COLLECTIVE BEINGS

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Preface

Why introduce a new concept such as *Collective Beings*, which is the subject of this book? The motivations are strongly rooted in the very history of Systemics. When its founding fathers, including Von Bertalanffy, Ashby, Boulding, Von Foerster, for the first time recognized the potential associated with the concept of "system" and understood that there were new possibilities for controlling and managing complex systems, physical as well as social, they were forced to rely on the achievements of systems theory existing at that time. This produced a great disparity between the available tools, on the one hand, and the complexity of the problems to be dealt with on the other. It was this disparity which limited the effectiveness of the application of Systemics to a whole range of domains, nothwithstanding the revolutionary importance of its ideas.

Over the years, however, the situation has changed and new contributions have increased the power of systemic tools: theories of self-organization, phase transitions, collective behaviors and of emergence have allowed a better understanding of many problems connected to extremely complex systems. Nevertheless, these new achievements were reached within specific disciplinary domains, such as physics, computer science or biology. In a number of cases this prevented a complete understanding and a correct assessment of their systemic value by researchers accustomed to different cultural traditions. Now is the time for a profound reflection upon these topics and for ascertaining whether the new tools will allow Systemics to make a qualitative leap towards dealing with more complex systems, which we call *Collective Beings*.

Roughly speaking, the concept of Collective Being embodies the main features of complex systems, such as social ones, made up of a number of agents, each endowed with a cognitive system, and belonging simultaneously to various subsystems. The introduction of this concept takes us beyond the traditional conception of systems in which each element is associated with a list of features with fixed and invariant structures. Namely, in a social system every element (it would be better to call it an *agent*) can change its role with time or play, at one and the same time, different roles: for instance, within modern society I can play, at the same time, the role of consumer, worker, member of a family and so on.

Clearly, new conceptual tools are required for describing Collective Beings, as well as a critical revisitation of all previous achievements of Systemics, even technical ones. But the effort in this field is necessary if we want, in the near future, Systemics to play a more important role in managing complex social systems.The aim of this book, therefore, is to introduce *new* ideas and approaches, based upon the most advanced research achievements in self-organization and emergence, with the prospect of applying them to Collective Beings, so as to promote their use in various disciplinary contexts, improving our ability to design and manage systems.

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 Chapter 1, we summarize information about the basis of General Systems Theory and of the more general cultural field of *Systemics*. A brief reference is also made to historical circumstances. Some outstanding contributions to dynamical systems theory (related to the concepts of equilibrium, limit cycles, chaos) are presented in some detail, even of a technical nature.

Chapter 2 discusses the fundamental role of the observer in modern science, mostly with reference to emergence. This entails an assessment of the role of uncertainty principles in science.Chapter 2 also introduces one of the new core ideas proposed in the book, the one of the *DYnamic uSAge of Models* (DYSAM). It applies to situations commonly occurring when dealing with complex systems, in which we cannot, in principle, resort to a unique model (the *correct* one) to describe the system being studied. Thus we are forced to allow for a multiplicity of different models (and modeling tools), all related to the same system. In this context DYSAM refers to the ability to *systemically use* the available models by *resorting to*:

- their results in a *crossed* way, that is when one is considered as a function of another, by *using* what are assumed to be *mistakes* (according to an objectivistic view) and not just *avoiding* them;
- learning processes developed on pre-processed frameworks, on past, current or expected contextual information;

- context-sensitiveness, depending on the global context, without reference to the specific decision or selection to be made;
- behavioral strategies adopted for any reason;
- any kind of recorded information to be considered for making decisions;
- affective-cognitive processes such as those regarding emotional activity, affection, attention, perception, inferencing and language.

An amusing computer simulation of a DYSAM-like behavior is presented briefly at the end of the Chapter.

Chapter 3 is devoted to a preliminary discussion of the concept of emergence. In this context we introduce the second new idea presented in the book, the one of Collective Beings. As previously outlined, this expression denotes systems emerging from interacting subsystems, in turn consisting of interacting agents simultaneously belonging to various subsystems. *Belonging* in this case means that the *same* components make different systems *emergent*. Nevertheless these roles may be played **at different times or simultaneously.** We see how such a level of complexity in emergence is related to the ability of autonomous agents to use the *same* cognitive models over time. This concept is obviously related to the topic of collective behaviors. On this point, we introduce a distinction between collective behaviors occurring within systems such as flocks, swarms and herds and those characterizing the emergence of Collective Beings. Namely, to use the metaphor of the flock, Collective Beings emerge from interactions among different flocks constituted over time by the same agents. Such a level of complexity is strongly related to the ability of the agents to use cognitive models. Human social systems are typically constituted in this way. We also refer to the idea that in each of these situations, the emergent subsystem, though it has the same components, may show different behaviors. These behaviors can be so different that, even though they have emerged from the same components, conceptually it is as if we are dealing with completely *different subsystems*. For example, the subsystem of a "crowd", emerging from people, may show the behavior of a riot, of people panicking or simply shopping, attending a concert or waiting for something to happen. Also, through *collective components* one subsystem may affect the other. If people have the experience of contributing to a riot, this experience may be remembered when they interact within another subsystem, such as a family or a company. When trying to model these situations we cannot rely on traditional models alone and we need an *architecture of usage* of different models, **a dynamic use of them,** as introduced with DYSAM. We can apply different models depending upon the context, the time, the kind of emergent behavior to be modeled or on the observer's purposes. The classical approach based upon the usage of single

models one at a time, searching for the most appropriate, the most effective, is not sufficient to manage, control and induce the emergence of Collective Beings. The classical approach based upon the **non-dynamic use of models** is quite adequate when interactions take place among inanimate particles, such as electrons, or agents following *single* behavioral models, but it is not suitable when interactions take place among agents using different **cognitive models**.
Examples of Collective Beings based upon components giving rise to subsystems having different behaviors according to their aggregation and interactions, include the stock exchange, families of financial operators, political parties, sports teams, as well as marketing centres, families, companies, clubs and financial companies acting on the same market, or within the framework of a global network engaging in many activities (as in the case of *Industrial Districts*), or within a virtual company.

Chapter 4 introduces a detailed reference to the theoretical tools available for the problem of modelling emergence, by focussing only on traditional methods. The latter methods were the first to be used at the beginning of Systemics and are characterized by the search for exