that two different vacuum states connected by a U_1 transformation correspond to two equivalent forms of the same physical system, related by two unitary canonical transformations? In order to answer this question, let us write the field φ by using a polar representation, so as to have:

$$\varphi = R\,\mathrm{e}^{-i\,\theta/R}$$

where $R = \frac{\sqrt{2}\,m}{\sqrt{f}}$. Choosing the particular vacuum corresponding to $\theta = 0$, we can describe the radial excitations of the field around this point, denoted by h, through the formulae:

$$\varphi = (R + h)\,\mathrm{e}^{-i\,\theta/R}, \quad \varphi^{*} = (R + h)\,\mathrm{e}^{i\,\theta/R},$$

If we substitute the latter expressions in the original Lagrangian L_1, some straightforward but tedious computations lead, by neglecting the terms containing powers of h higher than 2, to a new Lagrangian having the form:

$$L_2 \approx \left(\partial_\mu h\right)^2 + \left(\partial_\mu \theta\right)^2 - \frac{3m^2}{f}\left(h^2\right)$$

By looking at this Lagrangian, it is easy to recognize that it describes two different fields: a massive field h performing radial oscillations and a massless field θ performing angular oscillations. The existence, in a spontaneous symmetry breaking situation, of the particles described by the field θ is predicted by the *Goldstone theorem*, one of most important theorems of theoretical physics (see, beyond the most important textbooks on QFT, also the technical reviews of Brauner, 2010; Burgess, 2000). Often the zero-mass bosons corresponding to these particles are called *Nambu-Goldstone bosons*. Their role is essentially the one of providing the long-range correlations able to keep invariant the new vacuum state produced by the spontaneous symmetry breaking despite external perturbations. The form itself of the Lagrangian L_2 allows to understand that these perturbations can produce only excitations which act on directions orthogonal to the direction taken by the field in correspondence to the chosen particular vacuum. Therefore, automatically they give rise to effects lasting in a Hilbert space which is intrinsically different from the one related to vacuum under consideration. It is thus possible to conclude that, while the transformations U_1 connect physically equivalent vacuum states, these latter cannot be connected by unitary canonical transformations. Therefore, the different vacuum states, while being related through symmetry transformations, cannot be considered, from the point of view of quantum physics, as physically equivalent systems. Any single vacuum state corresponds to a single physical system, different from the other physical systems represented by the other vacuum states.

It is to be remarked that the above described features of spontaneous symmetry breaking and of Nambu-Goldstone bosons hold only when the volume of the system under study *tends to infinity*. Moreover, these features are strictly dependent on the hypotheses adopted to prove the Goldstone theorem. If the previous condition and these hypotheses are not fulfilled, the description of spontaneous symmetry breaking and the associated phenomenology can strongly differ from the ones presented in our simple model. In this regard we remark that the hypotheses assumed by Goldstone theorem can be shortly listed as follows: (1) the symmetry breaking must concern continuous global internal symmetries; (2) we must deal with a Lorentz-invariant situation; and (3) the theory must fulfil a translational invariance. Of course, in most models of spontaneous symmetry breaking all conditions (1), (2) and (3) cannot simultaneously hold. For instance, the Lorentz invariance can fail in the presence of massive particles, of nonzero densities such as vortices or domain walls, of nonlocal interactions. Analogously the translational invariance disappears in systems underlying spatial translations or rotations. And the situation becomes worse when we deal with discrete systems. In any case, without entering into details about the approaches used to generalize the Goldstone theorem to the latter situations, we limit ourselves to take into consideration the cases in which the presence of a (at least partial) translational invariance allows to describe the excitations around a specific vacuum state as if they were *particles* or *modes*, each one of which endowed with a specific value of *momentum* k and of *energy* E_k. Within this context the Goldstone theorem can be formulated as follows:

the spontaneous breaking of a continuous global internal symmetry implies the necessary existence, within the spectrum of all possible excitation modes, of a mode such that $\lim_{k \to 0} E_k = 0$.

This formulation puts into evidence the fact that this theorem does not give any indication on the dynamics of Nambu-Goldstone bosons nor on their number, limiting only to assert that such a type of object (in the particle interpretation a zero-mass boson) must necessarily exist. This circumstance stimulated, from the first times of formulation of Goldstone theorem (the first fundamental paper is Goldstone, Salam, & Weinberg, 1962; a detailed account of the history of this theoretical achievement is contained in Guralnik, 2009), an extended investigation regarding the number counting of Nambu-Goldstone bosons as well as their energy-momentum dispersion relations (see Brauner, 2010; among the most important papers we mention also Brauner & Moroz, 2014; Low & Manohar, 2002; Nielsen & Chadha, 1976; Watanabe, Brauner, & Murayama, 2013; Watanabe & Murayama, 2013).

The most important result emerging from this research activity is that the details of Nambu-Goldstone bosons dynamics cannot be determined only relying on the general theory of spontaneous symmetry breaking but depend in a crucial way on the specific features of the system Hamiltonian as well as of the external perturbations introduced to alter the stability of the ground states taken into consideration. Namely, in the absence of this information, a large number of different kinds of dynamics are in principle possible. For instance, the bosons can reciprocally interact, travel at slower or greater energies and give rise to condensates with different spatial density distributions or even to macroscopic objects endowed with specific topological features. The detailed study of all these complex behaviours can be better performed by resorting to a modern technique known as *Effective Field Theory*. The latter, first introduced in the 1960s for the needs of theoretical particle physics, has been later extended to the domain of condensed matter physics and constitutes a useful tool to separate, within a model, the contributions coming specifically from low-energy components, like, for instance, the ones given by Nambu-Goldstone bosons. Among the large number of papers and textbooks devoted to this topic, we will limit ourselves to quote the reviews of Burgess (2007) and of Andersen, Brauner, Hofmann, and Vuorinen (2014).

Without further boring the reader with a plethora of technical details regarding the consequences of spontaneous symmetry breaking theory, we limit ourselves to remark that the existence of unitarily nonequivalent representations of CCR, as well as the features of Nambu-Goldstone bosons, can be viewed as the results of the application of suitable transformations to the representations of CCR themselves. There are different kinds of these transformations, called *canonical*, as they do not alter the algebraic structure of the CCR (a fundamental textbook on this topic is Blasone, Jizba, & Vitiello, 2011). A first example of a canonical transformation in QFT is given by the so-called *boson translation* (or Bogoliubov translation for coherent states). The latter can be applied to destruction operators and, for a single destruction operator a, has the simple form:

$$a \rightarrow a(\theta) = a + \theta$$

where θ is a suitable numerical parameter. In the case of an infinite number of degrees of freedom, labelled, for instance, by k this definition can be easily generalized as follows:

$$a_k \rightarrow a_k(\theta) = a_k + \theta_k$$

It can be shown that the bosonic translation has a fundamental role in the spontaneous symmetry breaking, chiefly in the occurrence of Nambu-Goldstone bosons as well as in the description of macroscopic condensations of these latter.

Another example of canonical transformation is given by the *Bogoliubov transformation*. The latter is used when we deal with models containing two different kinds of modes (here the meaning of the generic term ‘mode’ depends on the context of the model under consideration: in some cases a ‘mode’ denotes a particle, while in other cases it can denote a ‘quasi-particle’). If we use the notations $a_k^\dagger$, a_k when referring, respectively, to creation and annihilation operators of the first kind of mode and $b_k^\dagger$, b_k for the corresponding operators related to the second kind of mode, the Bogoliubov transformation gives rise to two new annihilation operators α_k, β_k generated as follows:

$$\alpha_k(\theta) = a_k \cosh\theta_k - b_k^\dagger \sinh\theta_k$$
$$\beta_k(\theta) = b_k \cosh\theta_k - a_k^\dagger \sinh\theta_k$$

By imposing suitable conditions on the functions θ_k, it is possible to transform the Hamiltonian of a systems, expressed in terms of the operators α and β, into an equivalent Hamiltonian, free of nondiagonal terms mixing α and β components. For this reason the transformation has been often used to diagonalize the Hamiltonians of models in domains such as superfluidity, antiferromagnetism and superconductivity. In any case the Bogoliubov transformation gives rise to a nonunitarily equivalent representation of the model to which it has been applied.

Taking now into consideration the boson translation, we must take into account the fact that it gave rise, applied to a model endowed with a specific ground state, to a new (nonunitarily equivalent) model characterized by a different ground state. The latter can be derived from the previous ground state through a number of mathematical manipulations (which will not be reported here, being easily available in the standard textbooks quoted before). In any case, what is important is that they show that the new ground state corresponds to a condensate of Nambu-Goldstone bosons, whose number is essentially given by $|\theta_k|^2$. We can thus assert that not only that the Nambu-Goldstone bosons are physically realistic particles (studied, for instance, though scattering experiments on magnons) but also that all dynamical features of the phenomena following a spontaneous symmetry breaking depend in a strict way on the dynamics of Nambu-Goldstone condensate. Among the most important effects of this dynamics, we mention the ones related to the large number of Nambu-Goldstone bosons, allowing their condensate to behave as a macroscopic entity. In this case we can have the occurrence of macroscopic extended objects, of topological singularities, like defects, monopoles and solitons, all ruled by dynamical evolutions which are practically of a classical nature (in this regard, besides the already quoted references, we underline the importance of the fundamental contribution by Umezawa, 1993).

We must remark that the construction of the 'hierarchical tower' of complex macroscopic systems, so far shortly mentioned, allowed by the quantum nature of spontaneous symmetry breaking, can encounter important limitations in some particular cases. The first one occurs when we deal with systems characterized by a finite volume. Such a circumstance entails that, near the system boundaries, the Nambu-Goldstone bosons behave like they acquired a nonzero effective mass, which limits the spatial range of their correlations. Substantially, this effect is in competition with the symmetry breaking. In this case, one speaks of 'Pseudo-Nambu-Goldstone bosons' (or of 'Quasi-Nambu-Goldstone bosons'). A similar situation occurs when we deal with a symmetry which is only partially broken owing to the introduction of an external perturbation. Namely, the latter, within the context of the whole system, makes the original symmetry only partial so that not all consequences of Goldstone theorem are fulfilled, in particular the masslessness (for a simple argument see, for instance, Burgess, 2000). The Pseudo-Nambu-Goldstone bosons appear in a large number of models used in theoretical physics, for instance, when dealing with Bose-Einstein condensates (Moskalenko et al., 2013; Moskalenko, Liberman, Dumanov, & Moskalenko, 2012) or other systems studied in condensed matter physics (Hofmann, 2016).

Before concluding this section on nonequivalent representations in QFT, we remark that the results obtained from the quantum theory of spontaneous symmetry breaking do not hold when the symmetry taken into consideration is a *gauge symmetry*. Without entering into details which, at the present, are important chiefly for the theories of elementary particles, we remind that gauge symmetries are related to the invariance of field equations with respect to *gauge transformations*. In the case of a generic field $\varphi(x)$, an elementary example of global gauge transformation is given by:

$$\varphi(x) \rightarrow \mathrm{e}^{i\alpha}\varphi(x)$$

where α is a constant parameter not dependent on the spatio-temporal variables x. A trivial example of a *local* gauge transformation is instead given by:

$$\varphi(x) \rightarrow \mathrm{e}^{i\alpha(x)}\varphi(x)$$

where the parameter α is a function of x. The gauge symmetries are very important when dealing with fields like, for instance, the electromagnetic field, which is usually considered as the prototype of most unified field theories (see, for instance, Mignani, Pessa, & Resconi, 1999). Now, in the presence of gauge symmetry breaking, it can be shown that the Nambu-Goldstone bosons disappear while, at the same time, the originally massless basic particles of the field ('gauge bosons') acquire a mass. This effect allowed the building of a number of sophisticated unified models of all fundamental physical interactions (see on these topics a textbook like Thomson, 2013).

6.5 Further Remarks

The arguments presented in the previous sections offered a variegate picture of QFT, at least as regarding its valence for the systemic approach. This picture, however, is far from being exhaustive in relation to the very large number of different technical developments undergone by QFT along a history lasted for more than 90 years. This is also a consequence of the extended number of applications of QFT in all domains of physics and mathematical physics, from elementary particles to condensed matter, from biophysics to artificial systems. In any case this complex situation leaves unanswered the following fundamental questions:

1. Is QFT a unitary theoretical corpus?
2. Is QFT the best theoretical tool to deal with emergence processes?
3. Can QFT be approached through conceptual tools simpler than the ones so far used?

The experience of theoretical physicists as well as of philosophers in the last years seems to support a negative answer to the question (1). Actually QFT, rather than being a single theoretical corpus, is a set of different (often conflicting) theories, methods and models. In practice we cannot speak of QFT but only of specific 'QFT models', each one adapted to specific goals. This circumstance makes dubitative the answer to the question (2). While some QFT models, chiefly related to spontaneous symmetry breaking and to phase transitions, allowed to build the first models of emergence processes, they could be still inadequate for a number of reasons: lack of realism, conceptual impossibility of building models of intrinsically complex systems and actual lacking of a suitable understanding of the concept of emergence (also if second-generation systemics made considerable advances in this direction). However, the plasticity itself of QFT conceptual structures does not preclude the unexpected occurrence of new models and new achievements helping to better understand what is emergence.

The question (3) could, on the contrary, receive a positive answer. In the last years, the number of tools and computer programmes allowing to perform numerical simulations of QFT behaviours and models undergo a fast growth. And, perhaps, the day in which these tools will be available to the majority of dummy practitioners is not so far. And the importance of QFT for systemics seems to stem from the fact that the auspicated progress of QFT in the previously quoted directions appears to coincide with a progress of systemic itself.

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Chapter 7
Towards a New Systemics

Contents

In this chapter we consider the conceptual framework given by multiple processes of emergence and properties of the *between* such processes of emergence. Multiple processes of emergence are considered establishing *levels* when one process occurs from *mechanisms* acting on entities and properties emergent in their turn from a different emergent process, horizontally or vertically – top-down or bottom-up.

However, the view based on considering processes of emergence as separable and occurring sequentially or hierarchically looks as a *simplification*, a kind of *second-order reductionism* corresponding to differentiate systems and nonsystems in the GOFS. Having in mind concepts as the ones of Multiple Systems and Collective Beings, we should consider multiple processes of emergence, for instance, when:

- Different processes of emergence may occur *simultaneously* originated by different elements of the same system, eventually in a stable way or differently along time, or by same elements whose interaction has multiple *meanings* of same roles like for Multiple Systems.
- Different processes of emergence may occur *sequentially* at different levels when one level is generated by emergent entities belonging to a different level.

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- While we must consider the possibility of dynamic and partial simultaneity, sequentiality and combinations, we must also consider both bottom-up and top-down processes.
- We must deal with the complexity of eventual *populations* of such processes and their eventual multiple dynamical coherences. While, for instance, in populations of oscillators, we may look for synchronicity(ies) as states and parameterized versions of the *same property*, i.e. synchronization – expression of the *same kind* of coherence – in the case of populations of processes of emergence, we look for multiple, combined and superimposed levels of dynamical properties and for single but more probably multiple *transience*, i.e. change from a level to another.
- Another very interesting subject relates to the *re-emergence* of the *same* properties after occurrence of intra-level emergences (emergences with memory of the previous levels?).

The topics listed above, rather than be considered technical issues *only*, should also be intended as conceptual framework where to represent and deal with the more general post-GOFS topics. Examples are given by words and concepts like coherence, complex, dynamical structures, fluctuation, meta-structures, multiplicity, pre-, quantum, quasi-, regime of validity and self-.

A biological example occurs when considering different *levels of life within a living being* such as of molecules, tissues, organs and bodies.

Examples of multiple levels of emergence are given by markets of markets at financial level such as in (Mainelli, 2007) and by shopping centres *sharing* the same customers in different times like Collective Beings.

However *multiple levels of emergence* may possess or not the same *kind* of emergent properties.

The dynamics between multiple levels of emergence is a very important research topic for the post-GOFS dealing with eventual *over-properties* intended as properties of the multiple levels of emergence and the study of their properties, stability, relations and source. For instance, what is the source of the reappearing of the same properties at different levels? Can we figure out some intra-levels invariants? What is the role of the environment, is it the place for the *memory* of some properties? What is the relation between elements and properties? Can this eventual relation be in some way considered as the intrinsic two-level description of nature mentioned in Sect. 7.1.2?

Another subject relates the eventual *properties of the sequence* of properties at the multiple levels of emergence.

Finally we mention processes of decay and dissolution of emergent systems and their related acquired properties occurring, for instance, with the *dissolution* of networks, scale invariance, topological, meta-structural or ergodic properties due to turbulences and perturbations.

It is a matter to introduce new different nonequivalent correspondent ***cognitive levels*** *and models in the post-GOFS, based on considering their new, partial levels of* ***systemic power****, intended as ability to represent and act on multiple, multilevel* *emergent systemic properties. This generalization should be based on looking for coherence(s) between levels and theoretically accepting irreducible multiplicity as for DYSAM and multiple representations in QFT.*

As considered in this book, it is not only a scientific issue but also a cultural issue as introduced in part B.

7.1 Between Levels of Emergence

This section is dedicated to consider levels of emergence (see, for instance, Baas, 1994; Chibbaro, Rondoni, & Vulpiani, 2014; Emmeche, Köppe, & Stjernfelt, 2000; Queiroz & El-Hani, 2006), possible orders and hierarchies and to deal with the issue of the *between* already considered above for different contexts. The between should be studied as *transient*, intended as process of transformation from one level of emergence into another one when *transitions* may occur in different ways like for phase transitions and acquisition of properties like superconductivity and superfluidity in physics.

Some crucial systemic questions relate, for instance, to *properties* of the transition like the *keeping* or the *transformation* or the *substitution* of previous properties. What do we mean by *level of emergence* (see, for instance, Emmeche, Køppe, & Stjernfelt, 1997; Emmeche et al., 2000)?

Properties emergent from a system of entities may have the previous ones as *necessary properties* such as in Schema 7.1.

What do we intend for *upper level*? We may intend it as level *depending on* the occurring of another *necessary* one taking place *previously* and considered *lower*. The upper may eventually emerge from the occurring of other levels and their possible combinations. The general meaning is that other(s) lower level(s) should be occurred *before* and being *simultaneous* intended as *generative*.

Examples of this phenomenon of *multiple emergences* occur for living (Kauffman, 1993) and social systems.

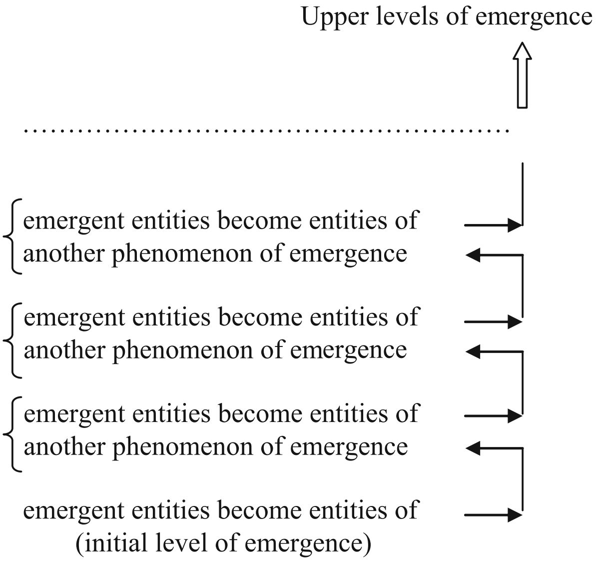
Living systems could be considered as a hierarchical sequence of processes of emergence like summarized in the Schema 7.2.

Each level has its proper emergence *mechanism* and properties. At the level of organisms as living entities, they assume emergent behavioural properties related, for instance, to reproduction, environmental roles – such as in ecosystems and migrations – and population dynamics.

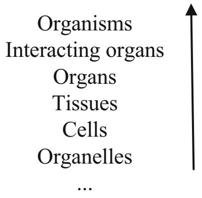
Subsequent levels of emergence occur in social systems when organisms assume emergent behaviour like summarized in the Schema 7.3.

Each level has its proper emergence *mechanism* and properties. At the level of living system, they assume emergent behavioural properties related, for instance, to behave in a non-stimulus-response way only but depending on increasingly complex cognitive systems of populations of neurons. It relates to acquisition of behavioural and social roles such as *from* anthills and beehives *to* colonization

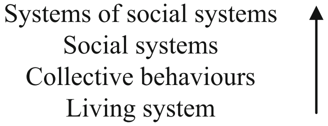
Schema 7.1 Levels of emergence



Schema 7.2 Living systems as hierarchical processes of emergence



Schema 7.3 Social systems as hierarchical processes of emergence



and *behaviours of categories of behaviours* such as hunting, fishing and agricultural societies.

Several systemic research questions remain opened such as:

1. Relations between emergent properties of the different layers.
2. Relations between the different emergent processes related, for instance, to different time scales (Kuehn, 2014) and eventual interactions and combinations between emergence mechanisms.
3. Relations between the different kinds of cognitive models and levels of descriptions to be used.
4. Eventual sequences or combinations of classical and quantum paradigms.

Furthermore the main research topic relates to the eventual general theoretical frameworks by which such processes and intra-emergent properties could be represented. This is asking for a *theory of the transient*.

Is the Science of Networks suitable to represent and deal with intra-emergence processes and phenomena of transience when considering the *changing* of properties like topological and fitness?

Can we consider meta-structural research as a possible conceptual framework where meta-structural properties may represent a level and changes of meta-structural regimes of validity may represent transients?

Is quantum field theory in search of oneness the suitable conceptual framework and approach (Licata, 2014)?

In such eventual general theoretical frameworks, could it be also possible to deal with the problem of the eventual *reappearance* of properties across nonsimultaneous or superimposed levels (see Sect. 7.1.4)?

A first possible general understanding is based on the fact that *lower* levels of emergence are supposed to be *active* when dealing with upper levels based on them. This is different from considering that the mechanism of a lower process of emergence *ceases* to be active when an upper process is in progress. This is, for instance, the case represented in the Schema 7.3.

This is the case of the hexagonal Rayleigh-Bénard prisms *like* the hexagonal cells of hives. It is a matter of *crossing* eventual several emergent noncognitive, e.g. properties of populations of neurons, and cognitive, e.g. memory and learning, levels of the same structure of properties changing from physical to cognitive. Those subjects relate to *transitions from non-living to living matter* (see, for instance, Rasmussen, Chen, Nilsson, & Abe, 2003; Rasmussen et al., 2004, 2008). We mention the related problem of the *eventual conversion of biochemical evolutionary constraints of living systems into behaviour*.

Some processes, such as the search for suitable liquids when feeling thirsty, may have evolutionary explanations related to the search for the breast for milk by infants and the search for more appropriate environmental temperatures by living beings of warm-blooded species and may be considered due to learning processes. However it is much more difficult to explain, for instance, the process of transformation of sexual and reproductive *biological needs* in behaviour. Examples are given by the selection-attraction for a partner of the same species and having appropriate age, the protective attitude towards babies and the visual evaluation of what can be suitable food and its quality (Asano, Khrennikov, Ohya, Yamato, & Tanaka, 2015; Curley & Keverne, 2005; Keverne, 2004; Minati, 2008, pp. 107–111). This relates to understand evolutionary processes of acquisition of cognitive abilities occurred at different levels for living beings as *matter knows itself* (Edelman & Tononi, 2000). The possession of a brain and the related ability to think, at different levels of complexity, should be intended as an evolutionary step after ones like acquisition of the ability to reproduce and use dissipation to live. This understanding helps to *explain* why nature is understandable and why abstractions like formal representations *contain* properties coherent with and to be then eventually recognized into the *real world*, such as symmetries, coherence and fractality (Vitiello, 2009, 2012a, 2012b, 2014), i.e. when properties of representations are in their turn *anticipations* of properties of the real world. This also relates to fractality and symmetries (Gruber & Yopp, 2013) when they recur, as emergent properties, at different levels. *The ability to think and its results should be intended as natural process*, functional *to nature*. In this view living beings should be intended as materializations of processes of nature, acquiring new transformative capabilities no more coincident with evolution processes. *We can intend living beings as nature in action*, operators, delegated to *invent* transformation, when nature represents itself. This reminds the comments introduced by *Karl Raimund Popper* (1902–1994) in Popper (1978) arguing that natural selection moved to ideas. This relates to evolutionary advantages for the acquisition of mind '. . .Let our conjectures, our theories die in our stead! We may still learn to kill our theories instead of killing each other. . .' (Popper, 1978, p. 354).

Finally we mention at this regard the phenomenon of *quantum correlations revival* occurring when a quantum system loses coherence through interaction with an external environment and it remains possible that, after some time, the lost coherence *spontaneously* reappears (see, for instance, Lo Franco, Bellomo, Andersson, & Compagno, 2012).

7.1.1 Bottom-Up and Up-Down Emergence

'Causation' (Kutach, 2013), see Sect. 5.4.3, in a deterministic understanding is coupled with 'effect' (Paul & Hall, 2013, see Sect. 5.5.3).

We focus here on causations having as effect the change of previously valid structure(s), like change of networks, e.g. with regard to links, weights and topology, change of structures of interaction and multiple dynamic structures as assumed for *structural dynamical changes* in Chap. 3 dealing with collective behaviours and Multiple Systems.

It is usually a basic implicit assumption that all *structural causations* go in a bottom-up fashion, like from micro to macro and from non-emergent or lower levels to higher more significant ones as in the Schema 7.3. However, other possibilities exist, like different forms of top-down causations as considered in Sect. 7.1.1. The reference is to the acquisition of more complex structures allowing more complex properties.

We denote here them as *structural* 'causations' since they are able to change *natures* of systems and phenomena, i.e. give their emergent acquired properties.

This is conceptually different from systemic properties acquired due to single-structured interactions, like for electronic circuits and mechanical devices.

A continuous dynamically multiple structured, i.e. changing multiple structures of interaction and levels, generative process is among the requirements to generate and maintain emergent properties within open systems. Examples are given by life, behavioural properties of emergent systems like markets and collective behaviours having, for instance, chaotic and dissipative nature.

In the same conceptual framework, 'structural causations' may be intended to produce 'structural effects' like due to chemical reactions, catastrophic structural damages and network changes as for phenomena represented as networks like the Internet, electrical and communications.

Emergent properties are coupled with eventual continuous coherent structural changes, while, for instance, phase transitions are understandable as single specific structural changes.

Dealing with processes of emergence, the process of 'structural causations' relates to *continuous and coherent actions on structures of the phenomena under study*.

Such 'structural causations' are well known for bottom-up phenomena as given by the establishments of processes of self-organization, intended continuous sequential, for instance, periodic, quasi-periodic and *parametrically* variable, acquisition of new structures.

However, the between is populated of different eventually interacting 'structural causations' such as:

(a) Classical causation dealing with *effects*.
(b) Bottom-up when multiple coherent sequences of processes of self-organizations allow emergence. Such multiple coherent sequences of self-organizations establish bottom-up structural causations since the nature of an emergent system is (continuously) acquired or changed in open systems.
(c) Top-down when structural causations interest backwards the previous generating processes or elements.
(d) The *dynamics* of networks, i.e. when nodes and links change as well as properties like topological, ruling the system when modelled with the Science of Networks.

The first three cases may occur simultaneously, at different degrees of intensity and coherence, while the fourth is a matter of modelling.

Case (a) is the more studied and considered as above.
Case (b) considers acquired properties giving structural new properties, e.g. collective behaviour, or changing the nature of the systems, e.g. collective intelligence.
Case (c) considers when bottom-up acquired emergent properties reversely *induce* top-down other emergent properties not as effects – case a – but using in an inverse way 'structural causations'.

A trivial case occurs by considering *side effects* of the mechanism of interaction allowing emergent bottom-up.

Top-down emergence relates to the fact that acquired properties may make elements to assume a new behaviour that while respecting the one generative of bottom-up emergence may in its turn generate new simultaneous *lower* process of emergence. We say *lower* since occurring at the original generative level.

As discussed in Sects. 2.2 and 3.7.2 and point 26 of Appendix 1, there are different possible ways to respect the constraints or degrees of freedom required by a mechanism of emergence. Bottom-up emergent properties may allow *compatible* emergent bottom properties.

Specifications of processes of top-down emergence are introduced in Ellis (2012) when considering five different kinds of top-down causations like:

Top-down causation 1:	*algorithmic* top-down causation when, for instance, the *low-level* electronic components act *in accord* with software, the *high level* whose structure cannot be explained by using the lower level.
Top-down causation 2:	top-down causation via *non-adaptive* information control when, for instance, the high level influences lower level entities in order to obtain specific, fixed goals like through feedbacks, e.g. the thermostat.
Top-down causation 3:	top-down causation via *adaptive selection* when entities interact and because of such interactions variations of properties of these entities occur allowing selection of entities that *better* deal with their environmental context, e.g. the Darwinian evolution.
Top-down causation 4:	top-down causation via *adaptive information control* when there is combination of feedback control and adaptive selection of goals for the feedback mechanism. Such irreducible goals are higher-level variables setting outcomes, but are not fixed differently from the case of non-adaptive feedback control. This is the case of associative learning for living systems, such as the Pavlovian effect.
Top-down causation 5:	Intelligent top-down causation is intended to occur when the selection of goals is performed by using symbolic representations and *cognitive processing* to consider effects of goal choices, like in design and engineering.

We mention how top-down emergence may be intended as mechanism allowing emergence as selection among eventual *pre-properties* as considered in Sect. 4.4.

We will consider in Sect. 7.2 the *multiple* occurrences of different cases and causations in the framework of systems of occurrences when coherence is maintained.

However, a comprehensive comment is given by the fact that *everything must happen in some ways, but the ways by which it happens are different by what happens*. This is to say that huge dynamical combinations may occur and that *how the becoming occurs* has not as degree of freedom the ways by which we model or expect. This is the case when the two phenomena have different *cardinalities*. It also relates to *theoretical incompleteness*; see Sects. 1.3 and 7.2.

7.1.2 Descriptions and Representations

In this section we consider multiplicity of descriptions and representations to deal with multiplicity of processes and levels of emergence. A general schema is presented in Table 7.1.

We mention how reductionism is often considered given by assuming exhaustive validity of a single level of representation and of description and that it is possible to *reconstruct* upper levels from lowest ones and *disassemble* and *demount* upper levels into corresponding lowest ones *disregarding* dynamic explicit and non-explicit processes of emergence occurring between levels establishing coherences, intended in this case reduced to assemblages. The adjective *lowest* than another one applies, for instance, when (a) a lower level is contained as specific case

Table 7.1 A general description for level of description, representation and model

Level of description	It concerns the *scalarity*, like: Microscopic, macroscopic, mesoscopic, quantum Mesoscopic, multiscale, and renormalisation (see, for instance, Zinn-Justin, 2007).
	It concerns the disciplinary description: For example, chemical, biological, classical and quantum physical, economical, mathematical, psychological.
Level of representation	It concerns usage, for instance, of:
	Symbolic variables
	Non-symbolic variables
	Mesoscopic as collective, clustered variables
	Networks
	Thresholds
	QM and QFT representations
	N.B.
	A logically open system allows *more formal* complementary representations. Each representation of a logically open system by a model at logical openness of degree *n*, i.e., having *n* completely specified constraints, is valid in a limited domain. For instance, it is able to deal only with a limited percentage of the information processes between system and environment (see Sect. 2.7).
Model	A *symbolic model* is given by mathematical relations between variables suitable to represent the behaviour of a system, being classical examples the Lotka-Volterra, Van der Pol and the *Brusselator* models. By changing the meaning of variables, it is possible to eventually deal with different systems.
	A *non-symbolic* model is given by generic abstract non-symbolic systems whose properties are suitable to represent, thanks to proper parameterisations, the behaviour of real systems, e.g., Neural Networks and Cellular Automata. See Chap. 5 for a more exhaustive presentation in which we considered, for instance, explicit and non-explicit, ideal and non-ideal models.

in the other one, e.g. micro into macro with assumptions of possibility to *reconstruct* or *disassemble* the higher into the lower, and (b) a process occurs *after* another necessary (not necessarily sufficient) one(s), e.g. acquisition of emergent properties. In the latter case, sequentiality relates to temporal and logical aspects.

Research performed by the post-GOFS is supposed to concern the *dynamics between* (a) eventual different levels of representation taking place at the same level of description, (b) multiple levels of description, (c) the study of their equivalence and non-equivalence and (d) their coherence (see, for instance, Skjeltorp and Vicsek (2001)).

This multiplicity may sound as DYSAM-like; however, it seems to require the additional need to know and to have approaches and strategies with regard to the transitions and the nature of changes occurring in the system under study as considering *networks of DYSAM* and *meta-structural DYSAM*; see Sect. 5.3.2.

7.1.2.1 Micro and Macro

In classical representations, like for classical physics, *microscopic* and *macroscopic* descriptions deal with two different levels of descriptions (see, for instance, Capasso & Lachowicz, 2008; Lachowicz, 2008, 2011).

They have different kinds of properties.

The first case, i.e. microscopic, relates to suitable scalarity where it is possible to treat *single entities* assumed separable. Hypothetically, in the classical case, they are *all different* since it can be assumable that lowering the thresholds ad infinitum values of measurements will finally be different. Furthermore the case corresponds to the *lower* scale when entities are assumed at their *ultimate* decomposability, e.g. particles in classical physics (see Pessa, 2009), and establishing so-called big data (Franks, 2012). Ultimate entities are assumed non-further *decomposable*.

The second case, i.e. macroscopic, may be intended in different ways, for instance, as related to suitable *indexes* having statistical nature, like temperature, and suitable *aggregative nature* allowed by considering *high* levels of thresholds whereby we consider properties of the aggregations and we lose all the microscopic information, as when considering properties of a ball and ignoring properties of its composing molecules. At suitable thresholds macroscopic entities are *identical*, i.e. having same *properties* even if possible different parameters. Examples are given by billiard balls, agents of crowd or traffic and apples. At this level we lose all the microscopic information, as when considering statistical properties. In this conceptual context:

- Apples are *microscopic* when we consider their single specific details, e.g. morphology, molecular composition, weight and density with *infinite* precision being all *different* in reference to some details.
- Apples are *macroscopic* when we consider related indexes like global quantities, for instance, per tree, and that they are *identical* for the diffusion of pesticides and as food. Macroscopic concerns to consider *averages* and

non-decomposability. All microscopic information is lost, while the focus is on global properties like *average* state of maturation, weight and conditions.

However, it is also possible to consider macroscopicity as related to *different scales* when, for example, a cell is macroscopic with reference to its components.

Other cases occur when considering quantum effects at *our* macroscopic scale, such as superconductivity and superfluidity.

Furthermore the macroscopic level is often identified with reference to the specific model under study.

7.1.2.2 Mesoscopic

Considering now the difference between ideal and non-ideal approaches introduced in Sect. 5.6, we may say that ideal models follow a *top-down* approach, while non-ideal models follow *bottom-up* approaches. It is possible to consider an approach based on the *philosophy of the middle way* (Laughlin, Pines, Schmalian, Stojkovic, & Wolynes, 2000) by taking into count the *mesoscopic* level of description intended as *areas of continuous negotiations between micro and macro*; see Sect. 2.4. Mesoscopic approaches are considered in different research areas as mentioned in Sects. 2.4 and 3.8.3 when considering mesoscopic variables.

7.1.2.3 Dynamic Networks

Currently descriptions and representations based on networks are considered constitute post-GOFS *tout court* or one of its fundamental parts as introduced in Chap. 8 and when considering *dynamics of networks*, whilst, nodes and edges change along time (see, for instance, Liu, Jiang, & Hill, 2014; Newman, 2010), and for *network evolution* (see, for instance, Corten, 2014; Dorogovtsev & Mendes, 2014).

7.1.2.4 Quantum

Other *worlds* are the ones of QM and QFT when at quantum level it is not possible to ignore the role of *quantum fluctuations* and for which we limit ourselves to mention contributions directly related to topics of the book (Blasone, Jizba, & Vitiello, 2011; Del Giudice, Doglia, Milani, & Vitiello, 1985) and discussed in Chap. 6.

The quantum level of description introduced by QM and QFT opened a new scenario where *quantum mesoscopic* relate to the role of quantum fluctuations.

An important theorem, proven by von Neumann (Von Neumann, 1955), states that in QM all possible representations are reciprocally *equivalent*. This theorem excludes any application of QM to the description of *structural changes*. Therefore, within QM, it is *in principle* impossible to formulate a theory of *phase transitions* and, a fortiori, of emergent phenomena.

Such non-equivalence, on the contrary, is possible within the context of quantum field theory (QFT) most often as *spontaneous symmetry breaking*. As this regards quantum electrodynamics, the explanation of the laser effect and the unified theory of weak and electromagnetic forces are among the most remarkable achievements of QFT.

Within QFT, unlike in QM, there is the possibility of having different, *nonequivalent* representations of the same physical system (Haag, 1961; Hepp, 1972). The existence of nonequivalent representations is strictly connected to the fact that if we interpret quantum fields as equivalent to sets of suitable particles lying in suitable dynamical states, then QFT describes, even in its simplest implementations, situations in which the total number of particles is *no longer conserved*. In other words, within QFT (and *only* within QFT), the processes of *creation* and *destruction* of particles are allowed. This gives QFT a descriptive power enormously greater than that of QM, where the number of particles is constant (Minati & Pessa, 2006, p. 237).

A further consequence is that *hypothetically* only within QFT it is possible to deal with *phase transitions*, i.e. with global structural changes of the system under study.

Only the quantum theory does provide models of intrinsic emergence? Today we know that the answer is *no*.

Some systems described by deterministic laws, to which it was added a stochastic ground noise, show behaviours identical to those of quantum systems with the appearance of long-range correlations, collective effects, etc. For them it is even possible to introduce *Planck's constant* whose value differs from that of the traditional h (see also Sect. 2.3).

Moreover when approaching the critical point of a phase transition, the fluctuations of the system tend to diverge, since going towards the destruction of the coherence associated with the pre-existing phase, while the system is not yet able to *decide* what form of coherence will be associated with the new phase. Below a certain distance from the critical point, the energetic contribution of the fluctuations exceeds that provided by quantum correlations, coherence is destroyed and the system behaves as a classic system.

Therefore, although the use of the QFT to describe the phase transitions is indispensable, in correspondence to the critical point, there is a momentary transition having classical dynamics.

Several studies (see, for instance, Pessa & Vitiello, 2004) have shown how this dynamic be of the type *deterministic chaos*.

Finally it must be stressed that '. . .quantum field dynamics is not confined to the microscopic world: crystals, ferromagnets, superconductors, etc. are macroscopic quantum systems. . . . their macroscopic properties . . . cannot be explained without recourse to the underlying quantum dynamics' (Blasone et al., 2011, p. ix).

We conclude this section by mentioning related emerging problems characterizing the systemic general approaches for a post-GOFS such as having an eventual general, unifying view of problems dealing with continuity and coexistence as superimposition, simultaneity, coherence, transformation and compatibility, *looking for a unified general theory of representation*.

7.1.3 Transient Between Validity Regimes

The subject relating to regimes of validity is introduced in Sects. 3.2.4 and 3.8.5.

In the section here, we elaborate about the change and eventual properties of the dynamics of change *between* regimes of validity, for instance, between *kinds* of networks ruling the system, usages of degrees of freedom, validity of specific mesoscopic vectors and between meta-structures.

Such eventual properties could state *meta-regimes* and be considered for systemic properties *propagation* (see Sect. 4.6) and to set environmental or space systemic properties setting modalities of change between regimes.

We relate also to the case when a system can be described only through a number of *different partial representations* as for Multiple Systems and DYSAM-like approaches (see Sect. 5.3.2, Appendix 1, points 5, 6 and 7) discussed above.

We relate also to processes of emergence, like in physics associated with (sequences of) phase transitions (Sachdev, 2011; Solé, 2011; Zinn-Justin, 2007); see Sect. 3.2.3.

The latter require the occurrence of two 'phases' (one following the other *after* the transition), physically 'not equivalent' one to another. It means that it is impossible to find a transformation that, while keeping invariant the expectation values of all physical quantities, also reduces the physical description of one phase to the one of the other.

Properties of the transience may be general and superimpose on specific regime's properties. Properties of the transience may specify the *nature of the complexity* of systems, like given by chaos, self-organization, emergence, quantum and their eventual combinations.

An example is given when considering *multiple dynamical attractors* and properties of their dynamics (Kauffman, 2011; Scarpetta, Yoshioka, & Marinaro, 2008). Metaphorically speaking it is equivalent to consider superimposed abstract spaces of multiple attractors. Each space could be considered given by corresponding different regimes. Furthermore we consider the processes of *changing space* and related transience.

The focus is on eventual ***systems of such regimes***.

A very simple example is given by the superimposed periods or cycles setting a multiple regime of periods that may relate to different phenomena like biological and economical in populations of social systems.

Similar conceptual contexts are given when considering cases like:

- *General multiple symmetries* (see, for instance, McClain, 2008). The case arises when multiple symmetries are established in connected networks of nodes. The

same nodes may belong to different networks (Nicosia, Bianconi, Latora, & Barthelemy, 2013) having different symmetries. Dynamics relates to the changes of structures and multiple roles of the element nodes.
- *Multiple fractals* (see, for instance, Chen, 2014; Harte, 2001). The case arises when multiple fractal rules occur and the same segments or surfaces belong to multiple, different fractals. Dynamics relates to the changes of rules and eventual multiple roles of segments and surfaces.
- *Multiple phases* (see, for instance Brovchenko, Geiger, & Oleinikova, 2005; Brovchenko & Oleinikova, 2008). The case arises when elements of the system are involved in multiple phases. Dynamics relates to the changes of phases and eventual multiple roles of same elements.

The concepts considered above are *compatible* with the multiple roles characterizing Multiple Systems considered in Sect. 4.5.

We considered above multiple regimes as abstract spaces and cases suitable to model complex phenomena. Examples are considered in Kauffman (2011) relating to biological systems and when dealing with distorted, 'rearranged' symmetries in physics (Blasone et al., 2011). 'A way of looking at this situation is to reinterpret the observed deviation from the exact symmetry as a phenomenological distortion or rearrangement of the basic symmetry ... The crucial problem one has to face in the recognition of a symmetry is, then, the intrinsic two-level description of Nature . . . This two-level description of Nature was soon recognized in Quantum Field Theory (QFT) as the duality between field and particles' (Blasone et al., 2011, p. 1).

The concepts introduced about regimes of validity may be considered not only suitable to model, but even as eventual representations of the intrinsic dynamics of nature.

This is a fantastic challenge for the post-GOFS.

7.1.4 Recurrence of Properties at Different Levels

In this section we introduce some comments about another key subject for the post-GOFS, scilicet the *recurrence* of the same properties at different levels of emergence.

First of all the general processes establishing emergence and acquisition of properties are understood to give raise to completely new worlds, non-reducible and non-deducible from the previous one. However, we already considered in Sects. 1.3 and 2.4 the concept of *continuity* preserving some categories of variables when dealing with emergent properties. Such *continuity* makes the observer to consider, for instance, in case of flock-like collective behaviours variables of elements like speed, direction and altitude while excluding, for instance, age, colour, sex and weight. Furthermore:

- Some emergent properties may have the *same nature* of the ones of the composing elements even if having different non-reducible *representation*, e.g. dynamics of single boids vs. the dynamics of the network representing the flock.

- Some emergent properties may have *different nature* from the ones of the composing elements, e.g. density, network type, scalarity, patterns and topology. This is the case for collective intelligence when behaving collectively provides solutions to problems which the individual components are unable to solve. For instance, space representation is essential to describe and represent swarm intelligence, since *intelligence is more in the representation of cognitive space* rather than in the individual agents: it is an emergent property of the space structured by their behaviour. Another case is given by the occurrence of a *collective representation with individuals unable to formulate an abstract representation.* An example is given by the behaviour of ants looking for food. When an ant detects a source of food, it marks the followed path with a chemical track by using the pheromone. This mark induces other ants to go towards the source of food. When the ants return, they leave a further track of pheromone reinforcing the original one. This kind of behaviour amplifies the importance of the discovery by organizing a kind of communication, but it also allows the ant to evaluate which path is more interesting than another. The closest source of food is the one having the strongest chemical track, while the others are associated with a weaker signal because of the decay of the chemical signal along the path due to its lesser frequentation (Deneubourg, Goss, Franks, & Pasteels, 1989; Franks, Gomez, Goss, & Deneubourg, 1991).

More precisely:

- *Emergent entities may* keep the same *properties possessed by* generative *elements or processes*. In this case properties apply, for instance, in summative or averaged way, like weight, age, direction and density both possessed by composing elements, e.g. boids, and acquired by emergent collective systems.
- *Emergent entities may* not acquire anymore *properties possessed by* generative *elements or processes*. In this case *emergent entities acquire properties* different *from those possessed by elements or processes without keeping properties possessed by* generative *elements or processes*. In such a case properties possessed by generating elements or processes *disappear* after the process of emergence. Examples are given by emergent topologies of networks, behaviour of bacterial colonies or swarms and collective intelligence.

While the first kind of properties may be considered responsible for some aspects of ***continuity*** *in processes or emergence, the second one may be considered responsible for* ***discontinuity*** *in processes of emergence, until they play the same role of the first one for eventual subsequent processes of emergence*.

Moreover we must consider the way by which such properties *vary* at suitable *thresholds* along time:

- At suitable *thresholds*, they may be *fixed* and characterize the *status* of a macroscopic process, e.g. the weight.

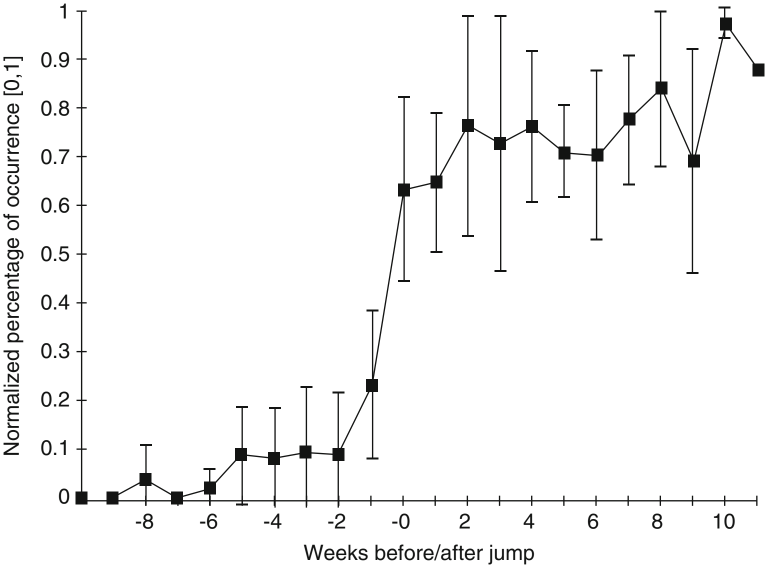


Fig. 7.1 The switching from the inability to grasp an object to the ability to grasp

- At suitable *thresholds*, they may be variable depending on external control variables, e.g. volume and pressure depending on temperature.
- At suitable *thresholds*, the observer may detect emergence and acquisition of properties due to ways of change like periodicity, multiple synchronizations and coherences (see, for instance, Acebrón, Bonilla, Vicente, Ritort, & Spigler, 2005; Ciszak, Euzzor, Geltrude, Arecchi, & Meucci, 2013).

It is possible to distinguish between:

- Usual properties however *dynamically* acquired, i.e. stable in their nature (e.g. density is density), but continuously changing in their values with *some* regularities characterizing the collective behaviour.
- Properties of different nature (radical emergence) like *phase transitions* in physics, e.g. from ferromagnetism to magnetism, life and consciousness, and in cognition, e.g. from the wrong hypothesis to the right one during the task of discovering the proper rule (Terai & Miwa, 2003) and during the evolutionary age for children when *switching* from the inability to grasp an object to the ability to grasp (Wimmer, Mayringer, & Raberger, 1999); see Fig. 7.1.
- Another interesting case is given when *elements establishing a collective behaviour are themselves collective behaviours*. An idea is given by international markets of local markets. This relates also to layers and scalarity when considering, for instance, dissipative structures and their emergent properties occurring at the scale of whirlpools and hurricanes. In the same way the Belousov-Zhabotinsky reaction may be generalized as by the 2-dimensional cellular automaton in (Dewdney, 1988). Other cases relate to symmetry.

We conclude by mentioning the so-called Anderson localization (Anderson, 1958) in condensed matter (see, for instance, Brandes & Kettemann, 2010; Hundertmark, 2008). The study of the conductance of electrons belongs to condensed matter physics. The study relates to modelling an electron in a *disordered solid*.

When disorder is small, the particle, like an electron, is usually *randomly scattered*, and the wave function remains *extended* through the system.

Conversely and unexpectedly, if the disorder is strong enough, the wave function becomes *localized*.

This is an example of keeping of properties, conductivity in this case, when the process goes through a structural change like small-strong disorder.

7.2 Partiality, Instability, Uncertainty and Incompleteness of Properties for Levels of Emergence

In this section we consider the case when the quasiness of quasi-properties introduced in Sect. 4.5 is considered given by multiple levels of emergence.

In particular the quasiness at a single level of emergence can be considered as an *open valence* suitable to *combine* with other simultaneous processes of emergence occurring at the same level.

Furthermore, partiality, instability, uncertainty and incompleteness of properties at a *single level* of emergence can be considered as *clues* of openness to assume and perform multiple roles.

This is sort of ***horizontal*** *quasiness* to be explored and studied by assuming *stability of same regimes*.

It is possible to consider the *robustness* of a level of emergence when partiality, instability, uncertainty and incompleteness of properties do not imply or are given by radical *changing* of nature of properties.

Partiality, instability, uncertainty and incompleteness of properties *specify* the quasiness of multiple processes of emergence assuming aspects like non-stability and eventual *robustness* due indeed to coherence, as for networks keeping topological properties.

This inevitably deals with *identity* of the system. We remind that in Sect. 3.5 we considered identity of a system the '...permanence of emergent properties and permanence of properties of the way to change at any level such as coherence(s), super coherence and ontological dynamics'.

Typical example is given by the coherences of a specific, and *inevitably multiple*, ecosystem, i.e. multiple, partial, incomplete and overlapping different processes of emergence.

Another example is given by general life styles of social systems. Life styles emerge from *systems* of eventually networked varieties of behavioural single, dynamical and interacting attitudes. Single eventual *extremes* are not *averaged* but *processed* by the network of interactions.

It is important to have suitable approaches to detect and maintain the system identity in case of horizontal *coherent* quasiness.

However, the level of description related to the horizontal quasiness should be properly established by identifying also when the quasiness eventually *disintegrates* quasi-properties into non-properties, for instance, when coherences of regimes of validity, network and meta-structural properties *disappear* at a specific level of emergence along time.

The eventual ***vertical*** *quasiness* considers partiality, instability, uncertainty and incompleteness of properties occurring at multiple levels of emergence. This is when considering the change from one level to the upper or to the bottom. The *verse* of the levels of emergence is given by the role of composing elements like in the Schema 7.1 and elaborated in Sect. 7.1.

A first question about the verse relates the eventual *reversibility* of multiple levels of processes of emergence. We discussed about the irreversibility of processes of emergence as generators of uniqueness and selections among equivalent configurations. But here we are considering *levels*.

Can the chain or hierarchy of levels be interrupted by eliminating one or more levels? Lower levels are probably *necessary condition* for the emergence of the upper ones.

However, the sequence is not simply causal, implicative and functional since the retroactive effect of emergent properties on the process of emergence as we will consider in the next paragraphs.

Furthermore can multiple, independent and irreducible processes of emergence develop from a *single* layer? Can we have a theory about such eventual multiplicity and how to make the system to select, collapse by choosing one?

Are levels *autonomous* in the sense that in some cases upper emergence cannot influence the lower one? The answer is probably *not* since the sequence of levels should be intended as *system*. Life, for instance, is a *transversal* property as for hypothetical cases of living cells *within* no-longer-living body or the reverse. Emergent mind has influence on the emergent levels and vice versa even when mind is no longer emergent as in case of coma and damaged brains.

Another example occurs when acquired emergent properties of a collective behaviour, like traffic, swarms or flocks, *reversely* not only *influence* but also critically contribute to the *subsequent*, i.e. *after* the occurring of the collective behaviour, emergence of the behaviour acquired by single entities. In this case it is considered:

(a) The behaviour of single entities occurring as emergent from a variety of interacting variables like biological, cognitive, energetic, environmental and physical depending on the *nature* of the entity, e.g. living, economical or physical. The behaviour of systems of suitable complexity is emergent. It is not emergent when based on *functioning*, as in artificial electronic devices, and processes of stimulus-response.

(b) The collective behaviour established by the interaction between single previously emerged entities as at the previous point a, but influenced, for instance, by perturbations, change of degrees of freedom – assumed irrelevant for single entities – and through linear or non-linear combinations. For instance, a boid in a flock is requested to contemporarily select one of the possible ways to respect the current coherence of the flock *and* contribute to make coherent eventual incoherent local behaviours (due, for instance, to linear reaction to external perturbations). As considered in Chap. 4, there is a variety of eventual equivalent ways to *perform* such reverse processes of emergence (see Schema 7.4) and establish new coherence(s) local and global.

However, when bottom-up emergence occurs from populations of interacting but in their turn *non-emergent entities* – see case a – e.g. mobile phone networks, cities and traffic of signals, the reverse effect is limited to influence the subsequent process of emergence since there are no or very limited possibilities to act on structural aspects of the non-emergent entity, like telephones, unless usage; buildings, unless restoration; and signals.

We consider here in the Schema 7.4 the eventual *two-direction* version of the process depicted in the Schema 7.2.

This is only a schematic ideal *mechanism* supposed to eventually occur in multiple, partial, instable, uncertain and incomplete ways.

The vertical quasiness should be intended given by the coherence of multiple levels and combinations.

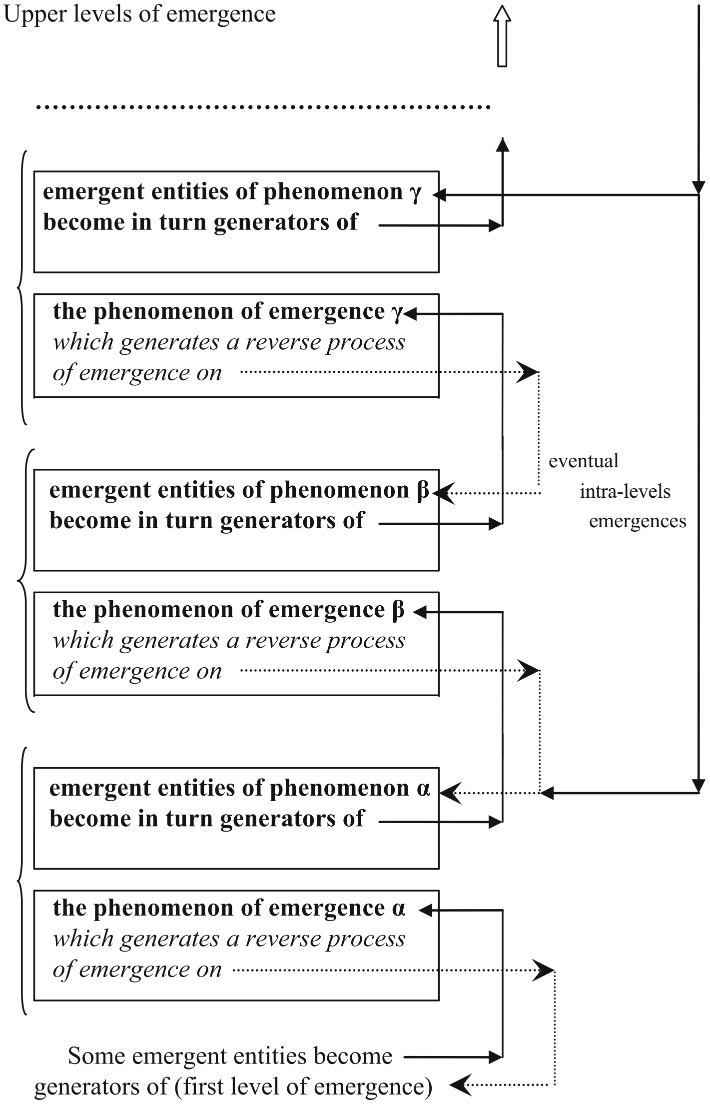
This calls for formalizations able to deal not only with well-defined cases as for classical approaches.

At this regards we may mention different cases as examples related to properties of levels of emergence and emergence of different coherences.

First we mention the phenomenon of *remote synchronization*. An interesting case of study occurs when considering a system of identical Kuramoto oscillators where directly connected nodes maintain a finite phase difference hindering global synchronization. However, after a transient, the system organizes into a regime of *remote synchronization* where two nodes with the same symmetry have identical phases despite their distance in the graph (Nicosia, Valencia, Chavez, Diaz-Guilera, & Latora, 2013). For synchronization in coupled model systems, see, for instance, Kreuz et al. (2007).

Another example is given by the so-called binding problem. In neurology *binding* is intended related to *combining stimulus features to form a unitary representation*. The problem considers how does information variously distributed in patterns of neural firing result in coherent representations? The binding refers to a whole class of problems, like across time; auditory binding; cognitive binding; cross-modal binding, i.e. associating single events; for interpreting object motion; perceptual binding; sensory-motor binding; and visual binding (see, for instance, Di Lollo, 2012; Hagoort, 2003, 2005; Pessa, 2005; Singer, 2001; Whitney, 2009).

A further example is given by *dominions of coherences*; see Chap. 3 and Del Giudice and Tedeschi (2009) for coherence among dominions of coherences



Schema 7.4 Levels of emergence where a process of emergence generates emergent entities both influencing up-down the process of generation itself and becoming entities generating another process of emergence bottom-up

considered in the case of water, *long-range correlations* (Campa, Dauxois, Fanelli, & Ruffo, 2014; Rangarajan & Ding, 2010), the keeping of *scale invariance* (Cavagna et al., 2010) and *regimes of validity* (see Sect. 7.1.3).

Post-GOFS needs ***formalizations*** *(can we still use this term?) representing such processes where the connection is not given by rules but by coherence of multiple dynamical rules.*

Several possible options are getting available, like network properties, meta-structures and the QFT.

7.2.1 Dynamics and Coherences of Emergence

In Chap. 3 we introduced and discussed emergence as phenomenon of dynamical coherence. After the topics discussed here, we should now consider that, in turn, dynamical coherence and levels of coherences are possible when dealing with levels of emergence.

We consider here the eventual dynamics and coherences of different processes of emergence. This may relate, for instance, to (a) the dynamics between *levels* of emergence when the system is given by coherence among levels or (b) the dynamics between, eventually partially, *different* processes of emergence, i.e. established by, eventually partially, different entities and acquiring different, eventually partially concomitant emergent properties, *when the system is given by coherence among processes of emergence themselves*.

In the first case (a), it is a matter of *vertical*, if not hierarchical, dynamics involving levels discussed above. What coherence among levels are we speaking about? As introduced in Sect. 2.1 and subsequent elaborations, coherence is intended as phenomenological, i.e. the keeping of the same emergent property, or given by any regularity in representations, like the keeping of synchronicity or periodicity at micro, macro or mesoscopic level and the keeping of scale invariance, network or meta-structural properties. In case of suitable representations, for instance, by neural networks, we may consider the case where there is *iteration* of the same architecture through the levels.

Should the request to keep such coherence be intended valid for any *subsequent* level or some more realistic changes can be assumed allowing adaptations and evolutionary processes establishing new coherences? The dynamics between levels should be intended as dialectical negotiation, adaptation and balancing. Such dynamics for coherence should *correspond* to exogenous changes about the general, overall system, like unusual input and ageing.

The case (b) is much more general. A way to *conceptually summarize* is to consider *populations* of, eventually different but usually crossed simultaneous and superimposed, processes of emergence acquiring dynamical coherences. This is the case of corresponding *populations* of interacting different systems acquiring emergent properties.

A typical example is given by social systems, populations of dynamic emergent systems of the everyday life. The endless list counts entries where functional aspects are present or not, like audience, buyers, classrooms, families, inhabitants, passengers, queues and workgroups. They are cases of Multiple Systems as introduce above.

Another typical example is given by ecosystems (see, for instance, Green, Klomp, Rimmington, & Sadedin, 2006; Higashi & Burns, 2009; Hobbs et al., 2006) where a huge amount of interrelated processes of emergence continuously occur, get exhausted and reborn.

In this case coherence should be intended, in correspondence with the case (a), by considering *regularity of regularities* in values of different properties of the processes of emergence like phases of synchronicities, periodicities, scale invariance, network or meta-structural. For example, different simultaneous synchronicities may keep the same values like average, statistical properties, distance and clusters. Multiple simultaneous different scale invariances may be replicated along time and network or meta-structural properties as well.

This relates to the concept of *super-coherence* introduced in Sect. 3.4. The point relates to the dynamics of/and coherences of processes of emergence.

We focus here on rules, models and representations suitable to represent their dynamics, levels and coherences. *The focus is on eventual properties of* ***populations*** *of processes of emergence rather than on phenomenological subsequent results of such processes*. The matter is to focus on processes as *operators* rather than on their performance and results.

This reminds as it is impossible to know in advance the result of a program for a Turing-machine without completely running the entire program.

In a conceptual correspondence, *we may consider subsequent steps of populations of processes of emergence* as computational process inevitably ‘computing’ the resulting emergence. There is a lack of suitable *representations* processes of such steps and to deal with their properties such as eventual convergences or attractors *when rules and operators are dynamical*.

This corresponds to similar cases occurring in linguistics where it is impossible to extract and detect properties, like the meaning, without reading the entire text – when dictionaries are *cemeteries of words* (Galeano, 1978) – or in music without performing the entire score, and deal with multiple levels and their properties.

It is a matter to detect a kind of collective emergence of semantics, from processes of emergence.

Different problem is the eventual *combination* of processes when rules may sequentially combine even in context-sensitive way. However, different combinations having power of influencing properties like a kind of *algebra* of processes are not available due the limited possibility to explicitly represent the processes. We may mention at this regard the cases considered in Sect. 2.4 where we consider studies and applications of multiple neural networks as combined, trained together and employing different models on the same data set.

We must mention here the usage of *arithmetization* of metamathematics – or arithmetization of syntax – as introduced in Gödel (1931) and Feferman (1960) allowing Gödel’s incompleteness theorems and conceptually considerable to arithmetize sequences of processes of emergence, as computational.

7.2.2 Multiple Emergence

In this section we would like to elaborate the case (b) considered in Sect. 7.2.1 considering eventual populations of processes of emergence dealing with their possible dynamics and coherence, where the dynamics is between *different* processes of emergence, i.e. established by, eventually partially, different entities and acquiring different, eventually partially concomitant emergent properties. The emergent global system is given by *coherence among processes of emergence themselves*.

This reminds the case of Multiple Systems and Collective Beings where multiple roles and multiple interactions give rise to multiple systems whose coherence is given, thanks to their eventual keeping of scale invariance, meta-structural and network properties.

We consider here a possible *generalization* of Multiple Systems and Collective Beings where multiple emergences may occur when different, and not just one, processes of emergence arise from the same starting level (multiple flocks), i.e. from the same population of interacting entities, *without the request of their single coherence*.

For instance, considering a population of oscillators (see, for instance, Acebrón et al., 2005; Boccaletti, 2008; Boccaletti, Kurths, Osipov, Valladares, & Zhouc, 2002; Ciszak et al., 2013; Kuramoto, 2003; Manrubia & Mikhailov, 2004; Pikovsky, Rosenblum, & Kurths, 2001), their phases may be idealistically considered to represent the crucial value of corresponding processes of emergence. In the case considered here, there are not any even dynamical, local, combined general synchronizations.

For processes, as well as their representing oscillators, there is not the request of their general coherence.

Such situation may be of no interest if not in cases where it comes from a previous situation of coherence. It may be intended as a process of degeneration and desegregation to be contrasted for *restoring* the lost coherence(s) or to *establish **new** previously non-existing coherence(s)*. If the situation continues, it may be intended as having *forms of stability* not necessarily to converge to coherence(s).

We may focus in the follow on the case of degeneration.

This may occur when the same entities of a level of emergence have *mutations*-like changes only affecting *a part* of the layer of belonging and only a part of the vertical sequences of layers of emergence, e.g. in biology processes that change a DNA sequence. For instance, mutations of normal cells into carcinogenic cells will affect in different ways the emergent levels of a living body combining previous regular levels of emergence with new ones. Incidentally, such carcinogenic cells will assume collective motion to increase resistance and their diffusion (Malet-Engra et al., 2015).

Emergent behavioural property of agents generating multilevel multiple social systems is another example when mutations have social, cognitive nature and their criminal or pathological natures avoid coherence(s).

The Schema 7.4 can be converted in any versions of the Schema 7.5 in which new paths of emergence arise from a single level establishing horizontal and vertical dynamical quasiness and distorting or breaking levels of coherences. While this process is suitable to represent the breaking of regularities occurring in pathologies, it also represents evolutionary changes occurring in the levels of emergence. We may consider mutations occurring at levels of entities but also for processes of interaction when due, for instance, to environmental and contextual reasons as considered in Sect. 4.6. The situation applies to multiple phenomena having high levels of virtuality such as allowed by cognitive models in social systems and Collective Beings.

In the Schema 7.5 we schematically represent the case of multiple emergences as *mutated emergence* splitting one level into more. We stress that the splitting may occur in any varieties of ways such as multiple and variable, *while effects in and from single levels with multiple boxes (only two in the schema) may be of any kinds*. For instance, the appearance of carcinogenic cells at a level has influences at its level and *diffusive* influence at other levels without keeping the initial clear and well-defined distinctions. These non-linear, quasi, multiple, variable influences are the subject for a future theoretical approach to model such multiple emergence non-reducible to the multiple levels only. The purpose for such plenty post-GOFS research will be the availability of tools to act on such a process to keep, change or avoid, for instance, coherences. We stress that processes of multiple emergence are often *invisible* in the framework of the GOFS suitable to eventually recognize single levels.

Another research issue relates to the ***nature*** *of sequences of the levels of emergence*. We may consider the case of hierarchy of levels of emergence, while different other cases are possible like *networks* of processes of emergence whose eventual regularity could be represented by scale invariance, network properties and grammars.

The subject asks also to introduce hypotheses and experimental activities about the phenomena generating the emergence of a new level.

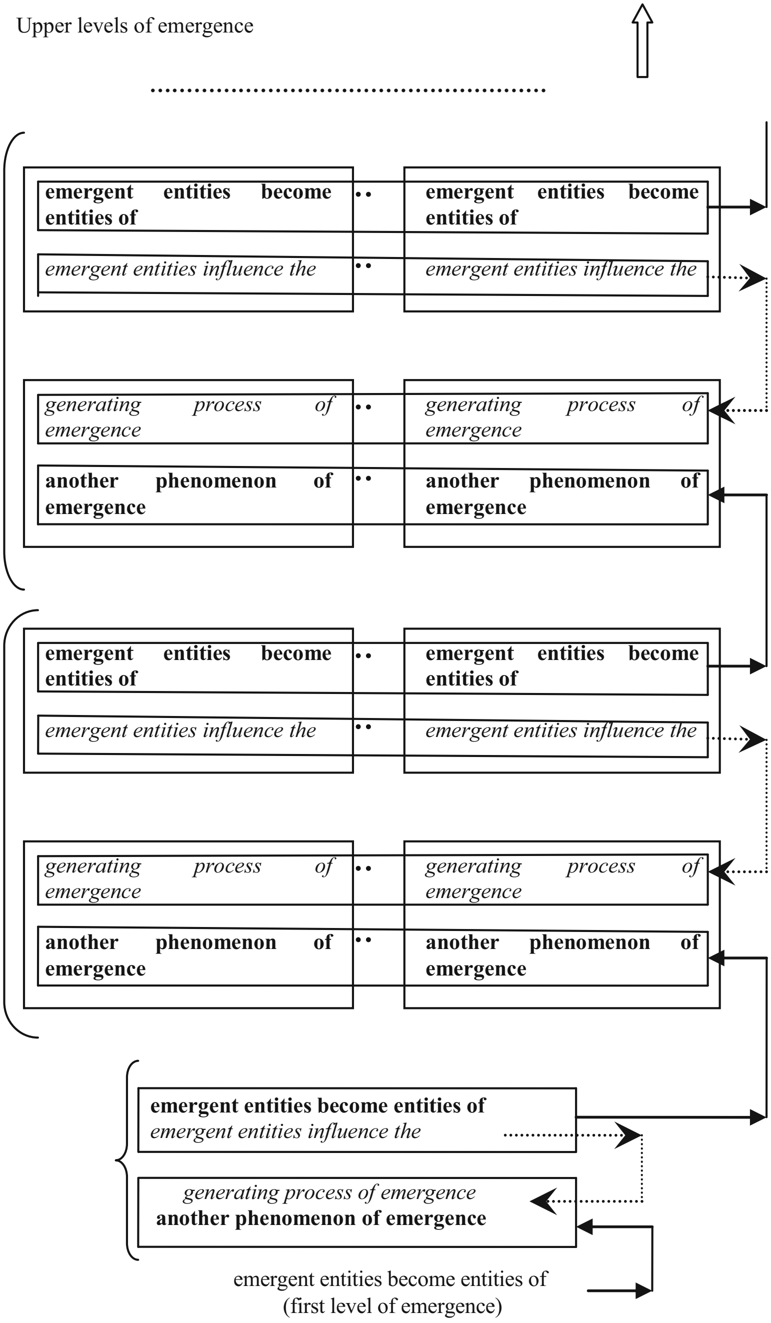
Why and how at certain levels of emergence a new one is established (restored *or* non-previously existent)? What starts the process? We consider in the following some possibilities.

- Saturation

Is it possible to consider that single specific levels of emergence acquire a kind of *saturation asymptotical level* after which a new level of emergence occurs in conceptual equivalence with sequences of curves as in Fig. 7.2 (see, for instance, Minati, 2012; Minati & Pessa, 2006, pp. 326–334)?

In Fig. 7.2 the change between a level of emergence and the subsequent one is denoted by ***f***. In the figure it represented the case when there is partial simultaneity between the ending of validity of one level and the starting of the following one.

We are considering here internally generated perturbations due to generic forms of saturations, like the decreasing, for any reasons, of *iterations*, i.e. repetitions of same actions and roles. *Saturation* may occur for different reasons like reaching critical dimensions (changing of pattern) and energy consumption to keep *same* coherence(s).



Schema 7.5 Multiple *mutated* emergences

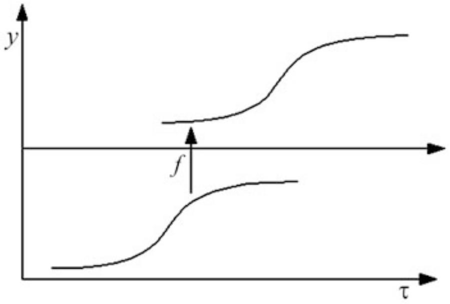


Fig. 7.2 Hypothetical sequencing of levels of emergence, where τ denotes time and y the levels of emergence

- Environment

Other reasons for the *emergence of new levels of emergence* may be related to the environment and given by perturbations of any kinds like noise-induced phase transitions, noise-activated transitions between attractors, in metastable systems and decoherence in quantum phenomena.

External perturbations *challenge* emergence for keeping the same coherence. Such keeping may reach *unsustainable* (e.g. ways to interact and energy consumption) levels asking for the establishment of a new level.

- *Emergence within* the same level

Another possibility is given by the occurring of eventual even partial simultaneous processes of emergence *within* the same level. Such simultaneous processes of emergence may in turn be interacting, influencing each other, and give rise to an upper level of emergence. As discussed above populations of processes of emergence of this kind are usual within living systems, while *combinations* of different kinds of emergences occur in the brain by combining multiple neurological and cognitive aspects (Kelso, 2012; Tognoli & Kelso, 2014).

We mention that in economics emergence of processes of development can be considered as acquisition of coherence within populations of growth – in reality positive or negative (Latouche, 2009) – processes where *jumps* from one growth curve, e.g. logistic, to another one are made possible, for instance, through scientific discoveries and technological innovations (see, for instance, Minati, 2012; Minati & Pessa, 2006, pp. 323–336). *Such jumps correspond to mutations considered above*. The population of growths is heterogeneous, establishes coexistence and dynamical, eventually local and temporary, combinations from which a single or new levels may emerge.

The possibility of such *combination* was not considered, for instance, by Thomas Kuhn dealing with *scientific revolutions* intended occurring with the introduction of substitutive, radical innovations and technologies and ignoring possible multiple coexistence of paradigms (Kuhn, 1962).

It should relate to a possible dynamics of levels of emergence not suitably reducible to fixed structures, like hierarchical or networked.

This case conceptually corresponds to the *dynamic structures* considered above in Chap. 3. Several conceptual scenarios are possible characterizing the post-GOFS.

7.2.3 Multiple-Way Causations

In the conceptual framework introduced in previous Sects. 7.1.1 (Bottom-Up and Top-Down Emergence) and 7.2.2 (Multiple Emergence), we can consider possible intra-level specifications of the directional lines of the Schema 7.5.

Usual approaches focus on bottom-up effects to model self-organization and emergent processes.

As considered above there is increasing interest on considering top-down effects and causality when acquired emergent properties influence the level where the generating processes of emergence occur.

In the simplest case, they can be considered as *separated* or almost conceptually *separable*, occurring one at a time and having well-defined starting and ending instants.

However, this is a simplified, reduced understanding of their complexity. We must figure to deal with *systems* of bottom-up and top-down causality, when they are multiple, partial and dynamically composed. The usual, *non-explicative* approach used to deal with them has *statistical* nature.

However, we think that the post-GOFS will use representations and models suitable to deal with the global, emergent rather than summative or averaged effects. Properties of network or meta-structural representations will define a new kind of macroscopic level of emergence when actions will be considered on such properties rather than on their *causes*. *The new problems will be, for instance, how to* ***vary*** *the topology of networks, their scale invariance, meta-structural properties and regimes of validity*.

7.3 Further Remarks

We may consider first of all that the entire chapter is pervaded by the effectiveness and importance of the *softness* – non-explicit, non-*analytical* actions – for complex systems as discussed above in its various aspects like changing levels or weights for neural networks. The *soft multiplicity* of complex phenomena should be respected not intended as a limit to our approaches, but as aspects of any strategy to be assumed to be *effective* with complex systems that cannot *suitably* process analytical interventions as *orders* and *prescriptions*.

Such conceptual softness is often coupled with multiplicity and specifically with multiple roles like for the RNA in gene regulation in this early stage of evolution (Sharp, 2009).

From the sections of this chapter, we tried to give evidence of the expected nature of the new post-GOFS.

Besides the outlined characteristics coming from the limits of GOFS and systemic disciplinary advancements, the challenge is the identification of a possible unitary conceptual framework and suitable formalization. Could we still expect properties come as *theorems*? Could we still *demonstrate*? See Chap. 5.

We expect to deal with *meta-levels* when *multiple emergences* ask not only for dealing with multiple structures and coherences, but with changing as *mutations*, non-equivalences, non-separability, appearance and disappearance of entities, all concepts proper, for instance, to QFT.

The crucial question is the eventual distance between post-GOFS and QFT when '…… a variety of phenomena are also observed where quantum particles coexist and interact with *extended macroscopic objects* which show a classical behaviour, e.g., vortices in superconductors and superfluids, magnetic domains in ferromagnets, dislocations in crystals and other *topological defects*, fractal structures and so on' (Blasone et al., 2011, p. *x*).

What is the meaning of the coexistence of classical and non-classical? Is such coexistence the domain of the new systemics theoretically oscillating between the two aspects never reducible one to the other as real source of irreducible complexity? The dynamics of this coexistence and of the transience is expected to be subject of the new systemics.

Box 7.1: Dissipation

Ilya Prigogine (1981, 1998), Prigogine and Nicolis (1967) introduced the term 'dissipative structures' referring to situations of *coexistence between change and stability*. A simple dissipative non-living structure is a vortex in a flux of running water: water continuously flows through vortex but its characteristic funnel shape shrinking in spiral is kept. The same kinds of structure are the ones manifested by atmospheric phenomena such as hurricanes. It is interesting to note how an established dissipative system needs constant flux of matter from outside. Analogously a living dissipative structure needs a constant flow of matter, as air, water, food and, in certain cases, light. Moreover, networks of metabolic processes keep systems far from thermodynamic equilibrium, i.e. thermodynamic death.

This attribute qualifies a system where energy dissipation, concomitant with non-equilibrium conditions, allows the emerging of ordered structures. Stability of dissipative structures does not come from low entropy production (intended as an index characterizing system microscopic disorder: entropy growth evidences a trend towards a more disordered phase – e.g. from ice to liquid, gas phase), but from the ability of the system to transfer to its environment a large amount of entropy.

As these systems are far from thermodynamic equilibrium, they are able to dissipate the heat generated to support themselves, so as to make emergent ordered configurations, i.e. to allow processes of self-organization. They are systems containing as well continuously fluctuating subsystems able to give rise to new organizations: such moments are said to correspond to *bifurcation*

(continued)

Box 7.1 (continued)

points (see box 5.1) and it is impossible to previously establish if the system will degenerate in a chaotic situation or it will reach a higher organizational level. In the last case *dissipative structures* are established. The attribute is related to the fact that they need more energy to be kept and that their keeping is exactly limited by their ability to dissipate heat. In a sense, a dissipative structure arises as an exact balance between the dissipation (e.g. under the form of diffusion) and the nonlinearity enhancing the inner fluctuations.

Box 7.2: Power Laws

If the behaviour of a phenomenon varies as a polynomial function of one of its attributes, e.g. dimension or number of nodes in networks, then it is said to follow a power law. For instance, the number of cities varies with the size of their population. A generic power law is $f(x) = x^k$.

Let us consider the example above when:

- x refers to the size of the population.
- f assigns the number of cities possessing that population.
- k is a constant.

The scale invariance of such a power law is given by the fact that if x scales for a parameter q, we have.

$f(qx) = (qx)^k = q^k f(x)$.

This is the case in biology for the relation between metabolic rate (B) – energy expressed in watts consumed by an individual at rest in the time unit – and the body mass (M) of living organisms. If we consider f to assign the metabolic rate to individuals with mass M, we have $f(M) = M^{3/4}$ valid for living organisms of any size apart from a coefficient of normalization. The same type of relationship is found for the mass of bodies with respect to blood circulation, considering the number of heartbeats per minute (Schroeder, 2009).

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Chapter 8
Network Science as New Systemics

Contents

8.1 Network Science

Starting from the last years of the past century, the number of papers and books using, within the most different scientific domains, the networks as the main conceptual tool undergo a fast growth. This circumstance allowed the introduction of the generic name of *network science* (see, for instance, Barabási & Pósfai, 2016; Lewis, 2009) to denote a number of contributions having in common the fact of using the mathematical machinery of graph theory as well as of its consequences. The interest in the network science was justified by the fact that its methods allowed to obtain new and interesting results regarding *collective systems.*As well known, this expression denotes systems made by a large number of reciprocally interacting basic units, whose study is often very difficult by resorting to traditional mathematical tools. Despite that, the tools of network science allowed, since the first papers, not only to characterize the possible dynamical evolution of some kinds of collective systems but also to forecast in advance their survival ability in the presence of damages and their usefulness as supporters of information transmission.

In this regard, it is to be remarked that the interest in collective systems, yet stimulated at the beginning of the systemic approach by cyberneticians like William Ross Ashby, Heinz von Foerster, Gordon Pask and Stafford Beer, received an exceptional impetus by Hermann Haken owing to its introduction of *Synergetics* (among the large number of books authored by Haken we limit ourselves to quote Haken, 1983, 2006, 2012). Namely, he showed that concepts like self-organization and emergence, rather than being a concern only for physicists and engineers, could

G. Minati, E. Pessa, *From Collective Beings to Quasi-Systems*, Contemporary Systems Thinking, https://doi.org/10.1007/978-1-4939-7581-5_8

be the subject of a unified scientific approach, regarding a lot of different disciplines, including chiefly the biology, the economics and the social sciences, that is domains linked to traditions and conceptual tools extraneous and very far from the ones of physics. In other words, the synergetics broke the old artificial barriers between disciplines, allowing to consider the problems, for instance, of biology as regarding with every right also the physicists, just because the methods and the concepts of synergetics were endowed with a universal valence and an unlimited number of possible applications. Despite the fact that the official birth of synergetics dates to the years around 1970–1971 (see for more details about the early years of this scientific development; Kröger, 2016), the very fast growth of this domain gives evidence of the fact that the ideas underlying synergetics' disclosed points of view and opinions about complex systems shared by many different researchers already before the official date of the first paper. Thus, when Stuart Kauffman introduced his first model of genetic regulatory network (see Kauffman, 1969), based, rather than on a plethora of strictly biological details, on a network deriving from the old artificial intelligence pioneered by McCulloch and Pitts, most researchers were already adapted to the new style of scientific work fostered by synergetics. The Kauffman model was suddenly taken into consideration, studied and expanded and became the primogenitor of a series of models (the Boolean networks; see, for instance Aldana-Gonzalez, Coppersmith, & Kadanoff, 2003; Balleza et al., 2008) still investigated by many scientists. Besides, the fact that the model was based on a network contributed to diffuse the idea that the concept of network could be a powerful tool to deal with the problems of biology. This idea was then reinforced by the further success obtained by applying network-based algorithms to other problems of genetics (see, for instance, Albert & Othmer, 2003).

But, in the same period – the last decades of the twentieth century – a large group of researchers, trying to implement the approach of synergetics to the study of complex systems, became to resort to network-like representations in order to achieve important results concerning a plethora of systems of different nature (not only biological). Among the names of these researchers – mostly physicists or applied mathematicians – we can quote Bernardo Huberman, Steven Strogatz, Duncan Watts, Mark Newman and Albert-László Barabási. The obtained results were concerning, among the others, the World Wide Web, the Internet, the movie-actor collaboration network, the science collaboration graph, the web of human sexual contacts, the cellular networks, the ecological networks, the phone call networks, the citation networks, the linguistics, the power distribution networks, the protein folding and the brain neural networks. What is important is that in all cases the interpretation of the system under study did not matter, because the results were a byproduct of the use of mathematical graph theory and of a branch of statistical physics known as *percolation theory* (classical textbooks are Bollobás & Riordan, 2006; Grimmett, 1999; see also Bunde & Havlin, 1996; Saberi, 2015). This circumstance suggested to a number of people that the network science could represent a sort of generalization of *General System Theory* and – perhaps – the principal tool for the study of complex systems.

However, despite the successes so far obtained by the network science when applied to the study of complex systems, its recent developments seem to point towards the need for a consistent widening and complexification of its methods and concepts. This fact induces, on one side, to formulate some doubts about the pretension of universality of network science itself and, on the other side, to ask ourselves what could be its intrinsic limits. In order to have at our disposal enough arguments to deal with these questions, we will introduce in the next section some preliminary notions about graph theory and its techniques.

8.2 Complex Networks and Graph Theory

Even if we still lack a universal consensus about the definition of 'complex system', undoubtedly most researchers would consider the collective systems quoted in the previous section as particular cases of complex systems. Therefore they would generally held that using the mathematics of graph theory is the right choice when dealing with these systems. And the supposition of a symbiosis between these two concepts – complex network and graph theory – has been, like mentioned in the last section, the principal cause underlying the fast development of actual network science.

As expected, this fact has been related to the appearance of a large number of excellent books and review papers concerning both complex networks and the main aspects of graph theory (here we will limit ourselves to quote only a restricted number of references, such as Albert & Barabási, 2002; Arenas, Díaz-Guilera, Kurths, Moreno, & Zhou, 2008; Barrat, Barthelemy, & Vespignani, 2008, Barzel & Barabási, 2013, Boccaletti, Latora, Moreno, Chavez, & Hwang, 2006; Börner, Sanyal, & Vespignani, 2007; Cohen & Havlin, 2010, da F. Costa, Rodrigues, Travieso, & Villas Boas, 2007; Dorogovtsev & Mendes, 2003; Estrada, 2011; Newman, 2010; Newman, Barabási, & Watts, 2006; Pastor-Satorras & Vespignani, 2004).

Let us now start our short description of the contribution given by graph theory by remarking that, like occurring in a number of mathematical theories, the graph theory can be approached from two different points of view, which we will denote as *explicit* and *implicit*. More precisely, the explicit point of view is focused on a set-theoretical description of a particular graph, while the implicit point of view tries to characterize the general properties which originated a graph or a particular class of graphs. Thus, by adopting the explicit view, the simplest definition of a graph G identifies it with two sets N and L, so that we can write $G \equiv (N, L)$. The elements of N are usually called *nodes* (or *vertices*), while the elements of L are pairs of nodes (often called *links* or *edges*). This definition is so generic that we can, of course, identify a graph with a network, but without the previous definition giving some further information on the network itself. This induced to introduce further constraints on the previously quoted sets, so as distinguish between different classes of networks. For instance it is common to assume that the set N has an integer cardinality. Another possible constraint consists in assuming that L can contain only ordered pairs of nodes. In this case one speaks of *directed* graphs or *directed* links. In other cases it appears as more convenient to associate to each link a numerical value called *weight*.

It is evident that, dealing with particular kinds of networks, the explicit view allows to associate to them specific numerical characterizations, all deriving from particular computations. This elementary fact, however, raises considerable problems when the cardinality of N becomes very large or even tends to infinity. Namely, in these cases, it can occur that many practical computations cannot be performed because the computing tools work under their operating limits. This circumstance introduces some sort of unreliability in the assessment of the numerical characteristics of many networks, because the values of these characteristics are often obtained through different kinds of probabilistic arguments rather than through direct computations. In other words, in most cases we cannot consider the concrete networks as *existing* and *entirely known* entities, because their characteristics are only poorly knowable, and the structure itself of the network under consideration is nothing but the result of an hypothetical reconstruction based on suitable algorithms (for further details about the related mathematical and statistical problems see, for instance, Clauset, Moore, & Newman, 2008; Leskovec, Chakrabarti, Kleinberg, Faloutsos, & Ghahramani, 2010; Leskovec & Faloutsos, 2006; Lovász, 2012). This circumstance raises some doubt on the convenience of the identification of network science with the best form of General System Theory. Namely, within the history of systemics, it rarely happened that systems were not treated as knowable entities, and also in these special cases, the problem was dealt with by introducing suitable (and well-defined) constraints. On the contrary, a number of (typically very large) networks are only mathematical constructions based on our confidence on specific probabilistic criteria, a circumstance which makes the characterization of a network more similar to a bet than to a scientific measurement.

Now, continuing to adopt the explicit view and limiting ourselves to undirected graphs, we can easily introduce a square matrix $A \equiv (a_{ij}), (i, j = 1, \ldots, N)$ whose generic element $a_{ij} = 0$ if $i = j$ and $a_{ij} = 1$ if there is a link connecting the node i with the node j, while $a_{ij} = 0$ if this link is not present. Such a matrix is often called *adjacency matrix*. Of course, the previous definition presupposes that a node cannot have multiple links with another node nor a link with itself. Moreover, if $a_{ij} = 1$ the two nodes i and j are said *adjacent* or *neighbours*. Another quantity which can characterize the undirected graphs is the *degree* of a node, defined as the number of links connected with the node itself. Often the degree of the node i is denoted by k_i and can be related to the adjacency matrix by the simple formulae:

$$k_i = \sum_{j=1}^{N} a_{ij} = \sum_{j=1}^{N} a_{ji}$$

The *average degree* of a network is the average value of node degree for all nodes present in the network. Sometimes it is denoted by $\langle k \rangle$. Obviously the characteristics of undirected graphs previously quoted can be easily generalized to the case of directed graphs. However, for the sake of brevity, we will not dwell upon these details.

Once introduced the concept of node degree, it is natural to introduce also the concept of *degree distribution*, denoted by $P(k)$ and defined as the probability that a node of the network, randomly chosen from a uniform distribution, has the degree k. Of course, once computed a degree distribution for a given network (a problem which, as we already remarked, is very difficult to solve when we deal with large graphs), it is possible to define its *n-th moments* through the simple formula:

$$\langle k^n \rangle = \sum_k k^n P(k)$$

We notice that the latter quantities are very useful in order to characterize a number of important properties of networks.

Before ending this first introduction to graph theory, we remark that, generally speaking, a network can contain pairs of nodes which are not adjacent. In these cases, it could become possible to connect two nonadjacent nodes through an alternating sequence of links between adjacent nodes. If this situation occurs (a circumstance which, in principle, is not compulsory and depends on the type of network taken into consideration), then the sequence defines a *walk* (of length m if this is the number of used links). A walk in which no node is visited more than once is called *path*. A path of minimal length between two nodes (when existing) is often called the *shortest path* between them. The concept of shortest path allows to introduce the concept of *average shortest path length*, defined as the mean of the shortest path length over all possible pairs of nodes.

8.3 Network Typology

Before giving further information on graph theory, it is important to remember that the implicit view allows to group the possible networks into a number of categories, related to the general properties characterizing the network themselves and to the motivations underlying their introduction. Among the most popular categories, we quote the one of *random networks*, characterized by undirected links and, therefore, absence of weights, but in which the links are chosen randomly. The typical representative of this category is the *Erdõs-Rényi* network in which a network with N-labelled nodes is defined by randomly choosing each link from the repertoire of $N(N-1)/2$ possible links. Another possible way for building a random network consists in starting from an initial set of N nodes and then connecting with a probability p each pair of nodes with a link. It is to be remarked that a consistent part of our knowledge about network theory comes from the study of random networks. Unfortunately many other interesting networks belong to different network typologies, so that often the results obtained on random networks cannot be easily generalized.

The list of different network categories is, unhappily, very long. Thus, we must limit ourselves to mention only some well-known examples by referring the reader, for further details, to the quoted bibliography. This short presentation starts with the category of *artificial neural networks*, owing to their large and ubiquitous use in many domains of science and technology (the high number of excellent textbooks concerning this topic prevents us from an exhaustive quotation, so that we will limit ourselves to mention Bishop, 1995; Du & Swamy, 2014; Goodfellow, Bengio, & Courville, 2016; Rojas, 1996). The strong difference between neural networks and other categories of networks more popular within network science stems, on one side, from the fact that each node is a dynamical system (often designed in such a way as to imitate the dynamical behaviour of biological neurons) and, on the other side, from the fact that also the links – and the associated weights – are endowed with a variability strictly related with the global interactions between the network and the external environment. In other terms, a neural network is a very complex dynamical system whose study largely overcomes the possibilities offered by traditional mathematical tools, as evidenced by the fact that their computational power is greater than traditional Turing one (see Cabessa & Siegelmann, 2012; Siegelmann, 1998).

The fact that the biologically inspired networks give rise to very complex and often intractable models is typical not only of neural networks but also of other networks, describing artificial systems designed by exploiting biological analogies. A first example is given by *artificial immune systems*, which are machine learning systems inspired by the principles and processes used by the vertebrate immune system (see, among the others, de Castro & Timmis, 2002; Tan, 2016; Timmis, Hone, Stibor, & Clark, 2008). We remark that in both cases of neural networks and artificial immune systems, the design philosophy has been the one of starting from an already existing *natural* system translating its features into a man-made *artificial* system. However, such a philosophy has been in some cases reversed. An example is given by the so-called *molecular machines* (see, e.g. Balzani, Credi, & Venturi, 2008) in which the features typical of a man-made machine have been translated into chemical entities (partly already present in the natural realm) to implement artificial machines working on a molecular-level scale. These systems gained a large popularity owing to the award of Nobel Prize in Chemistry 2016 to Jean-Pierre Savage, Sir James Fraser Stoddart and Bernard L. Feringa for the design and synthesis of molecular machines.

A category of networks in which the features of *natural* systems gave rise to different kinds of applications is the one of the so-called *swarm models*. Namely, while on one side this expression has been used to denote the mathematical models of animal collective behaviours (see, for instance, textbooks like Kagan & Ben-Gal, 2015; Murray, 2002, 2003; Okubo & Levin, 2001), on another side, the same expression has been often used (under the label *swarm intelligence*) also to denote computational methods used in artificial intelligence and inspired by our knowledge about the different forms of animal intelligence (see, e.g. Saka, Doğan, & Aydogdu, 2013; Yang & Karamamoglu, 2013). Each of the two different applications is associated with a specific kind of mathematical tools. Namely, while biologically oriented swarm models are formulated in terms of continuum models based on partial differential equations or integro-differential equations (a typical example can be found in Mogilner & Edelstein-Keshet, 1999), the swarm intelligence models are often concerned with optimization problems and the associated mathematics, sometimes requiring discretization procedures. The features so far mentioned allow to understand that, whatever can be the inspiration behind the introduction of these networks, they are characterized by a complexity which seems to overcome one of the networks traditionally taken into consideration by usual network science. This circumstance is concomitant with the fact that the use of principles and methods of network science often regards categories of networks introduced in a more abstract or schematic way, neglecting the requirement of biological realism. Two important examples of networks belonging to these categories are given by *cellular automata* and *coupled maps*.

As regards cellular automata, they constitute a so widely known topic that is enough to remind that they are mathematical models evolving both in discretized space and time, first introduced by von Neumann in the 1950s. A typical cellular automaton is characterized by a set of *cells*, each one associated with an instantaneous *state* value, located within a suitable geometric and topological environment, a *neighbourhood law*, stating what cells are neighbours of a given cell, and a *transition rule*, stating how to compute the state of a cell at time $t + 1$ as a function of the states of its neighbours at time t. The bibliography on cellular automata is, of course, so rich that we must limit ourselves to few titles like Adamatzky, 2010; Ilachinsky, 2011; Hadeler & Müller, 2017; Schiff, 2011. For what concerns the coupled maps, they have been already described in Chap. 3 of this book. Here we limit ourselves to add that these networks can be considered as particular cases of more general kinds of networks allowing random as well as noisy interconnections between elements, a circumstance which gives rise to very interesting dynamical behaviours (see, for an example, Jalan, Amritkar, & Hu, 2005; Manrubia & Mikhailov, 1999; Manrubia, Mikhailov, & Zanette, 2004).

We close this section on possible network typologies by two main considerations. The first one deals with the obvious fact that, owing to the intrinsic complexity of many networks, a reliable information about their properties and their behaviours can be obtained, in the majority of cases, only by resorting to numerical computer simulations. While the latter are supported by consistent arguments coming from statistical physics, we must acknowledge that a proof method based on simulations is at least far from the traditions holding in physics and mathematics. And this circumstance yet raises some doubt on the possibility of considering network science as the best candidate for building a new systemics. The second consideration deals with the usefulness of the results obtained by network science. Namely, they often derive from the study of particular networks, whose individual features play a very important role in explaining their behaviours. However, if we shift from a particular network to another different network, all could change. In other words, is a collection of individual network features useful? As it is well known, scientific research searches for some sort of *universality*. But what results of actual network science are universal? Despite some recent attempts towards this direction (Barzel and Barabási, 2013; Cardanobile, Pernice, Deger, & Rotter, 2012), it seems that in network science we find less universality than in physics of condensed matter, where at least some very general findings are available.

8.4 Simple Static Networks

In order to give concrete examples of the achievements of network science which raised the interest of scientific community in this domain, we shortly remind some notions concerning the most known static network models. They will be preceded by a list of some topological network properties, useful to better understand the later model descriptions.

This list starts with the *average shortest path length*, already quoted in Sect. 8.2. Another important topological network property is measured by the *clustering coefficient*. Its computation requires a previous definition of the *local clustering coefficient* of a given node, measuring the probability that each pair of neighbours of the node be in turn made by neighbouring nodes. In other terms, the local clustering coefficient is the ratio of the number of existing links connecting to each other, the neighbours of the considered node to the maximum a priori possible number of such links. Owing to the fact that, in general, the maximum possible number of links between N nodes is given by $\frac{N(N-1)}{2}$, it is easy to deduce that the local clustering coefficient of the node i, denoted by C_i, can be obtained through the formula:

$$C_i = \frac{2e_i}{k_i(k_i-1)}$$

where k_i is the number of neighbours of the given node and e_i is the number of existing connections between these neighbours. Then the global clustering coefficient of the whole network, denoted by C, is given by the average of the local clustering coefficients of the single nodes.

A further topological property is characterized by the fact that some networks have a small value of average shortest path length while, at the same time, they have a high value of global clustering coefficient. Such a property is called *small-world property* and has been introduced in 1998 by Watts and Strogatz in a celebrated paper (Watts & Strogatz, 1998). The name of this property comes from the one attributed by these authors to a network model which will be described later. The last topological property we included in our list is the *scale-free* degree distribution. It consists in the fact that that in some networks, the statistical distribution of the node degrees has a dependence from the degrees themselves represented by a power law that is given by a law like:

$$P(k) \approx A\,k^{-\gamma}$$

In many cases, the value of exponent γ lies within the interval between 2 and 3.

Our short presentation of some simple static networks now begins just with the typical network endowed with the small-world property quoted above: the *small-world* model (see also, besides the Watts and Strogatz paper quoted before, Watts, 1999). Here, rather than discussing the possible advantages produced by the simultaneous occurrence of the small value of average shortest path length and of the high clustering coefficient (related to the robustness of this network to perturbations), we will focus on the method for building this network, starting from an initial configuration of linked nodes and proceeding to add new links according to a given rule. The original procedure introduced by Watts and Strogatz starts from N nodes located on equidistant positions in a ring. Each node is symmetrically connected to its $2\,m$ nearest neighbours (here each node has a fixed number m of neighbours in both clockwise and counterclockwise directions, where m is a parameter of the building rule). Then, for every node, the link connecting it to a clockwise neighbour is rewired to a new, randomly chosen, node with a probability p, where p is another parameter. Of course, this implies that, with a probability $1-p$, the link is preserved. When $p=0$, this rule produces a regular lattice, while when $p=1$, it produces a random graph. Values of p intermediate between 0 and 1 give rise to a small-world network.

Another category of simple static networks is the one of *scale-free networks*, characterized by the fact that all networks belonging to this category have a scale-free distribution. There are many different methods for building a scale-free network, among which we will focus on the simple rule introduced by Goh et al. (see Goh, Kahng, & Kim, 2001). The building process starts from an initial set of N nodes. To each node i, we associate a weight $w_i = i^{-\alpha}$, where α is parameter chosen in the interval $[0, 1)$. Then the process starts by selecting pairs of nodes within the initial set. Each member of the pair is associated with a choice probability given, for the i-th node, by $w_i / \sum_{l=1}^{N} w_l$. Once selected a pair, it is connected by a link provided there is not an already existing link between the two pair members. The process is repeated m times so as to obtain mN links. When $\alpha=0$, this procedure gives rise to a random graph, while when $\alpha \neq 0$, we obtain a network whose degree distribution has the form $P(k) \approx k^{-\gamma}$, where $\gamma = 1 + \frac{1}{\alpha}$.

The last model we will describe is based on an *evolving* network, in the sense that the number of both nodes and links is not fixed but changes with time as a function of a growth process. Even if this model cannot be considered as static, nonetheless we will describe owing both to the fact that it is well known (mostly because inspired to the formation of the World Wide Web) and to the fact that it introduces some primary growth rules and then used in a number of other models of evolving networks.

This model is known as *Barabási-Albert* model. It has been introduced in 1999 by Albert-Lászlo Barabási and Réka Albert in a famous (and sometimes discussed) paper (see Barabási & Albert, 1999). The building of this network model starts from an initial number of nodes and links and follows an iterative rule which, at every step, adds a new node. The latter is connected to the previously existing nodes according to a criterion called 'preferential attachment'. It is realized by introducing, for each already existing node i, a probability p_i of attachment of the new node to it given by a law of the form:

$$p_i = \frac{k_i}{\sum_j k_j}$$

where k_i is the degree of the node I and the sum regards all previously existing nodes. This law rewards the nodes with higher number of links, which receive even more links, while nodes with few links tend to be neglected. When the number of steps of this algorithm tends to infinity, the degree distribution tends to a scale-free form given by:

$$P(k) \approx k^{-3}$$

In this model, the clustering coefficient C scales with network size according to a law of the form:

$$C \approx N^{-0.75}$$

We remark that this circumstance shows that this model differs from small-world model, where the clustering coefficient is constant and independent from network size.

Since its first introduction, a number of researchers criticized the Barabási-Albert model for its lack of flexibility (there is only a particular value, i.e. 3, of the exponent of degree distribution) and the neglect of further rules allowing to manage the clustering coefficient. Besides, in some cases, the model predictions do not agree with experimental data about particular kinds of real networks. This circumstance stimulated the introduction of a consistent number of different variants of the original model (extended descriptions of these latter can be found in Boccaletti et al., 2006; Cohen & Havlin, 2010; Newman, 2010; van der Hofstadt, 2017).

The simple models so far described in this section allow to understand, by making a comparison with the typology of possible networks mentioned in the previous section, that these networks are too simple to be directly applied to the huge world of different networks existing within science, technology and real life. However, the new systemics seems more interested, rather than in the application of network models to concrete cases encountered in the world, in assessing up to what point the network science can constitute a better approach, with respect to the traditional mathematical tools so far used in physics, biology, economics and social science for dealing with complexity and, chiefly, emergence processes. The problem of this assessment will be dealt with in the next section, which will also give a conclusion to this chapter.

8.5 Conclusion: Is Network Science the Privileged Tool for Dealing with Emergence Processes?

Before starting our discussion, we remind that the actual network science includes a large number of different models, most of which are far more complex than the ones described in the previous section. The study of these models engaged a very large number of researchers and required a lot of sophisticated mathematics, which will not reviewed here, essentially because any information concerning it can be found in many textbooks and review papers, partly quoted in the bibliography attached to this chapter. Besides, these models have been applied to deal with a number of practical issues. Among these latter, we can list error and attack tolerance; epidemic spread; cascading failures; congestion in communication; synchronization in collective systems; opinion formation in social systems; structure of the Internet and the World Wide Web; metabolic, protein and genetic networks; brain structure; and dynamics. In most cases, the models and their applications, even if using discrete mathematics, have been partly expressed in terms of continuum mathematics, allowing to use familiar tools such as differential equations. This interchange between discrete and continuum has been, in some cases, supported by suitable transformations or mappings and/or new interpretations of used variables. Typical examples of this strategy can be found in the researches dealing with critical phenomena in complex networks (see, e.g. Bianconi & Barabási, 2001; Derényi, Farkas, Palla, & Vicsek, 2004; Dorogovtsev, Goltsev, & Mendes, 2008). Not only, but in the latter domain the researchers detected also the emergence of new forms of transitions regarding the complex networks (see Boccaletti et al., 2016) which have been evidenced only because the researchers themselves were interested in the network science. Moreover, we cannot here withhold the fact that within network science, people already introduced generalizations of the traditional network structures based on multilayered networks (see, among the others, Boccaletti et al., 2014; De Domenico et al., 2013).

The previous considerations suggest that the actual network science, rather than being an autonomous discipline endowed with specific methods, is nothing but a branch of physics (or, better, of condensed matter physics), sharing with theoretical physics all methods so far introduced. As such its usefulness in dealing with emergence phenomena appears similar to the one of actual theoretical physics. Of course, the seeming greater simpleness of some networks gives rise to useful reasonings only if we deal with systems which are enough simple. But the presence of a suitable complexity needs suitable conceptual tools, and the fact of adopting a network-like perspective does not eliminate the need of using them. In any case, a great merit of network science has been the one of shifting the attention of researchers towards the importance of the role played by *topological features* in heavily influencing the dynamics of a system. This is a very useful conceptual advance if we take into account that the first models of emergence have been based on arguments based on the dynamical features of systems evolution. Now the experience made in many domains, like biology, economics, sociology, psychology and architecture, showed that the emergence could be a product of the interaction between dynamics and topology. And it is just such a consideration that allows to assign to network science an important role in the future studies of emergence processes.

Box 8.1: Scale Freeness in Networks and Scale Invariance

Scale Freeness in Networks

A network (Barabási, 2002) is said to be scale free if the *distribution of degrees*, i.e. the probability that a node selected at random has a certain number of links, follows a power law without depending on scalar parameters of the structure. Such networks have a small number of nodes possessing a high number of links and a high number of nodes possessing few ~~of~~ links.

Examples are given by the Internet, metabolic networks, the network of blood and vessels.

The peculiarity of these networks is that, in processes of growth, the number of links of a node depends on a power law considering the number of existing links.

In contrast, networks with a defined scale are networks where each node has the same distribution of degrees, such as hypercubes.

Scale Invariance

There is scale invariance when properties are independent from the scales. Typical example is given by fractality, property of geometrical objects of repeating their structure in the same way on different scales. A rule applied recursively generates self-similar structures. The properties of fractals are scale-free.

The phenomenon of scale invariance is ubiquitous in complexity. For instance flocks have been detected to possess scale invariance (Cavagna et al., 2010). Phenomena may in turn possess local and multiple scale invariances.

Box 8.2: Small-World Networks

The term *small-world network* relates to a type of networks in which most nodes are not *neighbours* of one another, i.e. separated by one link only, but most nodes can be reached from every other by a small number of links or steps. More precisely in a small-world network, the typical distance L, i.e. the number of steps required to connect two randomly chosen nodes, grows *proportionally* to the logarithm of the number of nodes N of the network. Such networks possess a very high *clustering coefficient*, measure of the degree by which nodes of a graph are connected.

In such networks, there are a high number of *hubs*, i.e. nodes with a high number of connections – high-degree nodes.

Some examples are electric power grids, food chains, metabolite processing networks, social influence networks, telephone call graphs and voter networks. (Lewis, 2009.)

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Part II
Translation into Social Culture

Chapter 9
Translation into Social Culture

Contents

In this second part of the book, dedicated to the cultural meanings of post-GOFS, systemic concepts are considered as being almost *redefined* within the general conceptual frameworks outlined above. The main challenge relates to the conceptual *coexistence* between:

- Disciplines based more on a *disciplinary usage* of advanced systemic concepts;
- GOFS concepts and approaches resembling a *generic conceptual tissue* among disciplines;
- Interdisciplinarity based on *transversal* usage of models, simulations (Shiflet & Shiflet, 2014) and methodologies and popularizations allowing the usage of specialized terms in generic ways;

and the new emerging post-GOFS.

The crucial point is that the new post-GOFS concepts are almost *culturally* incompatible with currently used extensions and generalizations of GOFS concepts. Even worse, many economic sectors, education, public services and academic careers are based on the assumption of the effectiveness of these concepts. Thus it is important to develop emerging systems of interacting, overlapping combinations of processes and events which can be suitably related to GOFS and post-GOFS. In DYSAM-like terms, the *same* event or process may present different

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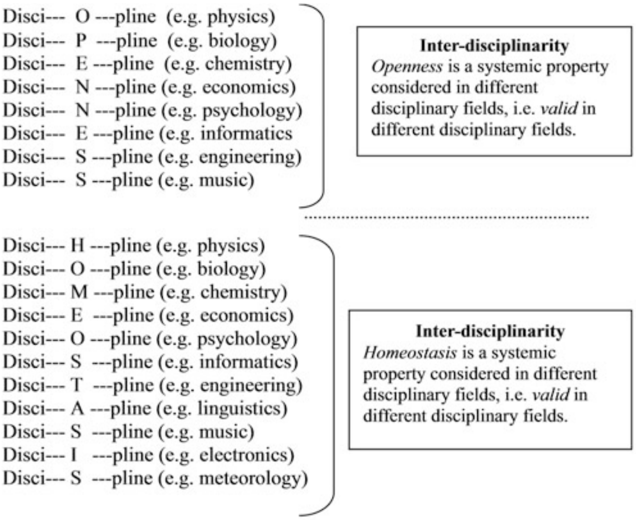
GOFS and post-GOFS aspects depending upon the context and the point in time in which it occurs. Post-GOFS systemics is not a kind of *innovation* or new technology. It brings to light the fact that science is a social enterprise contributing to changing the *general direction* of social systems and, as such, requiring and inducing sharing, interactions (collaborative or a hindrance may they be), decisions for investment, consolidation and diffusion at various social levels.

Of course, one welcomes the introduction of novel elements, such as electronics, which *extend* functionalities, or new molecules *extending* the effectiveness of drug actions, or new engineering solutions *extending* the effectiveness of services such as trains, cars and airplanes as well as *reducing* costs and levels of pollution, since they are comprehensible and have an acceptable, manageable and *compatible* level of perturbation.

However, one can also consider examples of *disruptive innovation* (Danneels, 2004), which displaces older technology, disrupting existing markets through substitution. Examples include digital photography replacing chemical photography and CDs and USB memory replacing floppy disks. Other cases relate to the birth of *new markets* such as that for mobile multifunctional phones. The use of innovations through the application of consolidated knowledge is ineffective even where there are cultural processes of adaptation, coexistence, *translations* of usages as well as usages made only in very *functional* ways, e.g. without knowing the working principles of a microwave oven, of magnetic resonance imaging (MRI) or of the Internet. This fits well with the consumerist approach which focuses upon markets of *unaware end users* and *foolproof* products. This corresponds to dealing with emergent post-GOFS situations through extending and deepening classical GOFS approaches where, conversely, the consumerist approach does not work since knowledge itself has to be completely and utterly changed. The challenge of post-GOFS is rather that of dealing, as in second-order cybernetics, with *changes in the rules* when representing, modelling, modifying, computing or simulating, including all the issues considered in part A of this book. This new approach claims that the main difficulty in meeting this challenge lies first of all *within* science itself. With reference to social systems, this chapter does not deal with *concessive*, possible or optional transformation – popularization – of advanced scientific concepts into social culture, nor does it consider the new post-GOFS as novel *directions of use*, but introduces a kind of virtual *social lab* in which it can invent new post-GOFS-based usages, meanings and *social invariants* coherently resonant at multiple levels of social culture.

The role of education is controversial from this point of view since teachers teach what they know, whereas the consumerist approach calls for new usages where comprehension is reduced merely to *directions for use*.



Disci--- O ---pline (e.g. physics)
Disci--- P ---pline (e.g. biology)
Disci--- E ---pline (e.g. chemistry)
Disci--- N ---pline (e.g. economics)
Disci--- N ---pline (e.g. psychology)
Disci--- E ---pline (e.g. informatics
Disci--- S ---pline (e.g. engineering)
Disci--- S ---pline (e.g. music)

Inter-disciplinarity
Openness is a systemic property considered in different disciplinary fields, i.e. *valid* in different disciplinary fields.

Disci--- H ---pline (e.g. physics)
Disci--- O ---pline (e.g. biology)
Disci--- M ---pline (e.g. chemistry)
Disci--- E ---pline (e.g. economics)
Disci--- O ---pline (e.g. psychology)
Disci--- S ---pline (e.g. informatics)
Disci--- T ---pline (e.g. engineering)
Disci--- A ---pline (e.g. linguistics)
Disci--- S ---pline (e.g. music)
Disci--- I ---pline (e.g. electronics)
Disci--- S ---pline (e.g. meteorology)

Inter-disciplinarity
Homeostasis is a systemic property considered in different disciplinary fields, i.e. *valid* in different disciplinary fields.

where:

- *Openness -thermodynamical* contrasted with *logical*, see Section 2.7- is a quality of systems when stationary equilibrium states can be established while system composition is constant in spite of continuous exchange of its component parts An open system tends to resist perturbations which tend to move it away from its evolution process. In open systems there is *permeability* between them and the environment, due to the fact that there is matter exchange, as typically happens with living systems.
- *Homeostasis* is a quality of a thermodynamically open system whose inner state does not change while its components and its environment are changing. Such a system keeps its inner state in a changing environment through internal adjustments and regulation. The process of homeostasis in living systems is performed by a number of self-regulating subsystems, such as the nervous and the endocrine systems.

Fig. 9.1 GOFS interdisciplinarity

9.1 The New Interdisciplinarity

The GOFS concept of interdisciplinarity is usually understood as the application of the same model from one discipline to another, with simple changes in the meaning of the variables, and where problems and solutions of one discipline become problems and solutions of another. More generally, interdisciplinarity is considered as the occurrence of the same systemic properties for systems established within different disciplines, as shown in Fig. 9.1. This GOFS interdisciplinarity is currently more and more integrated *within* disciplines.

However, interdisciplinarity (Bammer, 2013) can also be understood in a less rigid and simplistic manner: as the reformulation, for instance, of one problem into another, considered as being equivalent but with greater *treatability* such as from algebraic to geometric, from energy to social, from military to political and vice versa. Other cases of interdisciplinary approaches are given, for instance, when teaching a discipline through another one, such as teaching history using geography, mathematics using physics, sociology using urban planning and, of course, vice versa.

A new situation is outlined in this *mature* stage of GOFS where the concept of system *pervades* almost any discipline. The various disciplines, *islands* or shores to be not only inter*connected* by bridges, but visited and inhabited by interdisciplinarity, will no longer be the topics upon which systemics mainly focuses.

Thus, GOFS deals with *systemic properties* including adaptive, allopoietic, anticipatory, autopoietic, chaotic, deterministic, dissipative, equifinal, far from equilibrium, goal-seeking, homeostatic, open-closed, oscillating, robust, self-repairing and stable-unstable ones. As such, they are suitable for this interdisciplinary level of understanding. Post-GOFS, on the other hand, deals with categories of systems and systemic properties such as those established by collective systems, e.g. emergent and self-organized, network-like, coherent, meta-structural, multiple, quasiness-like, with time-limited validity, structural, critical and quantum-like. In short, post-GOFS deals with the *properties of families of systemic properties* as those listed above rather than merely with systemic properties themselves. *This corresponds to the collective and structural nature of the systems taken into consideration.*

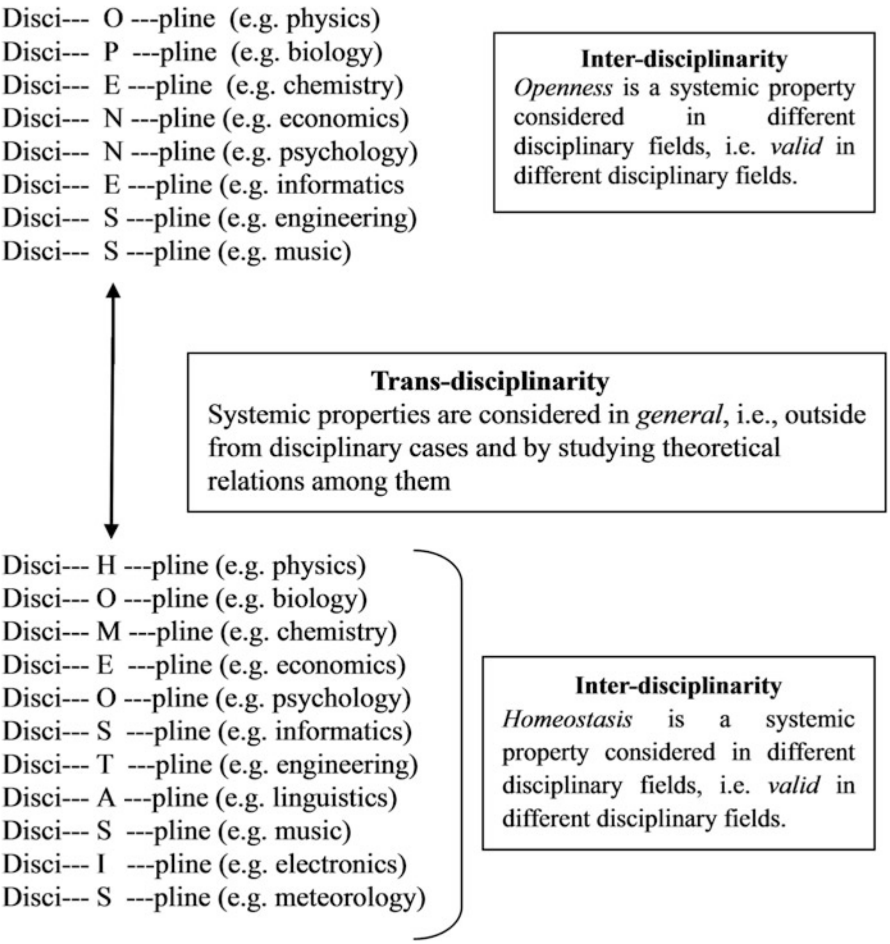
In post-GOFS, it is no longer a matter of disciplines, but of relations between categories of collective systems and systemic properties as in the simple case of couples:

- Quasi-emergence
- Multiple-transitions
- Quasi-multiple
- Multiple-quasi
- Coherent-multiple
- Emergence of quasiness

GOFS properties may eventually *re-emerge* as properties of categories of collective systems and systemic properties when, for instance, they are localized as for swarm intelligence becoming goal-seeking, processes of transition becoming chaotic and quantum phenomena when dissipative. This post-GOFS interdisciplinarity may be defined as *inter-collective systemic categories*.

9.2 The New Trans-Disciplinarity

The GOFS concept of trans-disciplinarity may be considered to occur when systemic properties, experienced and dealt with by disciplinary and interdisciplinary approaches (Repko, 2008), are studied per se. In this way, one can, for instance, study compatibility, interdependence and events occurring among such properties, as well as architectures, and their properties, of networked correspondences. Research at the trans-disciplinary level relates to properties of correspondence and analogies between models and representations. However, the study of properties of properties, their being systemic or not, is the focus of various approaches, as in computer science when dealing with categorizing and inquiring, or for ontology



Disci--- O ---pline (e.g. physics)
Disci--- P ---pline (e.g. biology)
Disci--- E ---pline (e.g. chemistry)
Disci--- N ---pline (e.g. economics)
Disci--- N ---pline (e.g. psychology)
Disci--- E ---pline (e.g. informatics
Disci--- S ---pline (e.g. engineering)
Disci--- S ---pline (e.g. music)

Inter-disciplinarity
Openness is a systemic property considered in different disciplinary fields, i.e. *valid* in different disciplinary fields.

Trans-disciplinarity
Systemic properties are considered in *general*, i.e., outside from disciplinary cases and by studying theoretical relations among them

Disci--- H ---pline (e.g. physics)
Disci--- O ---pline (e.g. biology)
Disci--- M ---pline (e.g. chemistry)
Disci--- E ---pline (e.g. economics)
Disci--- O ---pline (e.g. psychology)
Disci--- S ---pline (e.g. informatics)
Disci--- T ---pline (e.g. engineering)
Disci--- A ---pline (e.g. linguistics)
Disci--- S ---pline (e.g. music)
Disci--- I ---pline (e.g. electronics)
Disci--- S ---pline (e.g. meteorology)

Inter-disciplinarity
Homeostasis is a systemic property considered in different disciplinary fields, i.e. *valid* in different disciplinary fields.

Fig. 9.2 GOFS interdisciplinarity

as considered later, or when modelling processes as networks, as introduced in Chap. 8. Research at the level of properties of properties is at a more general and higher level of abstraction than disciplinary and interdisciplinary research, but *not independent* of them. If, on the other hand, trans-disciplinarity is considered as being *independent*, then it can be considered as being independent of applications, results and experiences developed at disciplinary and interdisciplinary levels. The purpose here is to establish *robust theoretical generalizations* (Minati & Pessa, 2006, pp. 445–446). If interdisciplinarity deals with a suitable reformulation of one problem as another, considered as equivalent, then trans-disciplinarity focuses upon *properties of reformulations* and their eventual correspondences.

The concept of trans-disciplinarity is illustrated in Fig. 9.2.

In post-GOFS, the level of abstraction of trans-disciplinarity is no longer limited to relating context-free systemic properties to their relationships, but can relate properties and relationships of *inter-collective systemic categories*. For instance, can phenomena represented by inter-collective systemic categories including those listed at the end of the previous section, in their turn, occur simultaneously within the same system? Do they occur with any regular sequences? Do rules of *incompatibility* exist? Are some combinations *essential*?

9.3 Knowledge for the Knowledge Society

From this section onwards, we deal directly with the challenge of transforming knowledge represented using post-GOFS, its application, problems and perspectives *into* general social culture. We are dealing with social systems which can generate very advanced knowledge which is *local*, both in usage and application, but which does not update the knowledge used to run the social system itself.

Natural languages (Kapetanios, Tatar, & Sacarea, 2013; Kumar, 2011) are intrinsically full of non-linear, contextual inheritances which can be used to represent and design new concepts and approaches rather than using the terminology of technological innovations. Such representations must be capable, in their turn, of representing breakthroughs. The case to which we refer has been studied for *post-industrial societies*, introduced through fundamental studies and research (Bell, 1973; Drucker, 1968, 1970, 1989), and then taken further by several researchers (Ramirez, Tixier, Heckscher, & Maccoby, 2003), and which emerged from the usage of advanced knowledge as their primary resource, but having a *generalized management* – of families, institutions and corporations – which was still based on pre- or GOFS concepts and approaches; see Sect. 2.6. Advanced knowledge is *used* for the production of advanced tools, entities and services but still *used with* the knowledge corresponding to social phases where such possibilities were not allowed (Minati, 2012). *GOFS knowledge* comprises all the concepts, approaches and problems presented in the previous chapters.

The crucial point is not given by any *wrongness* in the knowledge used, but by its *inadequacy* (Moeller, 2011) to deal with situations of acquired emergence possessing various types of properties. These inadequacy, inconsistency and incompatibilities between kinds of knowledge have been silently ignored and removed as the consumerist view focused on how to use, sell and artificially create needs to replace all in a *foolproof* way. It is possible to use technologies such as the Internet, point-to-point mobile communication (mobile phones), nuclear magnetic resonance (NMR), synthetic drugs and a large variety of services or tools without having a clue about their *functioning*. However, there is a kind of *continuity* between the levels of complexity characterizing disciplinary and technological post-GOFS knowledge and the levels of complexity characterizing *induced* social effects and properties such as economic, environmental, medical and military. Corresponding examples are given by the emergent properties of:

- *Development* in economics (Giugale, 2014; Nafziger, 2012; Ros, 2013), often confused through the use of pre-GOFS concepts of *growth* (Weil, 2013).
- *Climatic changes* (Fletcher, 2013) due, for instance, to pollution and energy consumption.
- *Health*, still considered by the *World Health Organization* as a 'state of complete physical, mental and social well-being and not merely the absence of disease or infirmity' from the Preamble of the Constitution of the World Health Organization as adopted by the International Health Conference, New York, 19–22 June, 1946, signed on 22 July 1946 by representatives of 61 states (Official Records of the World Health Organization, no. 2, p. 100) which came into force on 7 April 1948. This definition, using the concept of *state*, has remained without change.
- *Peace*, when considering peacemaking, peacekeeping and peacebuilding (Levine, 2014) as forcing an emerging property upon social systems. The case of *development* may be considered as (a) the property of a group of processes of positive, negative or zero growth when adopting and maintaining *proportionality* among them or (b) *sequences* of increasing processes of growth or, finally, (c) as an *emergent* property of *flock-like* processes of positive, negative or zero growth (Minati, 2012). These three kinds of processes may occur together by activating a continuously self-adjusting system as in the history of real economies depending upon external perturbations such as those due to globalization. Here, it is necessary to distinguish between *sustainable growth* and *sustainable development*: how to sustain development as a process of emergence? (Minati & Pessa, 2006, pp. 326–336). The lack of understanding of processes of emergence and acquired properties leads politicians and economists to insist on linear interventions, attempting to support and replicate processes of growth using financial tools to aid sectors of the economy experiencing difficulty due, for example, to *market saturation*, in turn due to a decline in the effectiveness of consumerism.

In the case of *climate change*, there are problems such as acid rain, air and water pollution, desertification, deforestation, global warming and melting of glaciers, greenhouse gas emissions, night sky pollution (light emission from artificial sources) and ozone depletion. This is not a list, but rather a set of interrelated negative properties acquired by the system Earth. They can be understood as a non-linear system of interacting causes and effects, as symptoms of climate change. Some of these are presumed to have occurred *naturally* during the history of the Earth due, for instance, to volcanic eruptions or possible external factors. Human-produced changes may be also considered as natural. However, in this latter case, there is knowledge and awareness. The problem is that both knowledge and awareness are *diluted*, non-linear and with fuzzy responsibilities combined among these aspects together with several others. We consider, with its due criticisms, the *Gaia theory* (Hamilton & Lenton, 1998; Lovelock, 1988) dealing with the planet Earth as an open system, far from equilibrium, subject to a constant flow of matter and energy. Such openness should be extended by considering continuous processes of emergence acquiring positive and negative properties. A pre-GOFS approach considers possible sequences of linear interventions having the purpose of reducing perturbative phenomena, but often with a poor understanding of their emergent roles.

Health (Fertman & Allensworth, 2010) should also be considered as being emergent rather than being a state. *Health should be considered as an emergent property emerging differently for each of us and in different ways over time*. Only a *few fundamental* conditions may be considered as being *necessary*, whereas health may emerge even in the presence of disabilities and aging (Minati, 2008). In the same way, there is a wide variety of approaches and methods with which to understand the concept of *care*. These include restoration, maintenance, replacement, adjustment, preserving a state or removing pathological occurrences, all related to *healing* (Good, Fischer, Willen, & Good, 2010). These approaches often have prescriptive or *invasive* natures relating to repair, removal or variations in degrees of freedom, all considered linearly as necessary conditions. They are, however, inadequate for affecting what happens between the degrees of freedom, which have an emergent nature. *Health is* among *the degrees of freedom and is a phenomenon of coherence*. The *crucial physical role* of mind is under study within various contexts as, for instance, in pain therapy (Colloca & Benedetti, 2005).

In the same way, *peace* should be recognized as being emergent and variable rather than as a state. It is non-exportable, like *democracy*, having contextualized aspects. It seems rather like a process of *translation* trying to keep the same meaning. Processes of peacekeeping, as in the case of health, may require the removal of pathological conditions as being necessary. However, a change in an emergent property requires a full knowledge of the processes of emergence occurring within the systems as well as external perturbations. It may be a matter of the *interdisciplinary transform* of the problem of keeping peace into merely the lack of *any* political, economic, medical, cultural or military *violence*. Otherwise traditional approaches may consider processes of imposing peace as equivalent to accepting *just wars*.

The quasiness should be considered as a typical aspect of social systems and their properties, due to their *intrinsic* structural variability. When dealing with simultaneous and sequential multiplicity of Collective Beings (CB), we must also recall that, most realistically, we should consider their coherent simultaneous and sequential multiplicity of processes of partial emergence as given by quasiness. The management of social systems adopted to deal with non-quasi systems as a question of tractability is, ultimately, a simplification, if not *second-order reductionism*. The quasiness of real social systems has been neglected as it was a question of the *imperfection* of real systems: they are quasi-like and one had to adapt to the perfection of simplifications. Traditional approaches assumed that real behaviours oscillate around an average produced by non-quasi aspects. However, post-GOFS is based on the ability to represent and use quasi aspects as a source of emergence, as a selection between equivalences. This problem is evident in the *post-democratic* phases of social systems. Post-democracy (Crouch, 2004) occurs when sophisticated processes of manipulation are possible thanks to new communication systems and cognitive science (Herman & Chomsky, 1988; Minati, 2004). This sociological and political change came about together with the shift from industrial to post-industrial or knowledge societies. Representative democracy is considered to be able to *summarize* the complexity of a social system into an elected leadership with the dialectical relationships between opposing political groupings. *Complexity is assumed to be explicitly represented*. Representative democracy is *summative* and selects people for others. It is the best system of democracy so far, but its evident manipulability shows that its upper level has been reached.

The key point is that we do not already know what to do with complex systems and processes of emergence: how to induce, orient, maintain, extinguish and combine them. The four categories of problems listed above, i.e. development, climatic change, health and peace, are examples of a lack of knowledge when dealing with social systems.

Could future post-GOFS knowledge be used to establish post-manipulable democracies? The concept of post-manipulable should be seriously considered when dealing with the *autonomy* of collective systems. Is it matter of collective intelligence?

How can one have *emergent leaderships* when their success and wealth came from their *oxymoronic* nature? It will be necessary to move towards quasi-*post-manipulable democracies*.

9.4 Ontologies, Knowledge and Language

The constructivist role of languages dealing with systems propagation was briefly mentioned in Sect. 4.6.

It is well known that activities of cognitive processing, such as modelling, deciding and communicating, are based on the use of *languages* (Bender, 2013). However, languages do not objectively exist per se, but are strictly related to, if not defined by, their *usage*. It is not even easy to decide *what should be considered as* a language and *what* should *not*. Besides, we must take into account that different languages are endowed with different representational powers, a circumstance of crucial importance when dealing with *knowledge representation* (Croitoru, Rudolph, & Woltran, 2013; Jakus & Milutinovic, 2013). Here, it should also be recalled that in a number of cases, there is the occurrence of a *collective knowledge representation within a set of individuals, each of which individually is unable to formulate an abstract representation* (Brooks, 1991, 1999). One example is the behaviour of ants looking for food. This shows that, when *using* certain kinds of concepts, it may not be necessary to *represent* them, contrary to claims made by Whorf's hypothesis (Von Bertalanffy, 1968; Whorf & Caroll, 1956).

We focus here on language, as used by social systems, and with regard to the knowledge they *use* and *produce* to deal with their social activities. This is typical of the fields of research of the *sociology of language* and *socio-linguistics* (Fishman, 1972). Ontological and linguistic aspects, already introduced in Sect. 3.4 as being representative of social change, are considered below particularly on going from the industrial to the post-industrial or knowledge society with emphasis on the concepts of post-GOFS.

9.4.1 Social Dynamics as Changes in Ontology

We concentrate on *social dynamics* as *changes in ontology* where ontologies (Effingham, 2013), *in contrast* with languages, may be metaphorically considered as *semantic accumulations* constituting *cognitive order parameters* able to diffuse their coherence within social systems.

This line of research may lead to suitable approaches for *inducing*, or even making possible, innovations in social systems such as entrepreneurship, management or education. Section 9.4.6 provides an example of a change in ontology on going from industrial to post-industrial society. Ontologies are considered to represent semantic coherent cognitive spaces used by social systems over time. In particular, we focus on the correspondence between social changes and changes in ontology. Ontologies are viewed as inducing cognitive coherence allowing the establishment of social systems, usually modelled by considering rules of interaction between the component parts. Thus changes in ontologies are related to changes in social systems. A meta-ontology is considered here as a coherent matrix of ontologies characterizing a social system over time.

A definition and the subject of ontology is the study of the *categories* of things which exist or may exist in some domain. Therefore an ontology is considered as being given by a formal description of the terms used within a domain and their relationships (Genesereth & Nilsson, 1987), that is, to an explicit specification of a conceptualization (Gruber, 1993). The latter is equivalent to a characterization of semantic spaces of *homogeneous* and *coherent* sets of linguistic items, such as verbs, nouns and adjectives. The attribute ‘homogeneous’ denotes the fact that one understands the reference to the same semantic subject even when considered from different points of view. Examples are given by the ontology of *optimize*, *separate*, *define*, *coherence* as non-contradiction, *freedom* and *decision* as a selection of various possibilities and *existence* as a necessary property. The attribute ‘coherent’ denotes the fact that one understands the reference to various semantic subjects only inasmuch as they are semantically related.

In some cases, ontologies may be considered as *closed* since they are used to describe world elements and their properties. From this point of view, they may be intended as *static* pieces of knowledge, contrasted with possibly rapidly changing facts. Furthermore *closedness* is considered in the sense that processes such as mixing, composition and exchange between different ontologies are not possible.

However, in other cases, an ontology can *change*, i.e. extend or adapt. This is the case during the development of an ontology, when axioms are added, changed or removed. The same situation can occur when we deal with reuse (Simperl, 2009), conflictual ontologies (Castelfranchi, 2000) or emergent semantics (Cudré-Mauroux, 2008). *Open* ontologies (Froehner, Nickles, & Weiss, 2004) are intended to focus on the *acquisition* of semantically non-homogeneous knowledge in open environments such as the web.

While traditional approaches to ontology acquisition focus upon finding homogeneity and consensus, open ontologies allow for heterogeneous semantics providing the possibility of changing to manage inconsistencies (Huaang, Harmelen, & Teije, 2005; Mazzieri & Dragoni, 2012).

One typical *example* relates to the classification used, for instance, in knowledge representation (KR) by using hierarchies of categories (Jakus & Milutinovic, 2013). KR ontology is not considered as a fixed hierarchy of categories, but as a framework of distinctions automatically generating the hierarchy itself.

On the basis of the method and principles of *formal concept analysis* (FCA) (Ganter & Wille, 1999), a simple example is given in Fig. 9.4 with a graph of the classification of concepts used to define the semantics of the concept of management. Such hierarchical graphs of concepts are considered as ontologies representing semantic coherent cognitive spaces which represent the cognitive aspects of social systems over time.

9.4.2 Social or Collective Ontologies

The subject of this section applies to social systems established by autonomous agents provided with cognitive systems sufficiently complex to be able to adopt *different* ontologies over time. The concept of *social ontology* (Pratten, 2014; Tuomela, 2013) is given by a collective intentionality, that is, as a general, shared and emergent ontology *maintaining* the *coherence* of social systems over time. Social ontology may be viewed as constructing social reality (Searle, 1996), intended here as the *structured*, *implicitly self-constructed systems of* cognitive *degrees of freedom* possessed by a social system over time. This definition has a powerful constructivist meaning (Fosnot, 2013; Sapir, 1929; Vigotsky, 1962; Von Glasersfeld, 1995; Whorf & Caroll, 1956).

This allows the introduction of another kind of coherence acquired by social systems, different from that related to *classical* collective behaviours established through suitable collective interactions. These kinds of collective behaviours take place when autonomous agents interact by collectively applying rules of interaction such as for flocks, swarms, fish schools and traffic. There is, however, a difference between social systems and collective systems. *We intend here* ***social systems*** *as emerging from unlimited, in-progress and variable interactions of various* ***natures***, e.g. *economic, political, religious, emotional, professional,* etc., *whereas* ***collective systems*** *may be intended as coherent sequences of self-organization processes using limited sets of rules of interaction applied in different ways and sequences. The coherence of collective systems may be intended, for instance, as meta-structural or deriving from suitable network properties, whereas social coherence is of a different nature, being* ***ontological****.*

In other words, the coherence generated by social ontologies consists of sharing the same structured sets of cognitive degrees of freedom influencing cognitive models and constructive actions. Ontologies constitute the structural frameworks within which information is organized. This context allows different rules of interaction of different natures. Ontologies allow social systems to exist by using the same or semantically equivalent cognitive models, i.e. possessing the *same* ontology. Section 9.4.4 considers the process of *changing ontologies* where ontological regimes may interact with each other and coexist (Mazzieri & Dragoni, 2012).

9.4.3 Culture, Values and Ontologies

The subject proposed and explored here is that the properties of social changes are induced, if not given, and represented, by changes in social ontologies, i.e. changes in *cognitive entities* such as concepts, their relationships and hierarchy and their coherence. The most common examples are revolutions, where changes in ontology may be adopted to partially *represent* changes in values and culture.

On the basis of the considerations in the previous subsection, a social ontology may be identified with the *structured*, *implicit*, *self-constructed systems of* cognitive *degrees of freedom* possessed by a social system over time. While a *culture* can be considered as a dynamic system of generic cognitive resources such as language, traditions, art, science or religion possessed by a social system together with their contradictions and dynamics, ontologies can *represent* partial, networked cognitive states adopted by social systems possessing such a culture. Within a context where *uses* are changing rapidly as in today's world, ontologies are both rapidly variable and local, dealing with dynamical inconsistencies corresponding to internal social dynamics and their contradictions.

While languages are *sediments* still in use of previous social phenomena, here the social ontology of a social system is considered as the current library of cognitive degrees of freedom *in use*.

Values may be considered as assumptions and transversal invariants of resources establishing a culture, i.e. constraining the *usages* of ontologies (Smajs, 2008).

9.4.4 Sources of Social Ontologies

What are the *sources* of social ontologies? Various sources can be put forward and listed.

Before introducing specific examples, it should be noted that social changes may be adopted because of, and represented by, changes in ontology both as updates and extensions of a previous ontology or as a structurally *radical* one when they are incompatible. The coherence of social systems can be induced and continuously maintained by the ontology of religions; powers such as a kingdom, democracy, communist or dictatorship regimes; economic system; or scientific principles. In the case of particular social groups of intellectuals, sometimes exerting a strong influence on other more general social groups, coherence is maintained by assuming the general validity of *objectivism* both within science and in society at large, i.e. assuming the existence of the best and unique solution, the necessity of non-contradiction, the absolute positivity of optimization, the absolute effectiveness of planning and the search for solutions and the prominent role of linear causality.

We may also consider general cultures as sources of ontologies. However, another important source of ontologies derives from technological changes which are socially *transformed* into usages, concepts and assumptions characterizing *normality*. Examples include the ontologies of travelling and communicating. The ontology of writing using computer systems with their software *syntaxes* has now replaced the ontology of writing or typing in the office, while the ontology of communicating through mobile phones, the Internet and their software *syntaxes* has replaced the ontology of paper communications and other previous interactions. Technological changes induce updates in the cognitive degrees of freedom of a social system coupled with *usages*. Ontologies are considered here for their *effectiveness*.

Realistically, ontologies do not *prescribe directly* the nature of a social system. That is, ontologies prescribe and represent current aspects of social culture and are able to orient general processes of emergence occurring within them. This form of representation is related to the *coherence* of continuous self-representations of social systems such as architectural aspects, lifestyles, literary, musical or scientific representations, considered by several different approaches including the study of *social mind* (Pagel, 2013; Sherman, Gawronski, & Trope, 2014; Todorov, Fiske, & Prentice, 2014). We recall how self-representation is related to the topic of *consciousness* when considering that a *state*, as mental, is conscious if it represents itself and uses its representations. Various approaches towards the study of consciousness have been introduced (Arecchi, 2011; Dehaene, 2014; Graziano, 2013; Joseph, 2011).

Important issues, not discussed here, include those of the relationships between social mind and social ontology, social consciousness and represented social ontology, coherence of social systems and their social ontology.

9.4.5 Social Changes and Ontological Changes

A significant amount of research has studied the *correspondence* between structural social changes and cultural aspects (Dutta, 2011; Everton, 2013). Here, we introduce the possibility of considering *local social structural changes* as being related to ontological changes. Examples of social local structural changes include changes occurring within social systems regarding approaches, strategies and technologies in entrepreneurship, education, lifestyles, politics and defence. The ontological changes occurring in social systems may be intended to break their *metaphorical meta-stability* by activating the diffusion of new attitudes requiring new levels of social coherence.

The idea is to consider a kind of *meta-ontology*, different from the concept used in philosophy (Van Inwagen, 1998, 2001), making meta-ontological relationships explicit in an ontology network (Díaz, Motz, & Rohrer, 2011) under the form of a hierarchical matrix of single ontologies, networking, for instance, ontologies of education, caring, feeding, health, inhabiting, management, parenting and safety, as representing a culture. In this view, a social system possessing a specific culture and values may be considered to behave using different ontologies networked within a coherent meta-ontology.

We propose here the idea of considering the changes occurring in social systems as suitably represented by changes in ontologies as well as changes in their networked coherent relationships within a corresponding meta-ontology.

9.4.6 An Example of Change in the Ontology of Management

With particular reference to the case of social entrepreneurship, the issue is: *Which knowledge is required for managing the knowledge or post-industrial society* (Minati, 2012)? A suitable formal representation of knowledge using the corresponding ontologies may be very effective in making evident, designing and supporting the process of change in using knowledge from industrial societies to using that from post-industrial societies. The effectiveness of this approach derives from the adoption of new and more appropriate social and managerial cognitive models using new local ontologies, which become coherent within a culture and which we may tentatively name the *social culture of complexity*. An outline of industrial and post-industrial conceptual distinctions is presented in Figs. 9.3 and 9.4.

A very simple ontological representation of the knowledge used to manage industrial societies is outlined in Fig. 9.5.

A very simple ontological representation of the knowledge used to manage post-industrial societies is outlined in Fig. 9.6.

Other ontologies such as those of precision, rapidity and exhaustiveness correspond to technological eras and should be used when suitable and be combined with those of quasiness.

The representations of knowledge in the two cases should be considered and analysed by social scientists as suitable instruments for designing social changes at various levels helping to understand usages and *possible* usages.

Fig. 9.3 Outline of differences between industrial and post-industrial societies

9.5 Further Remarks

In the long term, we consider ineffective the consumerist assumption that a market must be expanded through extremely reductionist approaches focusing on product features such as easy-to-use, suited to lower cultural levels, or creating false needs. This strategy works only in the short or medium terms. That is, this view implies that new consumerist cycles should be continuously generated to keep the game going. We agree with economic analyses considering subsequences of such cycles as non-sustainable (Weidinger, Fischler, & Schmidpeter, 2013) and establishing neither processes of growth nor of development. We are living in times where

Examples of contrasting concepts in Industrial and Post-Industrial Societies

Concepts in an Industrial Society	*Concepts in a Post- Industrial Society*
Completeness	Non-completeness as a resource
Computability	Non-Computability
Linear correspondence between micro and macro	Non-linear correspondence between micro and macro
Decisions from optimisation	Process of decisions from emergence
Equilibrium	Coherence
Measurement	Properties of multiple measurements
Multiplicity as a set	Multiplicity as a system
Optimise	Generate coherence
Properties possessed	Properties acquired
Reversibility-irreversibility	Non-reversibility as a source of uniqueness
Solve	Manage using multiple approaches
Stability	Coherent Dynamics

Examples of contrasting knowledge used for industrial and post-industrial societies

Knowledge used for Industrial society	*Knowledge used for Post-Industrial society*
Absolute values	Creating and offer roles, tools and services to create coherences for development
Anticipation	Development as emergence of systems of growth
Automate	Dynamic usage of models and knowledge
Consensus	Emergence and adaptability of rules
Control	Emerging continuous coherences
Decide, prescribe a solution	Focus is on the scenarios
Forecast	Incompleteness as a degree of freedom for logical openness
Growth	Increasing and maintaining coherence
Objectives	Inter- and trans-disciplinary knowledge
Organise	Iteration substituted by learning and modelling
Planning	Making processes autonomous
Precision	Measuring business success not only by growth, but by development
Regulate	Multiple knowledge
Standardise	Multiple strategies
	Multiple, Dynamic coherent properties rather than single objectives

Fig. 9.4 Outline of differences between *ontological* knowledge used in industrial and post-industrial societies

economic crises are linked to such phenomena and to approaches based on restoring economies which are still based, in their turn, on restarting such cycles through financial interventions. This does not work and is not strategically sound. In the past, such restarting was activated by infrastructural investments, post-war reconstruction and military expenditure.

A more strategic, post-consumerist approach could be based on evolving systems of usages extending from *competition phases* where revenues are reduced during processes of optimization of the *same* item or service. It is a question of reaching the top of the logistic curve (Fig. 9.7).

Traditional economic intervention *iterates* the logistic trend, whereas it does not maintain the dynamical coherence or, worse still, is able neither to sustain nor even interpret, if not by consumerist *reductionism*, the multiplicity of the process *coherence* and *incoherence* given by the temporary coexistence of *incompatibilities* or *inconsistencies*. The latter may be due, for instance, to technologies and related disruptive innovations and the occurrence of outdated technologies surviving side by side with new substituting technologies, with different rates of change in their social use due to cultural reasons. In a similar way, there are social coherences and incoherencies between religious and social assumptions when dealing with topics such as abortion, divorce, euthanasia and gay rights. Analogous inconsistencies

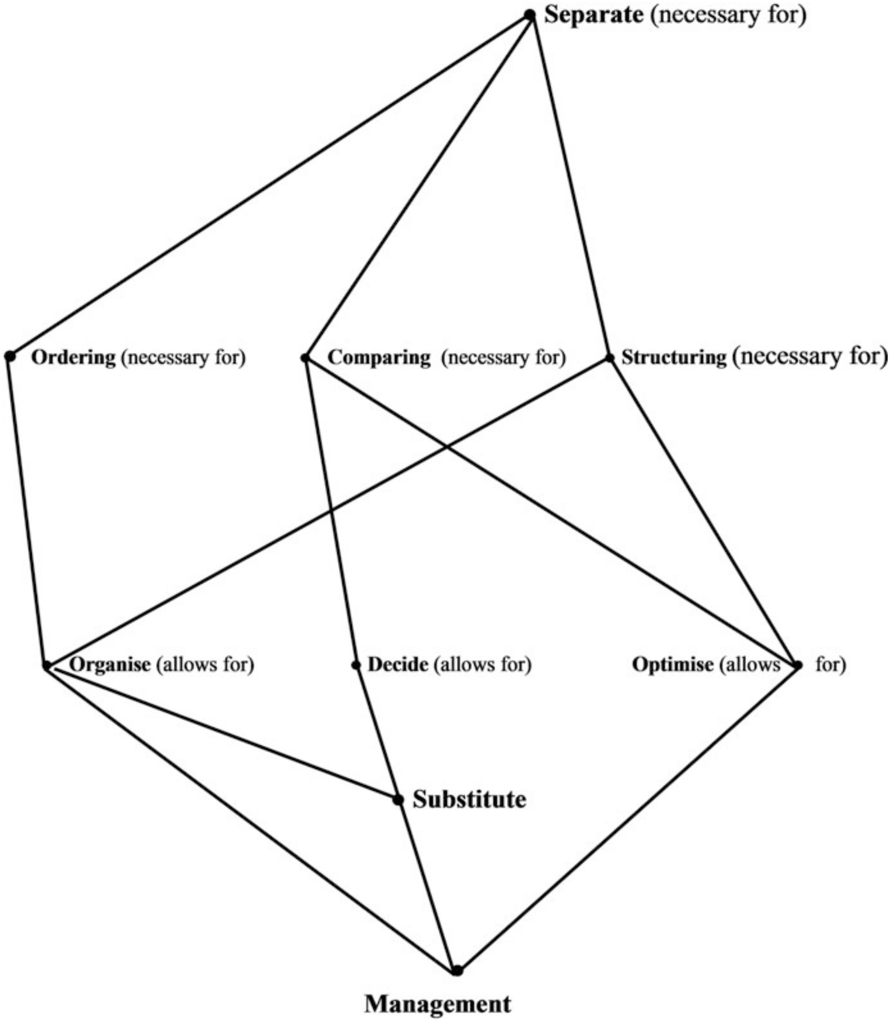


Fig. 9.5 An example of a hierarchical graph of implicative and inferential concepts tentatively representing the ontology of *management* in the conceptual framework of the industrial society

characterize the relationship between wealth and poverty, where *tolerance* denotes the coexistence of coherence and incoherence, i.e. living in the presence of an incompatibility.

The assumption of user stupidity in the provision of foolproof services and products is self-limiting in the long term. The abilities of users should be increased to increase needs and abilities to invent usages and ask for new innovative services. *Increasing user competence and the levels of their requests has strategically positive aspects and should not be considered as a limitation.* Various electronic- and communication-based devices and services are marketed in a self-referential

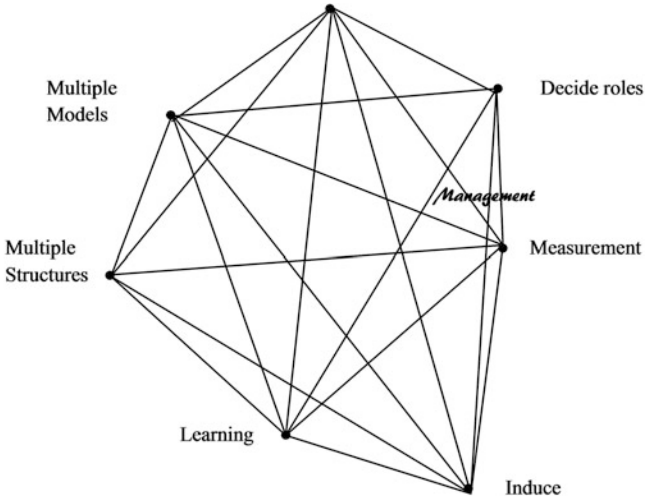
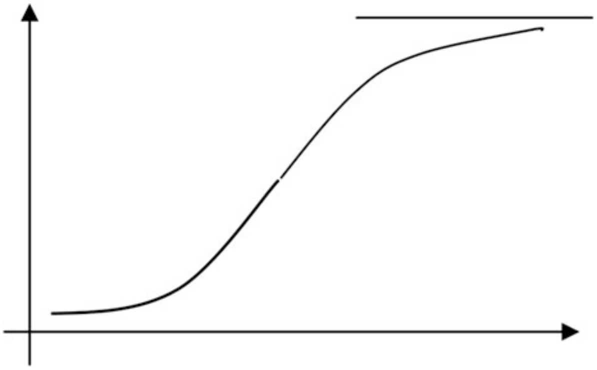


Fig. 9.6 An example of mutually networked concepts tentatively representing the ontology of *management* in the conceptual framework of the post-industrial society

Fig. 9.7 The logistic curve is used to represent *saturation* (the asymptote) of a market. External aids may be intended as an artificial increase in the asymptote



manner (with a *confirmatory nature* as with children, who like *repeated* stories and music), leading the user to accept predefined *black box* products with predefined limited usages to be extended only through the introduction of new products and services eventually made possible by modest technological changes and then being marketed as completely new products. In this way, the dialectic between *coherence* and *incoherence* is confined to usages with no, or only distorted effects, on assumptions and knowledge as mentioned in the introduction. Learning is limited to how to use, to learn the ‘Directions for Use’ rather than understanding the principles of the *why*.

For instance, it might be more useful to *reproduce*, i.e. to represent, translated using multimedial approaches, principles, conceptual schemes, approaches, methods and representations of modern science without just confronting and applying, for instance, rapid reactions as in videogames where time is self-referentially consumed without using the opportunity of raising the attention of the player to deliver useful knowledge (McGonigal, 2012).

Often the enormous processing and communication possibilities available are consumed just for what is forced to be considered as *fun*.

This can be considered as a serious waste of the potential to develop forms of economic development within the knowledge societies where more traditional and mature industrial sectors are sustained by public intervention with resources being diverted from as yet not even formulated processes of development.

A ***structurally new*** *entrepreneurship and management is necessary.*

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Chapter 10
Cases

Contents

This chapter is devoted to discussing situations in which the properties of certain systems are of, or may be considered as belonging to, a post-GOFS type. We refer to systems which can be represented and considered as acquiring properties, pre-properties, meta-properties and quasi-properties through explicit or non-explicit processes such as dynamical coherence(s) and multiple emergence(s).

In particular, we consider the case of architecture where, as introduced and discussed below, there is evidence both of acquired emergent social properties *materialized* in architectural artefacts and of structures of architectural artefacts *inducing*, in their turn, the acquisition of social properties. Architecture was chosen to be studied in detail, among other possible disciplines, since this two-way and superimposed process has more and less questionable evidence than, for instance, in other disciplines or artistic expression affecting social systems as mentioned in Sect. 9.4.4.

On this point, we also mention below how the possibility of *inducing* the acquisition of emergent properties within social systems *fits* with aspects of post-GOFS. This occurs when properties of complex systems, as discussed in Chaps. 2–5, cannot be explicitly and symbolically *prescribed* because their *nature* is different from those possessing GOFS properties.

As already discussed, suitable strategies have to be adopted in order to induce complex systems to acquire properties and possibly related and desired changes. Some characteristics of such strategies consist of using low-energy and

G. Minati, E. Pessa, *From Collective Beings to Quasi-Systems*, Contemporary Systems Thinking, https://doi.org/10.1007/978-1-4939-7581-5_10

non-invasive interventions, taking into account multiplicity, non-explicitness and the impossibility of symbolic prescribing, i.e. giving explicit *orders*.

In a metaphorical sense, we could say that suitable post-GOFS strategies are equivalent to '*whisper' to the system* the changes we have in mind, by resorting to orienting processes so as to *induce* autonomous *structural rearrangements*. In other words, we need to *convince* the system to acquire new properties, pre-properties, meta-properties and quasi-properties by *allowing the system to work* under the influence of dynamical coherence(s), multiple emergence(s) and *usage* of contradictions (Stokes, Dunning, Nazareno, & Brusco 2013).

The approaches suitable for *acting* upon complex systems constitute examples of effective strategies. The dynamic correspondences and coherences between the properties of social systems and their related architectural structures suggest a possible strategy based on acting upon architectural structures to *accordingly* act upon the properties of the social system inhabiting that architecture.

This is the main topic of this chapter which will also mention other cases such as multimedia, education and medicine.

As often remarked in this book, the new post-GOFS approaches should be grounded on principles and concepts used, for instance, in the *science of networks* (Barabási, 2002; Carley, 1999; Lewis, 2009; Valente, 2012) and in the study of meta-structures where actions upon emergent properties occur through actions upon properties of suitable features such as those relating to topology, scale invariance or meta-structural regimes.

The following cases consider the point at which complex properties are assumed as being *materialized* and not only *represented*, thus allowing the introduction of modifying interventions on *material representations*.

Ignoring such aspects, as in cases related to social systems, may produce, as stated in the previous chapters, a kind of ***second-order reductionism*** *which occurs when complex properties are misunderstood and treated as if they were GOFS properties.*

10.1 Architecture, City Planning, and Design

> To imagine a language means to imagine a form of life.
> (Wittgenstein, 1953, Part 1,§19).
> *Does imagining an architecture mean imagining a form of life?*

Within the conceptual framework of the theory of emergence and second-order cybernetics, focusing on the theoretical role of the observer as generator of *cognitive existence* rather than of relativity, architecture may be intended as the *self-design*, by a social system, of boundary and structural conditions suitable for making *structurally* emergent suitable social ontological properties (Della Torre & Canziani 2009; Fontana, 2012; Minati & Collen 2009).

Self-design is related to the processes of *transformation* of emergent social properties, e.g. lifestyles and customs, into structural constraints, aiming to provide a structural status to those properties, so as to avoid considering only the properties themselves as emergent.

Clearly, human settlements are the product of human societies, generally built and developed by a vast number of unconsciously interacting acts, performed over a long time, rather than by *purposely designed single acts*. Such a vision generates the idea of an *implicit* (or sub-symbolic) *project* which relies upon the systemic approach (Di Battista, 2009). As will be seen below, *the implicit project* is considered as *the sub-symbolic transformer of emergent social properties in architectural structures*.

The project is implicit because it is self-generated by the random combinations of many different and distinct needs and intentions, continuously carried out by undefined and changing subjects. It develops in a totally unpredictable manner. It is, moreover, a project produced by random combinations which are nevertheless continuous over time and transform and/or preserve all built environments.

The project is also implicit since "Architects are responsible for no more than perhaps 5 percent of all the buildings in the world. Most buildings (...) which give the world its form (...) come from the work of thousands of housewives, the officials in the building department, local bankers, carpenters, public works departments, gardeners, painters, city councils, families..." (Alexander, 1979).

Here, we recall that the identification of architecture with the self-design of boundary conditions forces us to introduce a concept originally considered in mathematics. Namely, when dealing with differential equations, a *boundary value problem* is given by at least one differential equation *and* a set of additional constraints called the boundary conditions. The concept of boundary condition can be generalized to include the degrees of freedom or constraints given by structures, e.g. the geometrical and topological properties of *living space* as shaped by architectural design, inhabited by interacting agents establishing a collective behaviour (Minati & Collen, 2009).

Examples of boundary conditions affecting single and collective behaviours adopted by inhabitants and inducing emergence of social behavioural properties are:

1. The availability of sidewalks inducing or preventing pedestrian traffic.
2. The availability of living surfaces inducing residence for singles or families, e.g. collective housing.
3. The central role of some functional areas in flats, such as the kitchen, traditionally the warmest place, and the availability of several bathrooms.
4. *Internal* or *external* facilities, inducing suitable usages such as a laundry or places for food storage.
5. The shapes of walls and their topology, according to their specific roles in houses, hospitals or schools.
6. Lighting, which makes possible particular living styles and inducing them (e.g. street lighting and artificial dynamics of lights, such as traffic/pedestrian lights).
7. The number of entrances and exits in a block of flats.

8. The shapes of roads, inducing particular properties of traffic.
9. The various types of stairs, e.g. stairs with one handrail or two handrails, and the availability of a slide for baby carriages and wheelchairs.

The structural aspects of architecture, specifically the materials used to build, behavioural facilities, shapes, dimensions, illumination, acoustic properties and energy usage for illumination and heating have functional and inductive behavioural effects on those who live and spend their time in such a structured space (see, for instance, results of research presented on the web (Space Syntax Laboratory, http://www.spacesyntax.com/; University College London (UCL), http://www.casa.ucl.ac.uk/; The behavioral design lab, http://www.designcouncil.org.uk/).

Individuals, as well as their established social systems, introduce multiple, sometimes shared, cognitive representations of the space in which they live and, because of this, they become *inhabitants*. As a result, they not only respect the boundary conditions from a functional point of view, but also cognitively process and use the representations they have of the space structured by those boundary conditions adapting their behaviour. This is why there are different architectures from different era and social systems.

A related subject is *Landscape Architecture* and its emergence (see Sect. 10.1.4), where “Architecture materializes our lives in the network of signs and meanings that all our landscapes are, such as our rooms, houses, roads, villages, cities, and territories” (Di Battista, 2012, p. 523).

Architects have the power and responsibility to set the boundary conditions, because they draw up the plans and models which organize the spaces for the inhabitants. We may say that architects cognitively synthesize in a temporary way, by representing them, the coherences and incoherencies of the social system.

10.1.1 The Implicit *Project*

The concept of implicit project is introduced by the following quotations and anticipates self-architecture as emergent and corresponding to processes of emergence occurring within social systems as introduced in Sect. 10.1.2:

> Architecture organizes and represents the settlement system; it interprets, materializes, interacts with and confirms the references of cognitive systems, and projects (foresees) and builds *coherent occurrences* (steadiness, confirmation) and *incoherent occurrences* (emergence) in the settlement itself. Architecture operates in the interactions between mankind and natural environment with *coherent actions* (communication; consistent changes; confirmation of symbols and meaning) and *incoherent actions* (casual changes, inconsistent changes, new symbols and meanings).
>
> Coherent actions are usually controlled by rules and laws that guarantee stability to the system (conditions of identity and acknowledged values); incoherent actions generally derive from a break in the cognitive references (breaking the paradigm) or from the action of *implicit projects*.
>
> These are the result of multiple actions by different subjects who operate all together without any or with very weak connections and have different – sometimes conflicting – interests, knowledge, codes, objectives. Implicit projects always act in the crack and gaps of

> a rule system; they often succeed, according to the freedom allowed by the settlement system.
>
> Perhaps, the possible virtuous connections of this project, in its probable ways of organization and representation, could identify, today, the boundaries of architecture that, with or without architects, encompass 'the whole of artifacts and signs that establish and define the human settlement'. (Di Battista, 2006, p. 398)

> In the open system of the built environment and in the continuous flow of human settlements that inhabit places, there are many reasons, emotions, needs, all of which are constantly operating everywhere in order to transform, preserve, infill, promote or remove things.
>
> These intentional actions, every day, change and/or confirm the different levels of our landscape and built environment. This flow records the continuous variation of the complex connections between people and places.
>
> This flow records the continuous variation of the complex connections between people and places.
>
> This flow represents and produces the *implicit project* assuming that all built environments carry out to update uses, values, conditions and meaning of their places.
>
> ....
>
> No single project, either modern or contemporary, has ever been and will ever be so powerful as to direct the physical effects and the meanings brought about by the *implicit project*. (Di Battista, 2009, pp. 45-46)

*We deal here with the passage from **acquired** to **structural** properties where architecture is intended as a **structural synthesis**.* Examples of this are given by the architectures of dwellings, intended first as a materialization of ways of housing and then inducing them. The same holds for the architecture of hospitals (Nickl-Weller & Nickl 2012), intended first as a materialization of conceptual *repair-like* therapeutic and medical approaches and then inducing them, and for the architecture of schools (Gelfand & Freed 2010) intended first as a materialization of ways of considering knowledge, i.e. based on a disciplinary fragmentation, and later inducing it.

*These examples illustrate the passage from **implicit, unexpressed** properties to **structural** properties, where architecture is considered as the design of new structures, in turn intended as **representations, translations** of the properties of social phenomena.*

Moreover, architecture does not only materialize and transform acquired emergent properties of social systems into structural constraints, but it also induces new emergent properties when introducing innovative ways of structuring space. Examples are given by vertical constructions, such as skyscrapers, or underground constructions. Their usage leads to the emergence of new properties.

10.1.2 The Concept of Self-Architecture

The concept of self-architecture is related to the transformation of acquired emergent social properties into structures playing the role of constraints, leading to the *functional* establishment of those properties themselves. *It may be intended as **self-***

***design** occurring through implicit projects, and cognitive materializations, as **translations** made by architects or anyone carrying out design and structural changes*. As discussed below this translation is not only one-way and limited to replicating the same ontology in various ways but a two-way process inducing and also reporting inconsistencies and contradictions. Self-architecture relates to the transformation of implicit, still unexpressed, cultural properties of social systems into structures, structures of structures whose properties are able to confirm and induce the emergence of coherent behavioural properties. Therefore, self-architecture is related to the global *interdisciplinary coherence* between various simultaneous aspects of social systems such as those relating to language, music, literature, religion and science. Self-architecture also represents the evolutionary processes occurring when a temporary incoherence allows social systems to restructure and reach a new equilibrium and coherence. Namely, architectural design often shows temporary syntheses representing coherences and incoherencies of the social system. *This allows one to recognize a sort of **continuity** between architecture, the practice of dwelling, fashion, music, literature, practicing religions, etc., occurring in different periods such as baroque, rococo, neoclassical right up to post-modernism.*

Of course, by adopting a trans-disciplinary view, this continuity may be considered as characterizing the disciplines in general. However, while some disciplines, such as engineering and architecture, design *concrete* constraints, other disciplines mainly design *cognitive* constraints.

Another important topic is that of the relationships between architecture and law. Namely, analogously to what happens in architecture, laws prescribe individual as well as collective constraints related, for instance, to security, land use and roads which operate as boundary conditions. This limits social behaviour in the design, construction and use of living spaces, and as such, these constraints also are able to induce, at another level of description, processes of emergence in social systems.

One crucial aspect, among others, was introduced by the practice of Post-occupancy Evaluation (POE), allowing reciprocal feedback between designers and *users*, as well as the *effects of usage*, of the designed architectural structures, necessary for triggering a learning process regarding both the design activity and user habits (Blyth, Gilby, & Barlex 2006; Federal Facilities Council 2002; Preiser & Nasar 2008; Preiser, Rabinowitz, & White 1988; Preiser & Vischer 2005).

An elementary and related ethical aspect, before and during the planning and construction of a building, is the *consulting* of stakeholders who are impacted by decisions concerning aspects of using, altering, maintaining and improving living spaces occupied by human social systems. It should be recalled that the subject of ethics and architecture (Taylor & Levine 2011) is very difficult and often debated from an interdisciplinary perspective.

The practice of POE highlights the *second-order cybernetic double loop* of *self-architecture*, i.e. how one influences the other not only through normal regulatory feedback but through *redesigning* processes (Minati & Collen 2009) going, for instance, from the materialization of lifestyles to its opposite, converting structural materializations into lifestyles (Minati 2015).

The most important point is to be aware of the problem, make explicit and publicly available possible choices and include systemic effects such as considering cities not only as ***places*** *within spaces* (Mostafavi 2014) *but as systems of networks and flows to better comprehend how cities both emerge* ***and*** *function* (Batty 2013).

10.1.3 Environment and Architecture

A number of different aspects must be taken into consideration when trying to ***distinguish*** *between the concepts of environment and architecture and even when trying to define them. A brief overview* (*Di Battista,* 2006*, p. 395) also introduces the following tentative definition of architecture intended as a* ***whole of artefacts and signs that establish and define the human settlement****, based on William Morris's definition of architecture as '...the moulding and altering to human needs of the very face of the earth itself, except in the outermost desert'* (Morris 1878)*, while the concept of* ***human settlement*** *was discussed in* Sect. 10.1.1.

On the basis of such a definition, this section presents some cases which highlight the conceptual interaction between the environment and architectural structures, as well as the dynamics of their coherences and incoherencies, as discussed above.

Here, architecture, intended as a discipline dealing with multiple systems of architectural structures, town planning and land usage, is understood to *represent* the settlement which generates it. In turn the settlement influences the architecture, for instance, by usage and re-usage when places are multiple systems of *sediments* (Di Battista, 2009). In this regard, approaches such as those based on the concept of *social field*, as introduced by the social sciences, and on the conceptual structure of *environmental psychology* will be mentioned.

We begin by remarking that the effectiveness of architectural structures and *design* (Zeisel & Eberhard 2006), when assessing up to what point *usage* is able to *induce behaviour*, is crucial when dealing with problems such as those related, for instance, to evacuations, line management, crossing, decision-making in emergencies and stair usage (Cucurnia & Giallocosta 2016). However, it should be stressed that, besides the critical issues quoted above, architectural structures are always able to induce *behaviour*, as in the architecture of housing, which is often designed with local current *ways of dwelling* in mind and then inducing and replicating the same approach (Mosha, 2012). Here the expression *architectural structures* relates to a wide range of structures establishing architectural systems such as cities, neighbourhoods, houses, apartments and the landscape itself. The reference is, for instance, to urban design, town planning, civil and industrial architecture, the design of outdoor and public spaces, i.e. landscape, and the design of tools for inducing usages.

Within this context one might consider the combination of aspects due to the interdisciplinary actions and reactions of inhabitant agents possessing complex cognitive systems such as human beings. These aspects are related, for instance, to shapes, colours, details, dimensions, functional properties, interconnections, visibility and availability of natural resources, e.g. lakes or rivers, trees and green meadows. In this way architectural structural properties are coupled with cognitive properties induced in inhabitants by usage and re-usage (Minati & Collen 2009). Accordingly, architectural structures should be designed bearing in mind both their power in influencing social systems behaviour and their emergent role (Keith, 2005) in materializing social properties.

Research in this area is crucial to reveal such interconnections allowing architects, on the one hand, to consciously and ethically design and plan the built environment as well as, on the other, inhabitants to develop social behaviours deriving from the built environments. This research should be interdisciplinary (Di Battista, 2009) by taking into account, for instance, psychological, functional and anthropological aspects, being based upon a systemic view allowing models and simulations of processes of emergence, i.e. the acquisition of social properties, by using suitable tools (Fontana, 2016). In addition to research on Post-occupancy Evaluation, when dealing with the design and emergence of social fields, it should be then possible to obtain a *pre-occupancy* evaluation of social emergent properties (Sawyer, 2005). By setting crucial properties of inhabitant agents, together with those of the architectural field, in a suitable usage simulator, one could outline possible acquired emergent properties.

Thus, we believe that the concept of social field, as well as the concepts used by environmental psychology, could be suitable for describing and understanding the effects of architectural structures on the inhabitants and on human settlement in general.

We recall that in the social sciences and in psychology, the concept of field was introduced by the psychologist *Kurt Lewin (1890–1947)* (Lewin, 1935, 1936, 1951). Lewin proposed this concept within the framework of Gestalt Psychology founded by Max Wertheimer, Wolfgang Köhler and Kurt Koffka (Koffka, 1935). The *force field* or life space was assumed to be present in any individual or social group, changing on the basis of experience and intended as a representation of the environment with personal values, emotions and goals. We may identify life space with the cognitive system combined with representations and stimuli related to the environment. Lewin also referred to *social space* or *social field*, intended as the joint life space of more than one person. The latter concept was however criticized as it fails to clarify how the life spaces of two people would have anything to do with one another (Mey, 1972). The usefulness of an approach based on the concept of field is still under discussion, for instance, in sociology when considering *Field Theory* (Martin, 2003).

We recall that the concept of field is borrowed from classical physics, where it considers the association of physical properties to points in space-time. Examples are given by electric or gravitational *vector fields* where at each point we have specific components of the electrical or gravitational field vectors. Other examples are given by *scalar fields* where at each point we have a specific value of a scalar variable, such as temperature or pressure. In the social sciences, on the other hand, the concept of field refers to the association between a position (not necessarily of a geometrical nature) and the action of a *force* exerted on the person occupying that position. Usually such a force comes *from the inside*, having a cognitive nature as opposed to forces generated by external sources such as those considered in physics.

Within this conceptual framework, the concern with economical *optimization* is often of secondary importance with respect to social and cognitive aspects such as those brought into play by architectural attention to other kinds of details (Salingaros, 1997). Among these one can cite the search for beauty, the desire to meet others, a sense of hierarchies, a preference for multiplicity vs. standardisation, a sense of openness derived from opening doors rather than from a lack of boundaries, inducing topologies by labelling areas according to specific values, the use of building material which indicate the social status of the inhabitants, the use of land in a *non-optimised* way, e.g., for parks, playgrounds and artistic exhibitions, the use of street lighting, traffic lights and shop opening hours designed to set social rhythms, the colour of house fronts and their state of maintenance, the attention to harmony with neighbours, etc. Such aspects have been examined previously including works by Collen (2009), Di Battista (2009), Fontana (2012, 2016) and Giallocosta (2010). The subject is referred to as *Environmental Psychology*. There are also important texts on the subject (Carley, 2013; Clayton & Myers 2009), dealing with the interrelationship between environment, cognition, behaviour and human emotions by considering both built and natural environments. Typical case studies within this context include those related to the relationships between well-being and the environment (Cooper, Burton, & Cooper 2014), to the effects induced by the *broken windows* theory (Kelling & Coles 1998) and to the study of crime prevention through environmental design, within the conceptual framework of so-called Space Syntax, such as dealt with by the Space Syntax Laboratory, http://www.spacesyntax.com/ and others (Clayton & Myers 2009; Cozens, Saville, & Hillier 2005).

Environmental psychology, briefly, among other issues, studies how architectural structures can induce a social behavioural *field* for inhabitant agents, in this case inducing rather than prescribing behavioural properties acquired by agents located at a point within that field. More in general, environmental psychology is an interdisciplinary field, collecting the different competences of psychologists, architects, economists, geographers, cognitive scientists, sociologists, policy-makers, educators and entrepreneurs. Its general interest is devoted to the interplay between humans and their surroundings. Despite the current decline in the initial enthusiasm for collaboration between architects and psychologists, the domain is vital and growing at a high rate, the main problem still being the absence of a sound and commonly shared methodology (for useful reviews of the field, see Gifford, 2007; De Young, 2013).

10.1.4 The Cognitive Construction of Landscape

Among the many contributions introduced in the literature, a possible novel approach to and understanding of the subject is related to our discussion on post-GOFS.

On the basis of the emergent nature of the landscape (Barnett, 2013; Di Battista, 2016; Starke & Simonds 2013; European Landscape Convention 2000, http://www.coe.int/europeanlandscapeconvention), and of the central role of the observer, as a generator of its cognitive reality through cognitive models able to detect coherences or not, we propose here to consider conceptually the landscape as a Multiple System. That is, the landscape as a cognitive *representation* of the synthesis and its *constructivist coherence* between environmental Multiple Systems, such as houses, roads, factories, cars, airplanes, street lights, traffic lights, trees, lakes, mountains, etc. The same approach can be used when considering Multiple Systems within a room, identified by the furniture, windows, doors, chandeliers, paintings, carpets, etc.

Two possible, and somewhat interesting, understandings follow from such a conceptual approach:

1. The detected coherences and incoherencies represent processes occurring both in the Multiple System Landscape (MSL) and cognitive discontinuities between the coherence conceivable by the observer's cognitive system and those used to detect the landscape as an emergent property. A large-scale example is offered by the shapes of industrial plant or energy-producing wind turbines strongly contrasting with mountain landscapes. Of course, learning and adaptation processes can completely change initial evaluations of a MSL as with the Tour Eiffel in Paris, initially severely criticized, or with streets populated with cars.
2. A conceptual framework is established where an *inhabiting* component contributing to the emergence of a MSL also becomes an observer of its emergence. *It is as if a bird of a flock could also see the flock as an observer*. Can the component see the flock in an objective way? We know that the component will see it through the *eyes* of a component. It will henceforth play multiple roles, as component and as observer. She/he will need multiple models, using different logics, and will have to invent them. This circumstance metaphorically recalls the process of knowing the knowing itself as considered in cognitive science.

An MSL should be considered as a representation of the constructivist coherence generated by the observer. Such coherence concerns the relationships between the Multiple Systems establishing the environment, such as houses, roads, factories, automobiles, airplanes, street lights, traffic lights, trees, lakes, mountains, etc. This requires the study of multiple interdisciplinary (psychology, sociology, cognitive science, vision and memory, architecture, etc.) and trans-disciplinary models allowing one to deal with systemic properties in an abstract way as collection, representation, variation, induction and combination of coherences.

As implied in the concepts of implicit project and self-architecture, we should study not only the *local* but also the overall coherence between the various aspects of social systems, such as cultural, technological and sociological. Thus a MSL could be viewed as representing the evolutionary processes of coherence and, possibly, incoherence occurring within social systems. Thus Systemics, in its post-GOFS form, could be a cross-disciplinary and unifying approach for representing and modelling landscapes. It sets the theoretical *non-decidability* – i.e. *non-symbolic decidability – of the landscape given its emergent nature*. Finally we mention the correspondences between the MSL and the *image understanding* as the artificial process of interpreting what is actually happening in an image or frame.

10.1.5 Completing Architecture

In the same way as statements can be considered as *flocks of words* from which a meaning emerges, the correspondences within the complexity of architecture lead to the emergence of environmental properties as well as inducing behavioural properties among the inhabitants of that architecture. Architecture is intended here, according to current research approaches and results presented in the literature (Batty, 2005; Portugali, Meyer, Stolk, & Ekim 2012; Complexity, Cognition, Urban Planning and Design, https://www.tudelft.nl/en/2013/tu-delft/complexity-cognition-urban-planning-anddesign/), as establishing structural and cognitive regularities of correspondences, intended as *syntaxes* of shapes, spaces and building material, with which social systems *pronounce statements of inhabiting*. *Buildings and houses cannot be suitably considered* only *as 'machine à habiter'* as metaphorically stated in the age of *functionalism* by Le Corbusier, pseudonym of Charles-Edouard Jeanneret-Gris, in his fundamental work *Vers Une Architecture*, published in 1924 and whose translation is now available (Le Corbusier, 2008).

Such *statements*, made in different places, on different scales and in different periods, are then composed and become *stories* linked to social and historical events. *Social memory* synthesizes and sediments, as for the issue of *reuse* in architecture (Van Uffelen, 2010) such *architectural statements*.

Within this conceptual framework, we focus our attention on the multiplicity of corresponding, entangled dynamic components of coherence to be induced, recognized and maintained in architectural systems. The list of aspects with possibly various degrees of coherence could be very long and will depend upon the general culture and approaches within the simultaneous generation of and inhabiting within a social system.

Examples of such aspects include acoustic properties, building materials, details, dimensions, energy usage, functionalities, harmonicity, illumination, morphology, openness, colours, reuse, shapes and topology.

> Research has established the concept of the built environment as the peculiar eco-system of the human species, underlining... the need to resort to the scientific approach of biology in order to better understand such complex physical phenomena as cities.. (Fontana, 2012, p. 543; see also Batty, 2005; Giacomini, 1989; Hensel, Menges, & Weinstock 2004; Marshall, 2008; Minati, 2008; Science, 2008; Weinstock, 2010)

Within the framework of the huge variety of well-established modelling and simulation approaches used in architecture, including *EnergyPlus*, for energy simulation programs for buildings (EnergyPlus, https://energyplus.net/), and *Urbanism*, supporting planning and analysis of urban developments (Urbanism, http://www.urbansim.org), later reviewed (Chenn, 2012), agent-based models (ABM) may simulate pre-occupancy issues by considering constraints, i.e. boundary conditions, and interacting agents with specific characteristics.

Meta-structural analysis in architecture is also a possible approach using the values adopted by mesoscopic variables for *pre-occupancy assessment* and for performing simulations. The purpose is not only that of certifying functionalities but also of outlining aspects of possible processes of emergence of acquired properties, which could then be avoided or embraced, within the inhabitant social system.

The post-GOFS approach should be the general culture of this new understanding and promote the *systemic completion* of architecture which takes into consideration multiplicities of effects and roles often invisible when considered from within specific disciplinary professions.

10.2 The Complexity of Social Systems

Here, complexity of social systems is intended as deriving from the acquisition of properties and problems arising, for instance, relating to coherence(s), development, emergence, entanglement, irreversibility, multiplicity such as multiple non-equivalences, multiple non-homogeneity, multiple structures, network properties, non-linearity, non-symbolic aspects, quasiness, scenarios, self-organization, simultaneity, uniqueness, uncertainty and incompleteness.

The nature of such properties and problems are different from those dealt with using GOFS related to anticipation, automation, completeness, context independence, control, decision, forecast, growth, non-connectedness, optimization, organization, planning, precision, regulation, reversibility, separation, solution and standardization. Extensions or updates of GOFS concepts are not effective because of the different nature of the new properties and problems but could be eventually and adequately *combined* with post-GOFS concepts.

Different strategies should be implemented to act on post-GOFS properties in social systems such as acting upon coherence(s), communication, constraints, possibility of interactions, management of inconsistencies, memory, representations, available resources, robustness and time management.

The complexity of social systems can take on a vast range of properties of different natures. Sources of the complexity of social systems include the aspects listed in Table 10.1.

As is well known, within traditional economic theories, corporations and institutions are still conceptually considered as *social devices* which can be dealt with by using GOFS. The change occurring in post-industrial societies, as discussed in

Table 10.1 Examples of sources of complexity of social systems

Their being *knowledge-intensive*
Delocalisation and globalisation
Easy replicability
Highly general networked interconnections
High manipulability
High virtuality
Being endowed with hyper-connections
Importance of individuality
The occurrence of Instabilities to be recovered by coherences
Interchangeability
The possibility of on-line actions
Shorter time between design, implementation, and marketing
A generally short life span of products, ideas, projects
The presence of technological innovations and solutions, such as augmented reality, 3D printers, and huge data availability, creating new problems of a *different nature* (Minati, 2012b; Minati 2012c) where a *new theory of work* and *value* should be introduced
The arising of epiphenomena, i.e., secondary phenomena occurring alongside or in parallel to primary ones
Multiplicity
Non-linearity and non-sustainability
Networked availability of knowledge
The fact that products and services come with *induction for use* more than *directions for use*
The rapid transformation of solutions into new problems

Chap. 9, relates to the ways of understanding processes such as to manage, decide, develop, optimize, make profitable, obtain revenue and investments, take advantage, compete, produce, design and develop finance and marketing policies.

The usage of the GOFS approach for understanding such concepts will lead to iterative usage of technologies and innovation where consumerism is intended as the principle source of social and economic dynamics.

Conservation of such understanding is supported by a wide variety of reasons such as the ways of *writing financial statements*, budgeting, assessing the value of stock, and funding on the basis of guarantees, still reproducing assumptions valid in the old industrial society, reasons for lending, education, and coherence(s) with the general culture and way of thinking. A good example is given by *stability* assumed to be kept and defended, while its negation, that is the end of stability, is in reality the necessary passage to reach new phases of economics, i.e. development.

The conservative understanding is, for instance, given by the *sequences of consumer cycles*, designed and decided by producers. Innovation occurs *within* such cycles still considered as GOFS processes. The crisis of systems of such cycles is not reducible any of them. We face properties of systems of cycles having post-GOFS properties and affecting their unsustainable nature of consumerist cycles (Minati and Pessa, 2006, pp. 321–334).

Such processes and their properties will be dynamically represented in the architectures of corresponding systems. Eventual correspondences between complexities of social systems on their architectures should become a research issue.

10.3 Other Cases

We list in the following some examples of other application areas where it is possible to detect post-GOFS properties eventually combined with GOFS properties and use post-GOFS approaches to 'manage' coherence(s) and phenomena of multiple emergence(s) represented at different levels of description.

For instance, consider *multimedia*, i.e. television, mobile phones, Internet, CD and DVD, where services, methods of use and marketing *correspond* to the general properties of social systems such as the *reasons* for which people interact. For instance, multimedia make easier communication, reproduction and availability of text, voice and visual information. This implicitly confirms the *reasons* for use within a technologically up-to-date social system and eventually *induces* them within social systems where such products and services implicitly *export ontologies* facilitating the 'hosting social system' to adopt them (Strate, 2014). The *social syntax* of multimedia apparently adapts to any content and is semantically independent, but in reality using this syntax will affect their content in the long term. First of all, they are based on *virtuality* (Minati and Pessa, 2006, pp. 359–379). The process activated relates to the *dynamics of coherences* between text, images, data and music. The possibility of introducing *standards*, for instance, in music, movies and language establishes *cultural invariants*, and the dynamics of their usage, in turn, represents and can induce or *force* the corresponding *real* dynamics occurring within social systems *just as office software first supports and facilitates office work and then leads people to work in a given way*.

Post-GOFS properties may be indirectly represented and used to *prescribe* correspondences to social systems. It corresponds to the statement *let people listen to our music, watch our movies, eat our food, dress like us, use our products, use our language, etc. and they will become similar to us*. In the past, the same approach was used by exporting religions or ideologies.

The point is that the *extensions* of the usual ways of representing or processing information should not avoid the possibility of conceiving or designing *new logistic curves*, i.e. do different things by introducing radical innovations (Christensen, 2013). The general problem is to take advantage of *standardization*, but at the same time, the latter operates within a conceptual framework where *deviations* are possible, distinguishing between inefficiency and creativity.

Current ways, for instance, of communicating, writing and making office work prescribe methods of working in offices and indirectly ways of conceiving working itself and professional roles deriving from commercial software and procedures. *There is the adoption of the ontological view that optimization is unique* and we have reached it.

Which will change first? The software for marketing motives and procedures or the ways of doing things themselves asking for different software and procedures?

Another subject is that of *education*. Section 10.1 mentioned how *explicit architecture* is responsible for no more than perhaps 5 percent of all the buildings in the world. We might well ask ourselves the percentage of professional educators working in schools or *explicit educational systems* who are responsible for *education* (Robinson & Gerver 2010) and how crucial is the education of educators for the *science of education* (Keating, 2012; Oecd, 2013).

This is also an important issue when related to *learning organizations* (Minati, 2012a, 2012b; Minati and Pessa, 2006, pp. 375–381) where their learning cannot be considered as being linearly coincident with the sum of the learning processes involving the individual agents belonging to them (Biggiero, 2006, 2009) and is related to the issue of *knowledge management* (see, for instance, Hislop, 2013). The process can even be generalized by the concept of collective or swarm intelligence discussed in the previous chapters. A learning organization is not supposed to learn what individuals are used to learning, such as information and knowledge. Rather it learns how collectively, i.e. coherently, to use and process various individual learning processes. It is a matter of non-explicit learning as considered in *machine learning* (Flach, 2012) as, for example, in the case of neural networks where learning is not due to symbolic processing.

The post-GOFS understanding of social processes helps to realize that education should be reconsidered and understood mainly *as transversal, multidimensional and non-separable, i.e. embedded within a large variety of context-sensitive processes* including cognitive, psychological, emotional, social, physical and linguistic processes.

Knowledge societies paradoxically require and provide different levels of learning, the basic one being *induction to usages* of products and services. However, within this context, education has the main purpose of generating an average, shared social level of usage and understanding of products and services without the need to possess appropriated knowledge in order to understand technological or scientific content, as mentioned in Chap. 9. This *reduction* is required by the consumerist approach to expand markets even at the cost of their using such content unknowingly. Usage is predefined, and the consumer's lack of knowledge prevents awareness, necessary for sustainability and the *inventions* of novel usages for opening new markets.

The focus of education in post-industrial, knowledge societies is on the level of coherence(s) between various kinds of knowledge at different levels.

Post-GOFS will eventually be able to represent such dynamical coherences by using networks, meta-structural properties and regimes of validities. Such representations may be used to design and put into practice the post-GOFS systemic level of education and induce other suitable ones.

Such *non-symbolic* education should be simultaneously multilevel and multidimensional. This is the case where any information is provided *to* and learning process occurs *in* one of the several systems of a Multiple System or Collective Being. *It is then the dynamics of the MS or CB which process the* *knowledge made available to* ***composing*** *systems within a context of continuous emergence*. There is a huge variety of professional, scientific, practical knowledge and know-how which *merge* in usages and lead to social, dynamic, temporary and local coherences.

Another area where expected evolutions are assumed to be based on post-GOFS properties is the so-called predictive, preventive, personalized and participatory or P4 *medicine* (Hood & Flores, 2012; Hood, Balling, & Auffray 2012). P4 or proactive medicine has the theoretical purpose of supporting health in different forms, i.e. age, place, etc., and well-being as emergent properties rather than merely by the treatment of diseases. P4 combines hypotheses-driven (*top-down*) and data-driven (*bottom-up*) approaches and models (Cesario et al. 2014). The conceptual shift is from considering *systems of parts* to consider contexts or fields having *generative properties* (pathologic properties) different form environments intended *hosting* or influencing (see also the Sect. 4.6 System propagation).

10.4 Further Remarks

The cognitive shift discussed in this chapter with special regard to architecture and of a post-GOFS nature consists of *abandoning* the usual interventional, intrusive, dirigiste, decisional, symbolic and forcing approach because such a strategy is ineffective when dealing with complexity.

This does not mean that another, alternative strategy can be uniquely and precisely identified. The message is that an endless variety of possibilities are conceptually available. We now know their post-GOFS nature and that the focus is on properties such as coherence and emergence.

In this book we have mentioned some possible new methods including the network, meta-structural and 'QFT Systemics' approaches.

We consider this new understanding as being produced by the need to abandon approaches based on pursuing *objectives*, symbolic, measurable and objectivist goals *only*. It should be a matter of continuously looking for general, post-GOFS properties having a strategic nature and which can be locally materialized and quantified. Looking only for GOFS properties is partial and non-strategic, whereas post-GOFS focuses on properties typical of the dynamics of games. On this point, we recall that Peter Drucker used to say that the first thing to be decided in a strategy of development is what to abandon and not to identify new objectives (Drucker, 1970).

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Appendix 1: Some *Post-GOFS* New Systemic Properties

This appendix presents a list of *properties* suitable to outline general aspects of the new, post-GOFS systemics.

We summarize here, for the reader, some of the key concepts of the new systemics often sometime *implicit* in previous GOFS concepts but more often substitutive, alternative and possibly even incompatible since they design a new systemic scenario. In such a scenario, GOFS may be considered as a particular case.

We stress that such properties are considered within a constructivist conceptual framework. This means that they are always considered at suitable levels of description, representation, scaling and with reference to cognitive models where objectivistic approaches are particular cases.

Post-GOFS is a constructivist *process* where several, alternative *optimum* areas are conceptually possible. This is not agnosticism or relativism but relates to the self-constructive, on-going nature of knowledge generated by social systems.

Here we present a historical, classical case where it is shown how the objectivistic, single and absolute *truth* should be more *effectively* considered as a layered, networked, multiple, dynamic process where cognitive realities are *new worlds*, new ways of thinking. Consider, for instance, Euclid's famous *fifth postulate* introduced around 300 BC in his *Elements*, a geometry treatise consisting of 13 books. There are several equivalent ways of formulating this postulate. For instance, if a straight line falling on two straight lines makes interior angles on the same side of less than two right angles, the two straight lines, if prolonged indefinitely, meet on the side where the sum of the angles is less than two right angles. The content of the postulate seems obvious. However, it was suspect as several attempts to *demonstrate* it failed.

Among those mathematicians who examined the postulate, consider the efforts of the Jesuit *Girolamo Saccheri (1667–1733)*, Professor of Mathematics at the University of Pavia, Italy. He involuntarily opened the way for *non-Euclidean geometries* when trying to prove the validity of the fifth postulate. He believed, essentially, that it was absolutely *deducible* from the previous postulates (given its

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obviousness) and thus transforming it into a *theorem* making its alleged evidence a logical necessity.

He started by looking for a proof by contradiction, also known as *reductio ad absurdum*, when considering true hypothetical assumptions which give rise to logical contradictions. This invalidates the assumptions which must be then considered as false.

By assuming true negation of the fifth postulate and then deducing from the new system, i.e. Euclidean geometry, but with the negation of the fifth postulate, he developed a series of theorems expected to be contradictory. His attempt, however, did not lead to contradictions.

The failure of Saccheri's attempt represented a major turning point for at least two reasons, because he:

(a) Conceptually introduced the possibility of non-Euclidean geometries where the fifth postulate is not valid.
(b) Pioneered the idea of establishing the validity of a geometry through its non-contradictory logic and not its *intuitive evidence*.

The first official introduction of non-Euclidean geometries came from a number of mathematicians including the Italian mathematician *Eugenio Beltrami (1835–1899),* (Beltrami, 1868a; 1868b).

The fifth postulate does not apply in a variety of diverse geometries when substituting the plane, for instance, with spherical, parabolic, hyperbolic (Lobachevsky-Bolyai-Gauss geometry) or elliptic geometry (Riemannian geometry).

Nowadays, we know that *intuitive evidence* is not a robust approach for scientific research where it is still difficult to establish conceptual frameworks where negation is possible, for instance, using assumptions made using intuitive evidence such as the void being considered as nothing, lacking any properties; the disappearance of effects with increasing time and distance, thus excluding possible long-range effects; multiple localizations as for quasi-particles; and the exclusion of multiple, possibly equivalent or nonequivalent, representations.

Moreover, a *creative contradiction* is generally better than a *trivial* truth, which is *not generative*, such as articles containing foregone conclusions written only to lengthen CVs, which carefully avoid the risk of stating something new. Better to consider *intelligent mistakes*, i.e. requiring new knowledge to be confuted or conceptually introducing new approaches. Examples include 1) the confutation of the concept of *ether* in physics and 2) the introduction of the concept of *quantum void* with properties different from *nothing* by Hermann Nernst (1864–1941).

It should be recalled that terms such as *properties* and *characteristics* seem to be based on *objectiveness*, intended as being peculiar to the subject considered, whereas post-GOFS considers them as being emergent, continuously acquired. Such processes of emergence and acquisition are considered within the *cognitive worlds* generated by the active role of the observer where different levels of description, models and representations are not hierarchically ordered on the basis of convergence towards a unique optimum but constitute a variety of choices to be made according to the *cognitive strategies* employed to deal with *cognitive realities*.

Post-GOFS concepts described here include the following:

1. Coherence
2. Self-organization
3. Emergence
4. Levels of emergence
5. Multiple emergences
6. Dynamical multiple coherences in processes of self-organization and emergence
7. Structural dynamics
8. Regimes of validity
9. System propagation
10. Between
11. The transient
12. Irreversibility
13. Non-separability
14. Non-causality
15. Non-invasiveness
16. Non-prescribability
17. Pre-properties
18. Quasi
19. Quasi-properties
20. Quasi-dynamic coherence
21. Quasi-systems
22. Complex network properties
23. DYnamic uSAge of Models (DYSAM)
24. Meta-structures
25. Meta-structural properties
26. Usage of degrees of freedom

Here below a brief summary of these concepts is provided giving some examples of words and concepts of GOFS and post-GOFS:

1. Coherence

This subject is introduced in Sect. 2.1 and then considered from different points of view: dynamical coherence and coherences in processes of self-organization and emergence in Sects. 3.2 and 3.2.4; quasi-dynamic coherence in Sect. 4.7; dynamics and coherences of emergence with reference to multiplicity in Sects. 7.2.1 and 7.2.2; with regard to Network Science in Sect. 8.2.1.

In post-GOFS systemics, coherence is intended as the *maintaining* of acquired emergent systemic properties and system identity in spite of structural changes occurring within systems or as properties of possibly Multiple Systems or sequences of systems.

Nonsystems may *possess* properties such as weight or age.

Systems continuously acquire possibly the *same*, i.e. identical, properties thanks to *organized* interactions among elements such as functionalities or being deterministic, equifinal, goal seeking or open closed.

In such cases, coherence is intended as being given by the same organization and related variable structures.

Coherence of emergent open complex systems is intended as maintaining possibly the *same* properties in spite of structural changes, such as ways of interacting or topological transformations, Multiple Systems established by the same elements, exchange of elements or sequences of systems. Such coherence is assumed to be detected by an observer provided with a suitable cognitive system capable of recognizing the maintaining of emergent systemic properties such as swarms, flocks, industrial districts or *non-algorithmically predictable* traffic.

A well-known case study is where a system is able to maintain acquired properties through the *dissipation* of matter and energy as in the Belousov-Zhabotinsky reaction, Bénard cells or whirlpools. Living dissipative structures dissipate material flows such as air with carbon dioxide, water and food.

Structural, network dynamics allows the emergence of coherence.

However, post-GOFS studies consider the possibility of using suitable models with relative levels of representation to identify constructivist, nonsymbolic approaches to *recognize* and represent such coherence, for instance, by considering properties of scale invariance, power laws, networking or meta-structural properties.

We also considered *multiple dynamical coherences* of simultaneous or successive Multiple Systems and clusters to establish higher general levels of coherence among local coherences as for *areas* and *instants* of collective behaviours. One case occurs when considering the maintaining *properties of networks* emerging from coherent sequences of different networks exchanging links and nodes, possibly maintaining the same fitness and being represented by the same or suitably coherent topological dynamics.

Furthermore, the possible usage of meta-structural properties to detect and act upon various emergent collective properties was considered.

2. Self-Organization

The general idea of self-organization may be expressed by phenomena showing *spontaneous* adoption of regularities such as assonances, cycles, repetition, harmony, tuning, synchronizations or, more properly, coherence (see Sect. 3.2.3). The adjective spontaneous means that there are no *external explicit* prescriptions for such properties. Such properties may, however, arise as a consequence of, or facilitated by, interactions of any nature, noise or particular environmental conditions. A general example is given by *populations of oscillators*, biological or chemical, for instance, which begin, at a certain point, to oscillate *in phase*.

Processes of self-organization are considered here as corresponding to continuous but regular, for instance, periodic or quasi-periodic, variability in the acquisition of new structures. Examples are given by Rayleigh-Bénard rolls, structures formed in the Belousov-Zhabotinsky reaction, dissipative structures such as whirlpools in the absence of any internal or external fluctuations and swarms showing behaviour which can be considered as repetitive at a suitable level of representation.

Processes of self-organization may be understood as regular multiple *sequences of phase transitions when their changing* or transition *over time is, for instance, regular,* e.g. *cyclic or quasi-periodic. This is the source of their coherence.*

3. Emergence

As introduced in Sect. 3.2.3, *processes of emergence may be understood as the occurrence of even multiple simultaneous sequences of processes of self-organization where the corresponding acquired dynamic structures are* coheren*t,* i.e. *display the same property in spite of adopting multiple coherences.*

We consider emergence as occurring, for instance, when a specific phenomenon of self-organization *differentiates* in different but coherent multiple self-organized perhaps subsequent, superimposed phenomena, e.g. Multiple Systems, such as swarms or flocks following perturbation or when subject to internal fluctuations or predator attack.

Examples include the properties of flocks, swarms, industrial districts, markets, traffic, urban development (morphology and energy behaviour) and properties of ecosystems.

We may summarize by saying that phase transitions relate to order-disorder transitions, self-organization to acquire *single* coherence(s) or emergence to acquire multiple coherent coherences, *coherent collective self-organizations* which must be distinguished from *multiple synchronizations.*

With reference to scale-free correlations in collective behaviours (Cavagna et al., 2010), we consider self-organization as corresponding to the establishment of a single-correlated domain and emergence corresponding to the correlation of multiple correlated domains with different but constant correlation lengths.

4. Levels of Emergence

We consider a new *level of emergence* occurring when emergent properties of a system of entities become *generators* for the emergence of a subsequent one as shown in Scheme 7.1.

This subject is discussed in Sects. 7.1 and 7.2 which introduce the conceptual mechanism by which emergent entities become entities generating further subsequent phenomena of emergence as shown in Fig. A1.1.

We also consider how this process can be *non-regular*, bottom-up or top-down, where at each level *different types* or mutation-like changes in *emergence* may occur giving rise to multiple emergences as happens in biology (see Scheme 7–4 and point 5 below).

5. Multiple Emergences

The subject is discussed in Sect. 7.2.2 where we consider multiple processes of emergence occurring at the same level from the same elements and where various levels of emergence arise from the same starting level as shown in Fig. A1.2.

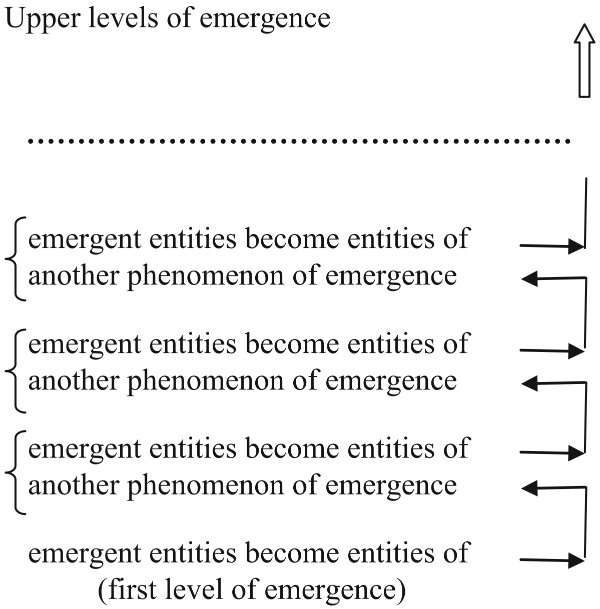

Fig. A1.1 Levels of emergence

Multiple processes of emergence occur at one of the subsequent levels from a single one. This is *horizontal* multiple emergence occurring at the same level of emergence and with *vertical* sequences of layers of emergence (see Fig. A1.2).

Issues relate to both the variety and possible stability of processes of emergence occurring at single, multiple or even non-subsequent levels of emergence and their possibly multiple coherences.

Possible processes of multiple emergences are often invisible within the framework of GOFS which is suitable for the recognition of only single levels.

6. Dynamical Coherence in Processes of Self-Organization and Emergence

This topic (see Sect. 3.2.4) may be considered using various approaches. Dynamical coherence is assumed to occur when considering processes of self-organization or emergence from a structural point of view, i.e. structural dynamics, dynamics intended as changes in structures.

In this view, processes of *self-organization* may be understood as being regular sequences of phase transitions where their changing or transition over time is regular, e.g. cyclic or quasi-periodic. Processes of self-organization are considered as being given by continuous and regular acquisitions of new structures, as for *regular* sequences of phase transitions.

Processes of emergence may be understood as the occurrence of possibly multiple simultaneous sequences of processes of self-organization where the corresponding acquired dynamic structures are coherent, i.e. displaying the same property in spite of adopting multiple coherences (see Sect. 3.2.3).

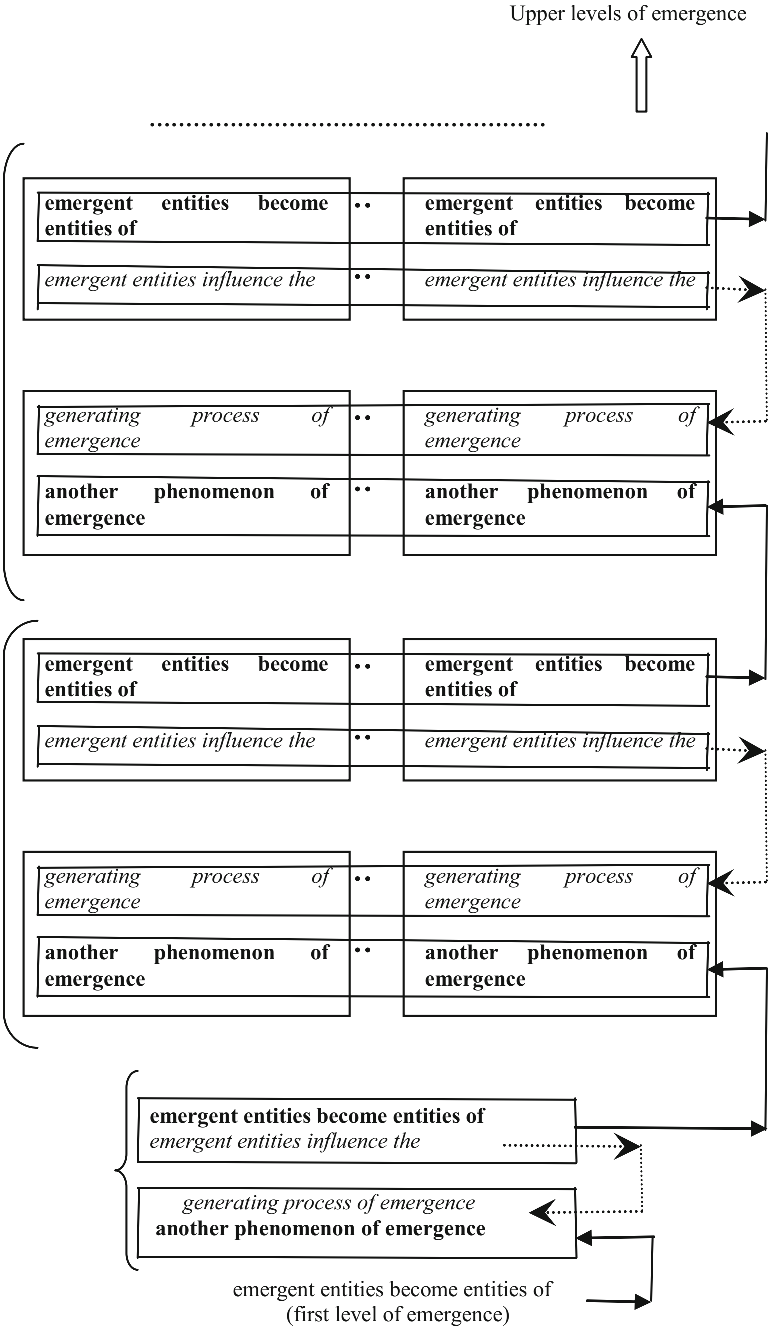

Fig. A1.2 Multiple vertical and horizontal emergences

Dynamical coherence relates, in this case, to the changing of structures (see point 7 below) while also relating to Multiple Systems, where *multiple roles* were considered to be sufficient.

We discuss the concept of dynamical coherence (see Sects. 3.2.4, 3.8.2 and 7.2.1) as being related to *structural dynamics*, processes of acquisitions or maintaining emergent properties.

Dynamical coherence typically relates to *Multiple Systems* as introduced in Sect. 4.5.1. In this case, we recall here that fundamental aspects are given by the *multiple meaning* of the same interactions and states allowing multiple roles. Dynamical coherence of Multiple Systems arises where different components may be simultaneously part of different systems or play *different independent roles* as for networked interacting computer systems performing cooperative and shared tasks, as occurs on the Internet.

More generally dynamical coherence(s) is given by multiple structural interactions (see Sect. 3.8.2). Dynamical coherence(s) can be modelled using suitable networks or meta-structural models and related properties.

The dynamics of coherence may be vertical, horizontal or given by their possible dynamical combinations:

- Horizontal, when there are *simultaneous* coherent different emergent systems, e.g. social systems.
- Vertical, when there are dynamics among *subsequent* coherent different emergent systems as, for example, in biology.

Furthermore both these cases may occur even if at different, possibly simultaneous, scales (see Scheme 7–5).

7. Structural Dynamics

This term (see Sect. 3.2.4) refers to changes in structure over time also considered in this book as *dynamic structures*, both considered to be in conceptual contrast with *changes over space or time of the same structure*.

The immediate meaning of these expressions relates to general processes of changing structures possessing the same components. Consider, for instance, structures of relationships, correspondences and interaction rules. Sets of such structures may have various properties, such as statistical ones, changing over time by developing some regularities. Structural dynamics relates to such changing.

Several approaches can be used to model such structural dynamics to identify properties of their sets.

Although in the case considered above, properties relate to *explicit representations* of structures, network or meta-structural properties or structural regimes represent cases of such changing where it can be expressed in a *non-explicit* way using network, mesoscopic and regimes of validity.

However structural dynamics is interesting when it has significant properties such as coherence(s), quasi-coherence or multiple coherences.

8. Regimes of Validity

The general concept, examined in Sects. 3.8.5 and 7.1.3, refers to single, possibly multiple, superimposed spatial or temporal areas of validity of single or any compositions of, explicit or sub-symbolic rules, parameters or networks.

In general, single structural; multiple structural; multiple, fixed or superimposed structural; or multiple, variable and superimposed structural regimes *relate to* the current validity of properties such as levels of clustering, mesoscopic dynamics, meta-structural, network, usage of degrees of freedom and values of the mesoscopic general vector.

Such structural regimes may be valid in various combinations or timing in an inhomogeneous way.

9. System Propagation

The topic is considered in Sect. 4.6 taking the hypothesis that the *status of being systemic*, intended as relating to properties at various possible levels, possessed or acquired by any entity or *process,* be no longer considered as *only* or *mandatorily* given by active roles due, for instance, to *interactions* of some kind.

Also considered is the suitability for studying the status of *systemic* as given, under suitable conditions, by properties, for instance, of the conceptual *hosting space*.

The hosting space may in its turn have active or non-active properties as an *environment* or *fields* adding, in active ways, properties to *internal* elements, for instance, when there are other elements and by supplying appropriated energy. *We may consider possible properties of the hosting space such as geometrical or topological ones for networks.*

The distinctions introduced above are in reality *simplifications* introduced to fix the ideas, while real cases are given by different levels of their possible dynamical combinations.

Propagation and diffusion are well-studied phenomena in various disciplines such as acoustics, electromagnetic, nanostructural, optical and seismic physics; chemistry; epidemics; and sociology. Approaches for influencing generic collective behaviours are allowed through the existence of *propagations*, for instance, of *phases* or patterns of activities through the network of connections.

The general idea is that forms of systemicity, such as the aptitude to acquire systemic properties and adopt systemic behaviour, could be *diffused* within the environment and hosting space, *emanated*, *induced* or even *transmitted* by systemic entities to other nonsystemic entities.

The general idea is to consider processes of any kind by which it should be possible to *propagate* from established systems a kind of *systemic regime* able to induce within sets of interacting elements the emergence of some kind of *systemicity*. Such *propagation* may occur in a variety of ways such as through interactions, environmental changes, information exchange, virtual structures (intended as *ways of respecting* degrees of freedom given, for instance, by real structures) or networking.

This subject can be introduced by distinguishing the *propagation* of nonautonomous or autonomous systemic properties, i.e. possessed or acquired by systems whose components, respectively, possess or do not possess cognitive systems.

Examples of properties possessed by nonautonomous systems are given by synchronicity, order parameters or the validity of a structural regime in the presence of simple belonging, e.g. immersion into and interaction with a systemic network, or meta-structural environment, inducing the acquisition of systemic behaviour.

Examples of properties for autonomous systems are given by considering *cognitive environments* deriving from cultures, ideologies, religions, languages and cognitive models.

In order to modify a collective behaviour, we consider the approach based on *inserting a* Perturbative Collective Behaviour (PCB)*,* see Sects. 3.8.4.5 and 4.6.1, *within* the collective behaviour to be modified to induce suitable changes. The inserted collective behaviour is not intended to *slave* the previous one through trying to *substitute* its behaviour but to suitably influence it in order to generate the emergence of a modified collective behaviour. Suitable strategies should be considered for such insertions.

10. Between

As introduced in Sects. 2.6 and 2.7, post-GOFS pays attention to *worlds* occurring *between*. For instance, between entities and processes considered as occurring at the same level of representation or at different levels of representations. Examples of the first case occur when considering states such as on-off, generic start and end-states, scaling, true or false, motion or constraints. Examples of the second case occur when considering processes of changing related to complexity given by structural changes or sequences of acquired emergent properties or when considering mesoscopic variables as in Sects. 2.3, 2.4 and 7.1 as well as multiple thresholds and multiple clustering.

Regarding the first case, with the same level of representations, focus is placed on the process of changing between the two possible states by introducing, for instance, different scales allowing one to elicit the between. The classical, simplistic approach is to consider this *between* as being *empty*, non-existent.

In classical geometry this related to possible *empty holes between* points. This is the subject of the famous Cantor's antinomy. Referring to the concept of the *power of a set*, expressed by its *cardinality*, that is the possibility of a one-to-one correspondence of its elements with the elements of another set, many questions arose. For instance, can a set having an infinite number of elements have more or fewer elements than another *corresponding* set having an infinite number of elements? Can a part of an infinite set be in biunivocal correspondence with the infinite set?

This relates to the case where segment length has nothing to do with the number of points as in Fig. A1.3 where at *any M* on *BC* there corresponds a unique specific point *M'* on *AB* and the fact that $AB > BC$ does not mean that they have a different number of points.

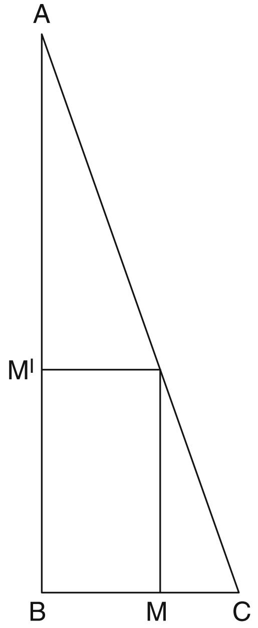

Fig. A1.3 Correspondences between points belonging to the segments BC and AB in triangle ABC

The length has nothing to do with the number of points. It makes no sense to refer to the *number of points* but to the *power of a set*.

The general idea is that *between two points there is almost always another point*.

Between states of on and off, there is a *short* time when a device receives less or more energy; between working and nonworking, there is a *short* time when a device begins or stops working, and something begins or stops being false or true.

The crucial point is that, depending on the level of description adopted, events occurring over such a short period of time are considered to be *insignificant*.

Through the use of different levels of scaling, it is possible to consider *levels* occurring between the two states as well as the properties of sets of such levels as in the case of the *usage of levels of freedom* discussed in Sects. 2.2 and 3.7.2.

Regarding the second case, different levels of representations, the focus is on *transitions* between *nonequivalences*, such as events requiring different levels of representation. A typical example is given by phase transitions. In first-order phase transitions, as for water-ice-vapour, there is temporary coexistence of phases, while this is not the case in second-order phase transitions, such as paramagnetic-ferromagnetic transitions. Other examples of transitions occur in processes of learning; during transience before self-organization, when processes of emergence allow sequences of acquired emergent properties such as behavioural ones, or decisions due to collective intelligence; or the topological properties of networks. The between is the *place*, the period of time during which (new) coherence is established and selection among various possible equivalent configurations, e.g. direction of Bénard rolls, occurs.

This is based on the philosophy of the ‘middle way’ (Laughlin et al., 2000) which considers the *mesoscopic* level of description as an area of *continuous negotiations between micro and macro* and the definition of families of possible observables as a research strategy.

Another example relates to the between degrees of freedom, i.e. their usages, see point 26 below.

11. The transient

Section 3.9 mentioned how structural dynamics could be understood to suitably represent changes between, for instance, phases, ontologies, levels of emergence and properties.

The transient relates to some aspects of the *between* as given by modalities, *properties* of potentialities rather than potentialities themselves, as well as boundary conditions, as already mentioned in Sect. 2.4., 2.6 and 2.7.

Focus is placed upon modalities and properties of transience such as continuous, discretised, convergent, irregular, etc.

This relates to the case of *usage of degrees of freedom* as outlined in point 26.

This is a real line of transdisciplinary research dealing with *general systemic properties*, i.e. *properties of properties*, impossible to approach within the context of GOFS.

12. Irreversibility

Reversibility is considered as the possibility of exchanging t with $-t$ in analytical representations of phenomena *completely* described by evolutionary rules without changing system behaviour. Irreversibility occurs when such a possibility cannot happen either because of certain limitations or *in principle*. Irreversibility, see Sect. 2.2, considered here relates to this latter case. It occurs when a complete analytical description is impossible rather than not *yet* available. This is the case, for instance, for dissipative structures (whirlpools), chaotic processes very sensitive to initial conditions, (smoke diffusion), as well as processes of self-organization and emergence. This is due to the *uniqueness* of such processes continuously selecting, for instance, through fluctuations and noise, various possibilities or configurations considered as *equivalent*, for instance, with regard to the respect of boundary conditions and degrees of freedom. *Theoretical irreversibility should be intended as the price of uniqueness.*

13. Non-separability

This topic, discussed in Sect. 2.3, relates to general aspects including (a) the possibility of considering interdependent processes as separate ones and allowing the possibility of obtaining *independent representations and models* notwithstanding correspondences and interactions, e.g. observer-observed and system-environment; (b) the possibility to consider, perhaps temporarily, *separate* systems of Multiple Systems establishing, for instance, ecosystems, levels of emergence or meta-structural regimes.

Both these aspects can be considered as re-editions of *reductionism*.

The point is that emergence cannot be *theoretically* represented as being given by the *functioning* of interactions between conceptually separate parts. It should be intended as a property of the general system having one single representation. General, local, temporal and partially acquired properties should be modelled in a unitary way, as when considering topology for complex networks, meta-structures and regimes of validity ensuring dynamical multiple coherences. For instance, *scale invariance, network and meta-structural properties exist only when considering the collective behaviour in its totality*.

In GOFS possible non-distinguishability, non-separability, non-traceability, and intractability of multiplicity of various interactions and individual agents were dealt with by using, for instance, statistical approaches and macroscopic indices.

In post-GOFS, possibly different, superimposed, and nonequivalent representations are considered through DYSAM-like approaches.

Within this conceptual framework, we consider at least three kinds of approaches based, for instance, on:

- Representation of one phenomenon in terms of another, i.e. they cannot be represented as *separate*. For instance, we should consider the couple *observer-observed* modelled with uncertainty principles, whose *theoretical incompleteness* is dealt with by constructivism and sub-symbolic approaches. Variables, properties and interactions should be formulated as multiple, *generalizing* the approach considered for the uncertainty principle as for aggregate variables given by *mesoscopic variables* used in Synergetics and meta-structures.
- Long-range correlations as *distance-independent*, i.e. violating the assumption that the strength of interactions decays with distance.
- Environment defined by *context-space-temporal properties*. In the classical view, the environment can be separated when properties can be considered deactivated *inside* and at the best *varied* in areas considered as being specified by its boundaries. Here the environment emerges from its interacting *original* components, thus becoming fully correlated as in ecosystems. Moreover, the conceptual selection of the environment allows one to find different descriptions of the *same* phenomenon. For instance, the probabilistic features of quantum mechanics (QM), based on particle-wave duality and uncertainty, or quantum field theory (QFT) assuming that the main physical entities are fields (of force) and not particles can be considered as a consequence of the fact that the ground state of the Universe is a particular kind of noisy state, preventing the existence of truly deterministic phenomena. This approach studies quantum fields by considering them as deterministic entities influenced by noise in a context in which time is imaginary as in statistical field theory. In QM and QFT non-separability is unavoidably given by properties of the void and termed *entanglement*.

We can, of course, still use approaches based on separation, but we must realize that this is a *level of simplification*. While this may be contextually effective, it is not generalizable because of its *severe theoretical limitations making emergent properties and mechanisms of emergence theoretically* ***invisible***.

14. Non-causality

An effective approach to this subject, discussed in Sect. 5.4.3, is to assume it as being related to abductive reasoning when distinguishing, for instance, between correlation and causality, since *correlation does not imply causation* and *correlation does not imply causation.*

The simplest concept of *causality* is given when assuming that an output, at any given time, depends only on past and present values and where certain terms are intended as causes and others as effects. Different forms and levels of causality are possible, such as linear, non-linear, multidimensional, first- and second-order causality [3] and so-called *Granger causality* (Ancona et al., 2004; Chen et al., 2004; Granger, 1969; 1980).

Moreover, systemic causation may be considered due to possible multiplicity of *causes*, such as probabilistic, networked, feedback based or non-linear. This is the case for chaotic systems where inputs are processed on the basis of initial conditions and which have long-term unpredictability since fluctuations may continuously *destabilize* the system by producing classical paths as attractors.

However, while assumption of the concept of non-causality really ***excludes*** *its various possible forms, it could also introduce some possible related new representations dealing, for instance, with theoretical incompleteness, uncertainty or of a nonsymbolic nature.*

Typical cases are given by *phenomena of the emergence of collective behaviours not* reducible *to sequences of cause effect, where emergence is continuously* locally 'decided' *by equivalences breaking in different ways and by keeping global coherence.*

We may state that causality is conceptually *substituted* ***by approaches which induce and maintain coherences*** as when dealing with network, meta-structural, topological and quantum properties.

15. Non-invasiveness

This subject is discussed in Sect. 5.4.1, and the concept is used here to underline that post-GOFS systemics does not adopt an *external* viewpoint when considering systems, their properties and problems in general. This means that it is considered possible to *decide, consider something as functioning, adopt the purpose to repair, replace or update*. In these latter cases, interventions are *explicit* since the general idea is to act on the system or upon phenomena as *functional*, *designed*: it is assumed that we know the rules given by the explicit symbolic model.

Invasiveness also means to insert *something which is assumed to do something the system is no longer able to do*, replacing or requiring explicit interventions.

Non-invasiveness generally indicates alternative approaches to *influencing* based, for instance, on post-GOFS concepts such as those listed in Table A1.1 and their suitable, possibly non-linear, networked, or dynamical combinations, suitable to *induce* the systems or the phenomena to change their behaviour as modelled by meta-structures or networks possibly combined.

Table A1.1 Some post-GOFS concepts

Between	Quasiness
Dynamical coherences	Regimes of validity
Long range correlations	Remote synchronisation
Non-causality	Scale-freeness
Non-prescribability	Small-world networks
Perturbative collective behaviours (PCBs)	Structural dynamics Topological properties and dynamics
Power laws	Usages of degrees of freedom
Pre-property	Environmental variations such as setting energetic or structural boundaries

In these cases the non-invasiveness is assumed to suitably ***destabilize*** *equivalences and* ***compete with fluctuations.*** This applies to complex systems and particularly to systems having different levels of complexity such as ecosystems, living systems or when dealing with medical interventions.

16. Non-prescribability

This subject is discussed in Sect. 5.4.2 and is mainly related to non-invasiveness, described above in point 15.

This point regards the impossibility of *explicitly* prescribing properties and behaviours of complex systems.

Explicit prescriptions are intended as parametrical and structural *variations* to symbolic, *complete* representations of systems or phenomena.

Interventions of this kind are inappropriately applied to unsuitable representations. We consider *non-explicit prescribability*, no- or low-intensive invasiveness and low energy in order to *induce* processes of emergence without *regulation* since *explicit*, *intensive* interventions are *incompatible*, non-processable by complex emergent systems, as discussed in Sects. 1.3, 4.2.7 and 5.6. Examples are given by *weak* (with reference to original values) changes in prices, taxation and exchange rates in the economy or biochemical equilibria in living systems. Examples of radical invasive interventions are given by possibly *necessary substitutions* leading then to deal with processes such as organ transplants or social rejection.

Complex systems can explicitly only be *destroyed* by strong explicit interventions since their multiple coherences and selections among equivalences are theoretically incomplete, nonsymbolically and non-analytically representable, non-explicitly *ruled*. Such interventions are conceptually like electric shocks or like a *bull in a china shop*.

Non-prescribability means that it is not possible to give *orders*, given their explicit, symbolic nature, to complex systems but rather suggestions using non-invasiveness. Actually, *invasive actions* relate to *prescribing* symbolically, i.e. substituting, removing, modifying or introducing structures.

When dealing with complex systems, we need to suitably and dynamically combine *alternatives* between prescribing or not prescribing. This is the situation for quasi-systems where we dynamically combine a variety of invasive *and* non-invasive, prescribable *and* non-prescribable approaches.

A general thesis and proposal of this book are that suitable general approaches to deal with complex systems are given by acting upon processes of emergence as when *prescribing*, in a DYSAM-way, network properties, regimes of validity and meta-structural properties and their possible changes.

Prescriptions *of such properties are not* ***linear****, nor* ***explicit****, but require approaches and strategies to* ***induce*** *them within the system* ***as if it were the system itself deciding to acquire them***. It is a question of inducing the acquisition of emerging properties.

Another example is given by considering the approach based on using Perturbative Collective Behaviour (PCB) to influence a collective behaviour (see Sect. 3.8.4.5).

An interesting example in medicine is given by the so-called *placebo effect*. We refer to the progress made in understanding the neurobiological mechanisms of the placebo effect allowing new light to be shed on mind-body interactions. *The point is that mental events induced by placebo administration can activate processes similar to those generated by drugs and such effects occur only if cognitively expected*. These new neurobiological advances change the conception of clinical trials and medical practice (Colloca and Benedetti, 2005).

17. Pre-properties

A pre-property, discussed in Sect. 4.1, and in contrast with the concept of quasi-property considered in point 19, is *initially* partially, irregularly, possibly converging towards a property, in a possibly inhomogeneous, implicit and unstable way.

The concept of pre-property may be intended as representing sets of properties visited or acquired by the system over time by keeping levels of coherence while adopting definitive *convergence* to one specific property.

The prefix pre- does not mean that the property is necessarily expected to convert into an explicit form, i.e. symbolic or materializing into something possessing such a property.

The prefix *pre-* should be not intended as *in progress* or in the process of adopting some explicit form but as a situation of metastability.

It relates to situations where systems *explore possibilities* which can perhaps be adopted. Consider the case of combinations of evolution and self-organization studied, for instance, by Stuart A. Kauffman. Instabilities of attractors act as a source for creating pre-properties which can then be consolidated. *It is a kind of creative process for systems*.

The concepts of lightness and non-invasiveness relate to the need to respect and facilitate this kind of creative process for complex systems respecting their implicit, incomplete forms.

The possibly only partial validity of meta-structural, network properties may be the clue that some pre-properties are active.

Pre-properties may be understood occurring during the early stages of the establishment of processes of emergence.

Pre-properties are *explored* by the system through configurations, incomplete roles and *unstable* emergent properties. *Detection of pre-properties can be looked upon as the detection of unvoiced potentialities or collapsing potentialities.*

An interesting case combining the two features of pre- and emergent properties is given when considering *collective intelligence*. In this case the process of emergence is assumed to take place and progress through an established collective behaviour. The collective behaviour comes *first* and eventually *hosts* and *generates* a process of collective intelligence. Collective intelligence is a property emerging *on request within* the collective behaviour. The r*equest* may be represented by a perturbation such as the detection of a predator by a flock or swarm. However, collective intelligence may be understood as an implicit pre-property, *potentially* given by multiple coherent structures. The actuation of such potentialities often occurs through fluctuations and perturbations.

18. Quasi

As discussed in Sect. 4.2 and following, the term has been used for a long time in various disciplinary areas. For instance, for ordered but not periodic structures in quasi-periodic crystals, i.e. *quasi-crystals*. Their patterns lack *translational symmetry*. *Fibonacci quasi-crystals* possess aperiodic structures.

Other examples include, for instance, quasi-homogeneity, quasi-homology, quasi-iteration, quasi-openness, quasi-probabilistic, quasi-random, quasi-regularity and quasi-reversible. The list could also include quasi-Turing machines, and one also needs to consider *quasi-networks* and *quasi-meta-structures*.

We consider *quasi* as a dynamical and *structural incompleteness*, a real identity of the intrinsic *becoming* of the quasi. Conversely, *fuzziness* relates to well-defined levels of belonging over time or probability as a computable uncertainty, i.e. *certain uncertainty*.

Moreover, we have also introduced the concept of *quasiness* when intended as dynamical, partial stability or regularity in possessing quasi-properties.

We consider here the *implicit* conceptual framework represented by the usage of the term quasi- as being suitable to apply and depict several novel aspects of the new *prospective*, post-GOFS systemics such as between, dynamical coherence, non-explicit, systems identity, transient and uncertainty.

The ability to model *quasi* is a major challenge for new post-GOFS systemics.

It is not a *becoming* between states, but a becoming intended as a *virtual state* itself. Examples of such virtual states, becoming as quasi, include levels of emergence, properties such as coherences and network, meta-structural properties.

19. Quasi-properties

As discussed in Sect. 4.3 and following, two cases can be distinguished: (a) when properties are *quasi* since they are properties of a *quasi-system*, see point 21 below; and (b) properties are quasi by themselves, even leading the system to adopt the nature of a quasi-system.

Systemic properties acquired through functional and structured interactions or due to any kind of process of emergence may be unstable, with possible regularities, local or possibly partial. In the latter case, they are considered as quasi-properties. They may also be part of a stable or dynamical mix of regular and quasi-properties.

In the cases above, it is the ***nature of the properties*** *which make the system a regular or a quasi-system.*

Quasi-properties are assumed to *convert* a regular system into a quasi-system.

In the case of a mixture of regular and quasi-properties: a) if possessed by a quasi-system, the quasi-nature of the system remains and b) if possessed by a regular, i.e. non-quasi-system, its nature may vary depending on the mixture used.

Examples of quasi-properties are given by:

- Quasi-openness, when the property is, for instance, unstable, partial, i.e. relating to some aspects of the system, or local, relating to some subsystems only.
- Quasi-autopoiesis, when the property is, for instance, unstable, partial, i.e. relating to some aspects of the system, and local, relating to some subsystems only.
- Quasi-emergence, when there is, for instance, coexistence of emergence and organized systemic properties being the mix or sequences of any kind.
- Quasi-coherence. Beyond the analytical meanings used in mathematics, we consider quasi-coherence taking place with the occurrence of a) multiple different coherences as properties of the same entities as for Multiple Systems and collective systems and b) partial sequences of coherent Multiple Systems, i.e. not all are coherent.

20. Quasi-dynamical Coherence

While the case of dynamical coherence (see Sect. 3.2.4 and point 6 above) relates to multiple coherences, quasi-dynamical coherence relates to multiple *partial*, subsequent or even simultaneous coherences.

Partiality may relate to local inhomogeneous adoption of coherences, temporal sequences of coherences, non-regular sequences of coherences and different *levels* of coherences. Moreover, various possible cases which may occur separately or together in any combination are changes in dynamics as related to *structural regimes* assumed to represent coherences, including:

1. *Single structural regime*. At each step all the entities will interact according to any one of the available rules.
2. *Multiple structural regimes*. At each step each entity *selects* which of the available rules to use to *calculate* its new position.
3. *Multiple and overlapping* fixed *structural regimes*. At each step each entity can select to interact with $m > 1$ of the available rules by computing the resultant. The number m is constant for all agents.
4. *Multiple and overlapping* variable *structural regimes*. At each step each entity can select to interact with $s > 1$ of *any* the available rules by computing the resultant. The number s is considered variable.

The general property of quasi-dynamic coherence could be interesting during *transience* when *establishing and acquiring* coherences, losing coherences during processes of *degeneration* or when an unstable mix takes place setting a metastable situation as a pre-property which can possibly be suitably collapsed.

Real applications seem suitable for not-yet collective behaviours, as for populations of elements collectively interacting but not *yet* establishing a collective behaviour, such as Brownian motion.

Processes of quasi-dynamic coherence establish the *place* where metastable interaction is open to a variety of possibilities, and there should be suitable approaches to orient and facilitate emergence of the desired behaviour.

We may consider in general that a ***quasi-dynamic coherent phase*** *may be intended as an* ***open*** *phase where collective systems develop an emergent adoption, sometimes reducible to a* ***selection,*** *of coherence(s).*

21. Quasi-systems

A quasi-system (see Sect. 4.4) is, in general, intended as the inhomogeneous possession or inhomogeneous emergent acquisition of systemic properties. For instance, a quasi-system may be open to energy but not to information, and a quasi-logically open system may have limited levels of openness such as the ability to adapt but by using a limited selection of cognitive models. A quasi collective system may only have *zones* of coherences or be able to acquire collective intelligence and adopt intelligent behaviour only for specific events.

A quasi-system may be established by possessing dynamical aspects of instability due, for instance, to local or temporal inhomogeneity of its status of system. Correspondingly, systemic properties in this case will be local or temporal. For instance, a corporation may act as such, i.e. as a system, only during working hours, and some of its departments may act as assembly lines, i.e. as structured sets rather than complex systems, depending on the tasks carried out.

In the cases above, it is the ***nature of the system*** *which leads to the acquisition of regular systemic properties as quasi-properties.*

Another case occurs when properties of a system are quasi-properties making the system adopt the property of quasi.

Other cases can be considered when dealing, for instance, with *potential systems* where suitable scaling configurations can establish pre-systems in a metastable status, ready to become systems thanks to suitable *small* variations or fluctuations.

22. Complex Network Properties

Complex networks (see Chap. 8) are considered within the framework of *Network Science* definable as *the study of network representations of physical, biological or social phenomena leading to predictive models or at least descriptions of them*. Examples of networks under study are given by computers and telecommunication networks (the Internet) and biological, chemical, cognitive and semantic, economical, neurological and social networks.

Network Science originated from the theories and methods of graph theory, lattice theory, operational research, data mining, statistical mechanics, network engineering, statistical mechanics and sociology. Within such a context *complex networks* can be *scale-free* or *small world* (see Boxes 7.2 and 8.1). Networks can have properties such as cluster or hub emergence, degree sequence distribution, diameter, evolution, fitness, robustness, susceptibility to infection, topological correlation, topologies or average path length of all links.

When considering dynamical networks, their complexity is given by the ability to acquire and maintain emergent properties.

Complex networks can be considered as general representations of complex systems.

23. DYnamic uSAge of Models (DYSAM)

DYSAM, introduced by Minati et al. (Minati and Brahms, 2002; Minati and Pessa, 2006, pp. 64–75) and discussed in Sect. 5.3.2, is intended as meta-modelling, i.e. the usage of models, based on strategies to select, invent and use models. DYSAM is based on previous approaches including:

- *Successive applications* of Bayes inferences and the *inverse Bayes*.
- *Machine learning*, based on a large number of techniques including neural networks and genetic algorithms.
- *Ensemble learning*, whose basic idea is to combine an uncorrelated collection of learning systems all trained in the same task.
- *Evolutionary games theory*, based on the work, for instance, of Axelrod (Axelrod, 1984; 1997), Maynard-Smith (Maynard-Smith, 1982), and the von Neumann 'minimax theorem', stated in 1928.
- Pierce's abduction.

DYSAM was introduced as a *constructivist* approach given by:

- Suitable level of representations to be adopted.
- A possibly evolving strategy allowing the researcher to decide upon the most suitable combinations of models to be applied.
- A possibly evolving set of, perhaps interconnected, models available to the researcher, where interconnection may be given by using the same variables which could have been learned by a neural network.

The usage of DYSAM is required in cases where:

- A system can be described only through a number of *different partial representations*. This is the typical case for Multiple Systems and emergent systems acquiring different properties.
- A system allows a number of different equilibrium behaviours, which have the same probability.
- The model of a system must allow the introduction of noise or fuzziness, related to individual or unforeseeable phenomena, as is the case for biological, socio-economic or cognitive systems.
- The model of a system must necessarily incorporate a model of the observer of that system or a model of the model builder.

DYSAM is conceptually appropriate for dealing with generic quasiness, particularly for modelling quasiness of quasi-properties and quasi-systems.

Examples of situations where DYSAM is to be applied occur when a system needs to be described from different points of view such as biological or psychological in medicine or economic or sociological for social systems.

Other examples of applying DYSAM include deciding corporate strategies, usage of remaining resources in a damaged system (i.e. to *compensate* for a disability) and learning to use the five sensory modalities during development (the purpose is not to select the best one but to use all of them together).

We stress here the profound theoretical relationships with the concept of logical openness (see Sect. 2.7.1).

24. Meta-structures

Structure (see Sect. 3.2.2) is considered as organization with specified parameters (e.g. number of layers, *weighted* interconnections in neural networks or electronic circuits). Consider the structures of interactions between elements within a collective system. In the simplest case, it is possible to consider a population of elements all interacting through the *same* structure given, for instance, by the *same* rules of interaction as in Brownian-like motion or simple cellular automata.

There are also cases of *dynamical structures* where, for instance, elements may interact by using simultaneously or sequentially different rules as for Multiple Systems. Rules of interaction are contextually decided from time to time on the basis, for instance, of cognitive processing performed by agents.

There is also the case where interactions occur differently for each element or over time, e.g. due to learning and cognitive activities.

The term *meta-structure* denotes multiple simultaneous (of the same, in this case *superimposed* or different elements) or sequential structures of interactions. Such dynamical structures are suitable for studying and modelling collective behaviours.

The concept of meta-structure is introduced in Sect. 3.8, intended as a dynamical set of simultaneous, superimposed and possibly *interfering* structures of interactions. In short, a meta-structure is the *result* of processes of any, explicit or non-explicit, linear or non-linear, dynamic combinations of structures of interaction. Different structures may of course apply, having different starting times and durations. *A meta-structure is intended as a dynamical structure of structures.*

25. Meta-structural Properties

Various approaches can be used to formulate meta-structural properties (see Sect. 3.8.4). With reference to mesoscopic variables, as mentioned in Sects. 2.4 and 3.8.3, one may consider their values and properties of the sets of their values.

The possible coherence of sequences of configurations given by sequences of different structures establishing, for instance, collective behaviour, is considered in the meta-structural approach as being represented and given by suitable meta-structural properties, i.e. properties of such sequences considering, for instance,

- Suitable mesoscopic variables *transversally intercepting* and representing values adopted by aggregates of microscopic variables. Values of mesoscopic variables then represent the effects of applying rules of interaction.

- Suitable properties of sets of such values represent the possible coherence of sequences of configurations, as well as the *mesoscopic dynamics* introduced in Sect. 3.7.3, i.e. the collective behaviour given by multiple structures.

Generic examples of meta-structural properties include:

(a) Properties of the values acquired by mesoscopic variables, single or crossed, such as any regularities including periodicity, quasi-periodicity, chaotic regularities possibly with attractors which characterize specific collective behaviours.
(b) Properties, e.g. geometrical, topological or statistical, of sets of generic agents constituting mesoscopic variables and their changes over time.
(c) Properties related to the usage of degrees of freedom as introduced above.
(d) Relationships between properties of sets of clustered generic agents and macroscopic properties such as density, distribution, scale freeness and numerical properties such as percentages.
(e) Properties of the thresholds adopted for specifying the mesoscopic general vector.
(f) Possible topological properties of network representations, power laws and scale invariance.
(g) Possible levels of ergodicity.
(h) Possible statistical properties.
(i) Properties of sequences of the mesoscopic general vector $V_{\mathrm{k,m}}(t_i) = [e_{\mathrm{k,1}}(t_i), e_{\mathrm{k,2}}(t_i), \ldots, e_{\mathrm{k,m}}(t_i)]$, see Sect. 3.8.4.7, over time.
(j) Properties of elements belonging to clusters *identified* by mesoscopic variables, such as metrical or topological ones.

As in point 22, when considering network representations, the links between nodes may be intended as dynamical structures and their properties as meta-structural properties, which is also applicable to *networks* when considering their properties such as topological, fitness or scale-free. Nodes may be considered as mesoscopic representations when nodes are, for instance, mesoscopic variables.

26. Usage of Degrees of Freedom as Constraints

The concept of degree of freedom in mathematics relates to the number of independent quantities necessary to express the values of all the variables describing a system. For instance, a point moving without constraints in 3D space has three degrees of freedom because three coordinates are necessary to specify its position. Possible constraints *reduce* the number of degrees of freedom when, for instance, considering such a point as a *simple pendulum* having only one degree of freedom since its angle of inclination is specified by a single number.

In this book we consider the concept of degree of freedom in a more generic way as used in daily language, i.e. intended as a constraint upon values adopted by single independent quantities such as geometry, velocity or direction.

This subject (see Sect. 3.8.3.7) relates to what occurs *between* such degrees of freedom, i.e. the ways in which they are respected by the system. Depending on suitable scaling, there are varieties of modalities by which the system may respect the degrees of freedom.

Consider, for example, a collective behaviour established by *k* agents when they are all expected to respect the degree of freedom stating that values adopted by a variable representing agent behaviours, such as speed, direction or altitude, must not be greater than $V_{\max}$ nor less than $V_{\min}$, when considering speed. Note that values of $V_{\max}$ and $V_{\min}$ could be *phenomenological*, computed a posteriori per instant.

If we consider the value taken by the velocity $V_k(t)$, it is possible to calculate the degree of usage of its constraint as a percentage of $[V_{\max} - V_{\min}]$. For instance, *real* behaviour may occur when the velocity is close to its maximum or to its minimum or oscillating with regularities, regularly distributed or completely random.

Sequences of these percentages provide *histories of use, behavioural profiles* of the use of the degrees of freedom by each agent.

The possible properties of sets of these percentages provide properties of *histories of use*, properties of behavioural profiles of use of the degrees of freedom on the part of the collective behaviour. These possible properties, such as distribution, periodicity and quasi-periodicity may be considered as properties representing *types* of collective behaviours and can be used for acting upon the collective phenomena by prescribing some suitable extra-behavioural rules relating the usage of the degrees of freedom to, possibly some specific or all, the agents.

To conclude, Table A1.2 presents a short list of some exemplificative words and concepts of GOFS and post-GOFS systemics.

Table A1.2 GOFS and post-GOFS concepts

Example of words and concepts of *systemic* (GOFS) understanding	Example of words and concepts difficult for *systemic* (GOFS) understanding	Words and concepts of post-GOFS systemic understanding
Anticipation Automate Completeness Compute Context-independent Control Decide Definition Forecast Growth Objectives Optimisation Organise Planning Precision Regulate Reversibility Separate Solve Standardise True *or* False	Coherence Development Dynamic usage of models to maintain coherences Emergence Incompleteness Incompleteness as freedom for logical openness Multiple non-homogeneous Multiplicity Non-linearity Scenarios Self-organisation Simultaneous Uncertainty and incompleteness as resources Uniqueness	Between Equivalence/non-equivalence Irreversibility Induction of properties Meta-structural properties Multiple and dynamical Coherence Mutation Networks Non-separability Non-causality Non-invasiveness Non-prescribability Pre-properties Propagation Quasi properties Quasiness Topological dynamics Transient

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Appendix 2: Some Questions and Answers about the Post-Gofs

In this Appendix we present some type questions that we assume of interest for the reader. They all relate to the general cultural meaning of the issues discussed and their perspective significance to establish and study scientific processes in the conceptual framework of the *complexity* intended here, in great synthesis, to take place when processes of emergence, e.g. collective behaviours, occur.

In the GOFS *age*, the scientific activity could be metaphorically grasped through the image of *mining excavation*. The conceptual paradigm was, and still is, the one of the *discovery*, i.e. the discovery (as, for some reasons, it was *covered*, hidden), related to objectivistic assumptions.

Concepts like the ones of knowledge production, knowledge representation and knowledge management relate to new understandings moving the focus from discovery to *generation*, moreover distinguished from explicit *production*, intended as given by suitable methodologies, technologies and approaches. Generation emphasizes the *emergent aspect* of the scientific activities, emergent from social systems and intended as a social enterprise where to assume suitable strategies, decisions, investments and selections. It relates to *effective cognitive realities*.

The *non-discovery* aspects are also given by the non-linear dependence of the generated knowledge from the previous available one, the introduction – i.e. invention – of *paradigm shifts*.

This complex, networked process continuously moves from and to *multiple interdisciplinary stabilities*. Such dynamics and its multiple coherences should be understandable and modelled through the post-GOFS systemics.

Furthermore, post-GOFS systemics is assumed to *transdisciplinary study itself* like the theoretical versions of disciplines are assumed to study themselves, e.g. *theoretical* biology, physics, chemistry, economics, architecture, computer science and cognitive science.

The expecting contribute is to make future disciplinary projects to unavoidably become almost interdisciplinary and networked.

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The list of hypothetical questions we will deal with includes the following ones:

1. What is intended for GOFS?
2. What is intended for post-GOFS?
3. Why the post-GOFS is needed?
4. What are the differences between the post-GOFS and the QFT?
5. What are the differences between the post-GOFS and the Network Science?
6. Who is interested in the post-GOFS and why?
7. Who and where the post-GOFS is supposed to be studied and introduced?
8. Shall we expect a post-post-GOFS and so on?

1. What Is Intended for GOFS?

The acronym GOFS means Good Old-Fashioned Systemics.

The attribution ‘Good Old-Fashioned’ comes from the experience of artificial intelligence (AI). In the latter context, the acronym GOFAI (Good Old-Fashioned Artificial Intelligence) denoted the oldest original approach to AI, based only on endowing computers with logical reasoning and problem-solving abilities. GOFAI was the dominant paradigm of AI until the late 1980s. This approach was based on the assumption that intelligence was almost fully consisting in the high-level manipulation of symbols. Therefore the GOFAI’s main purpose was to endow a machine with intelligence, in particular of a general and human-like form.

The acronym ‘GOFAI’ was introduced by *John Haugeland* (1945–2010).

Analogously we can identify GOFS with the first phase of systemics devoted to overcoming the old mechanistic views.

GOFS relates to approaches considered and studied, for instance, by theory of dynamical systems, automata theory, control theory, cybernetics, games theory, Gestalt approach, systems dynamics, catastrophe theory, chaos theory and sociobiology. ‘General *system* theory’ introduced by *Ludwig von Bertalanffy* (1901–1972) had the purpose to *generalize* by using some key concepts such as the ones of interaction, general interdependence, openness and closeness, organization and homeostasis, in the general framework of an assumed *isomorphism* between disciplines and looking for the unity of science.

GOFS tried to connect and build systemics on *disciplines that are not anymore under way*. Systemic approaches, models, recommendations and theoretical efforts to unify and globalize were made by considering disciplines that largely do not exist anymore in their original formulation and as *single* disciplines.

Such disciplines have now *embedded* levels of interdisciplinarity due to methodological reasons as the usage of models and simulations and to the concept of system, *disciplinarily* considered. Today there are systems everywhere. Easy examples are given by physics, biology and chemistry to don’t mention quantum physics.

Furthermore the presence of *inherent complexity* in many systems showed that the old *post-disciplinary conceptual tools* (typically post-mechanistic) were not enough. Such a circumstance marked the end of the golden epoch of GOFS, even if the latter is still here, though unsuitable to deal with the complexity.

Actually the relation between disciplines and systemics ***reversed*** *since almost all disciplines use the concept of system, while theories about systems are needed to assume, and eventually theoretically generalize, systemic concepts developed* ***within*** *disciplines.*

The actual advances in domains such as theoretical physics, mathematics, information engineering, biology, medicine, neuroscience, chemistry and other disciplines offer a variety of new conceptual frameworks, approaches and technical tools enabling to support the project for the building of a fully new general theory of change as well as a new systemics dealing with *spaces of systemic properties* such as multiple emergence, multiple self-organizations, multiple coherences and multiple transience.

Systemics is called to introduce theories about itself like general theories of emergence. Network Science introduced an autonomous, i.e. not generated by previous disciplines or the GOFS, steps in this direction.

At the end of Appendix 1 we listed examples of typical concepts and words used by GOFS.

We are actually living an age mixing pre-GOFS approaches and GOFS-based approaches. While high-level education is almost ***inevitably*** *dealing with post-GOFS problems, standard education is still based on pre-GOFS making professionals not only unprepared to deal with complex emergent problems but allowing the wrong assumption that GOFS is the only suitable cultural offer to be considered to set advanced approaches. New paradigm shifts are often not considered.*

2. What Is Intended for Post-GOFS?

Post-GOFS may be intended as a conceptual framework where GOFS concepts and its approaches can be eventually considered as *particular cases*.

Furthermore, while GOFS was both incompatible, not reducible to disciplines albeit grounded on their extensions and non-linear usages, post-GOFS uses conceptual paradigm shifts and new approaches considered by disciplines themselves. In post-GOFS such disciplinary, system-based paradigm shifts and new approaches are transdisciplinarily studied, i.e. per se without referring to specific disciplinary cases or applications, like coherence, networks, self-organization and emergence. Such paradigm shifts become *transversal* like in the Bertalanffy's dream.

Transversality, differently from GOFS, is not given by the concept of system and usages of same approaches but by very general systemic properties considered in the conceptual framework of *complexity*.

Examples of such properties considered for systems (see Appendix 1) are:

Coherence
Dynamical coherence
Equivalence/nonequivalence
Irreversibility
Multiple coherences
Multiple structural properties
Network properties

Non explicitness
Non-separability
Non-causality
Non-invasiveness
Non-prescribability
Pre-properties
Quasi
Quasi-properties
Quasi-dynamic coherence
Quasiness
Structural regimes of validity
System propagation

Those properties correspond to different levels and kinds of complexity asking for new approaches such as network science, meta-structures and quantum modelling. We underline that we are considering ***multiple approaches****. Examples of crucial problems for post-GOFS relate to the study of their eventual formalization, equivalence or nonequivalence, combinations, observability and incompleteness. May they be formulated within a unified single theory?*

3. Why Is the Post-GOFS Needed?

Because of the complexity, *the greatest enemy* of the GOFS.

In sum GOFS is suitable for dealing with single, fixed, single-structured, repeatable and explicitly representable systemic processes leading to *acquisition* of single, fixed, repeatable and explicitly representable systemic properties.

GOFS is unable to deal with systemic processes different in their *nature*, i.e. when systemic processes may be still considerable as based on interacting components but, for instance, not always distinguishable, multiple, instable, having multiple roles; where interactions are multiple, variable, non-linear and non-explicitly representable; networked; and systemic properties are themselves variable, quasi, multiple within sequences of emergences, acquiring dynamical multiples coherence(s) with unavoidable theoretical roles of the environment and the observer.

Such inability is mainly due to the fact that models and approaches of GOFS are based on assumptions of separability, explicit representations, completeness, structural stability, non-multiplicity, possibility to distinguish and suitability of looking for single optimum models, when *dynamics is intended for single structures and not for structures themselves*.

Eventually *extended* GOFS approaches may consider multiple, networked, non-linear, simultaneous, subsequent and variable *causations* still assuming adaptation, replicability and stability as valuable assumptions like in the case of chaos, artificial life, Synergetics, neural networks, genetic algorithms and cellular automata.

Examples of different approaches establishing a post-GOFS include the ones considered by:

(a) Dynamical structures.
(b) Dynamical symmetries and quasi-periodicity.
(c) DYSAM.
(d) Multiple Systems and Collective Beings.
(e) Network Science by acting, for instance, on the topology of networks and the fitness of nodes.
(f) Power laws.
(g) Regulating boundary conditions and their change for necessary resources such as relating to energy made available, financial, temporal and spatial structures.
(h) Scale invariance.
(i) Quantum-based models.

The post-GOFS is a project looking for an eventual generalization able to include the previous approaches as particular cases and leading towards a suitable general theory of emergence as general theory of change.

We need post-GOFS to deal with emergent complexity in its various forms.

4. What Are the Differences Between the Post-GOFS and the QFT?

First of all we must notice that several general *systemic requirements* such as acquisitions of properties, interdependence, multiplicity, nonequivalence and acquisition of coherence are *intrinsic* in QFT thanks to the entanglement, the dynamics of the *quantum vacuum*, including the spontaneous fluctuations of all physical systems of the universe and an infinite number of nonequivalent vacua.

QFT is undoubtedly almost a *part* of the post-GOFS, as Network Science is.

However there is no *coincidence* in the sense that levels of descriptions and theoretical assumptions also different from the ones of QFT allow to model and explain phenomena of intrinsic emergence.

For instance, the probabilistic features of quantum mechanics (QM), based on the duality particle wave and uncertainty, and quantum field theory (QFT) assuming that the main physical entities are fields (of force) and not particles, can be considered as a consequence of the fact that the ground state of the Universe is a particular kind of noisy state, preventing the existence of truly deterministic phenomena.

Some systems described by deterministic laws, to which it was added a suitable stochastic ground noise, display behaviours identical to those of quantum systems, appearance of long-range correlations and collective effects.

For them it even possible to introduce a *Planck's constant* whose value differs from that of the traditional h.

In other words, the Planck constant could lose its unique value, and, in particular noisy contexts, we could have different 'Planck constants' as a function of noise intensity. Moreover, some authors (see Fogedby, 1998; 2002) were able to recast a stochastic reaction-diffusion model described by a suitable master equation in terms of an equivalent QFT, in which the value of the 'Planck constant' was equal to *1*. All these results point to the fact that a number of particular stochastic models could, from a formal point of view, be reformulated in such a way as to take on the appearance of a QFT-based model. Of course, in each case we would have to redefine in a suitable way the 'Planck constant' of the system. Such circumstances seem to suggest that, once granted the presence of the three fundamental ingredients of intrinsic emergence, that is non-linearity, spatial extension and fluctuations, allowing for coherence, all theories can be found equivalent to one another, at least with regard to their formal structure. This opens a new perspective on non-ideal models of emergence. If the above claim were true, then a non-ideal model, provided it is endowed with noisy fluctuations, should have a good probability of being already equivalent to a QFT model, without the need for quantizing it.

It then sets out a complex series of interrelations between chaos, noise, order, coherence and quantum processes, which constitutes the current object of study of science and of post-GOFS.

5. What Are the Differences Between the Post-GOFS and the Network Science?

A general equivalence should be based on the assumption that *any* systemic problem, process and property can be represented in terms of networks. Actually several of these problems and processes occurring in different disciplinary fields such as physics (even quantum physics in the case on the Bose-Einstein condensation), biology, economics, sociology and information science were successfully represented as networks as well their related processes of emergence.

Eventual nonequivalence should focus on phenomena and processes non-representable *in principle* as networks.

It reminds in some ways the *falsification principle* introduced, in opposition to the *verification principle*, by the 'Vienna circle'. According to *Karl Raimund Popper* (1902–1994), the main exponent of an approach based upon *falsifying*, any scientific theory cannot be selected once and for all, but it must be possible to confute it through experience. The success of a critical confuting experiment is sufficient to refute, invalidate, the hypothesis forming the basis of a scientific theory. Moreover any theory should be *completed* with a number, almost one, of *critical hypothetical falsifying* experiments formulated by the researcher introducing the theory or proposed by anyone proposing or assuming its general validity.

However in the case under discussion, which is the general equivalence between Network Science and post-GOFS, we should assume a less idealistic approach.

First of all we may consider the eventual different ***effectiveness*** *of the representations, models and approaches as sufficient distinctions, assumed having or not* ***epistemological*** *meanings.*

We consider here the discussion about DYSAM, already introduced, as suitable conceptual framework where to deal with several possible, eventually nonequivalent approaches introduced in the post-GOFS. *Their eventual coherence is a problem for the post-GOFS when GOFS eventual coherence is assumed* ***granted*** *in a unitary vision, Bertalanffy like. Within another vision the eventual* *incoherence is the manifestation of nonequivalences, irreducible multidimensionality, incompleteness and* ***complexity*** *of the world.*

The *territory* of post-GOFS is to detect and represent emergence and complexity *within* processes of change not 'domesticable' or treatable by using ideal models based on the assumption of predicting. The assumption, in this case, is the epistemological possibility of zipping the essential characteristics of change in a set of ideal equations.

However, since the processes of change are essentially 'historical' and marked by constraints, such approach is often unsuitable.

On the contrary post-GOFS begins by putting aside the 'prescriptive models' introduced according to aprioristic general principles and investigating the change starting from the past, that is, from its phenomenological history.

Post-GOFS searches for significant 'a posteriori' correlations within the history of the change itself, being eventually data driven.

The point above may be a useful example not as *falsification test*, but, rather as interesting example of irreducible *multidimensionality* of post-GOFS.

The point relates to the ***possibility*** *of* ***reformulations*** *of representations and approaches as* ***equivalent*** *in the post-GOFS.*

However, the occurrence of unitarily nonequivalent representations characterizes QFT occurring when different Hilbert spaces – each containing a unique ground state – are needed in order to describe symmetry breaking systems like in the case of ferromagnetism when at high temperatures the atomic dipoles fluctuate randomly and below a certain temperature they tend to collectively align to a specific direction and no direction is preferred.

Correspondingly, one has to employ nonequivalent representations. This appears to be a severe obstacle for any ontological interpretation.

We think that a crucial possible question will be the one of deciding if post-GOFS be established by using a conceptual world of equivalences or nonequivalences?

6. Who Is Interested in the Post-GOFS and Why?

A simple answer is *anyone dealing with complexity,* i.e. *problems intractable by using nonsystemic or GOFS approaches.*

One may consider that the world successfully *survived* the pre-complexity era without the post-GOFS. Were problems that we now term complex inexistent or non-recognized at all as such *before*? Are complex problems new or refinement, extensions and sophistications of the previous ones?

We are in some way considering changes as in physics from mechanics, to thermodynamics, electromagnetism and quantum physics.

Changes relate to the *nature* of problems, representations, approaches and *effectiveness* of modifying interventions.

Mechanical problems did not *turn* into thermodynamic ones.

Thermodynamic problems did not *turn* into electromagnetic ones.

The changing of such nature is matter of paradigm shifts occurring within science and dealing with *new* problems nonrepresentable by using previous approaches.

History of science is very explicative of such when interpreted as a *system*.

Post-GOFS should be considered in the same way as made possible, necessary and generated by the current system of technological and cultural resources and understanding and by *internal* scientific and cultural processes.

Then who is interested in the post-GOFS and why?

The assumption that our culture often has as *starting points* simplifications without uncertainty (or computable uncertainty), with completeness and without complexity is more and more *unacceptable because of its ineffectiveness* .

The reality should not be intended as a *platonic approximation* of perfect simplifications.

Changes of *nature* of problems calls (due to cognitive strategies) for new suitable approaches even given by the fact that *solutions to previous problems become and generate new problems*.

By assuming a constructivist approach, evolution of knowledge may be considered as combinations of formalist, searching for coherences and *activating* incoherencies as introduced at the beginning of Appendix 1, *and* creative, abductive processes of inventions of new, irreducible cognitive approaches and cognitive realities.

This may be intended as the unavoidable role of *knowledge agents*, generators of knowledge and cognitive reality, performing an evolutionary cognitive role. This is the step considered by cognitive science when science studies itself. This relates to the need to have suitable knowledge to deal with knowledge, complexity in any fields both in social systems (Minati, 2012) and science as considered in previous Chapters like 2, 5 and 9.

Knowledge agents are assumed to perform such processes of transformation in relation to science when ***matter represents itself cognitively***. This view has several conceptual historical references such as *Epicurus (342–270 BC), Titus Lucretius Carus,*[1] *(ca. 99–55 BC), Giordano Bruno (1548–1600)*, see, for instance, Mallock, 2007; Blackwell et al., 1998, and Schroeder, 1996.

The post-GOFS is expected to constitute a viable conceptual context for approaches and models able to deal with problems having ***different nature*** *realized by GOFS as* ***complex.*** *This has important effects on social culture* ***challenging*** *and not assuming reductionist views.*

In conclusion the knowledge agents are the subjects interested in the post-GOFS.

7. Who and Where the Post-GOFS Is Supposed to Be Studied and Introduced?

The GOFS was introduced from outside disciplines and disciplinary approaches. The post-GOFS is made necessary by developments occurring *inside* disciplines

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[1] *De Rerum Natura* by Titus Lucretius Carus.

themselves using in innovative ways the concepts of Systemics and because of complexity.

The post-GOFS is expected to generalize and theorize such new approaches.

GOFS was not *institutionalized* in schools, research institutions and professional trainings. Several institutions and associations worldwide were volunteering (*and* looking for local effectiveness and profitability) established to focus, make research, study applications and make education in GOFS. However, they are of very different cultural and scientific level, ranging from trivial to high level. Moreover some institutions have been established dedicated to study complexity.

Industrial and military interests are still, even not only, important actors to support such researches.

We may underline how studies on post-GOFS are expected to have *strategic nature*, looking for long-range scenarios. Economies when only looking for *survival* sequences of short-run consumerist cycles are not interested in the post-GOFS neither even in GOFS if not as money and time-saving tools generators.

The crucial question is who may invest in suitable research and applicative strategies and set scenarios? Future seems given by *extensions of short-run problems*, effects and methodologies.

Are only military industry free from short-run constraints?

In such a case, we should deeply reflect on what kind of social systems we have and on the meaning of their *development* (Nature 2011).

8. Shall We Expect a Post-post-GOFS and so on?

This question really relates to the epistemology of knowledge. We (or, better, future generations) should be ready for any sequences of interrelated knowledge. We can term the current on-going process as post-GOFS, but we have no concrete reasons to assume that the process may iterate or not in the future or radically change.

Knowledge creation is a complex activity combining constructivist aspects *balanced* with experimental activities considered as questions to nature who responds to our cognitive systems and cognitive models. Which nature, which questions and which answers we will get in the future?

We think that the first requirement is to don't label them in advance... avoiding to figure out *ultimate* phases.

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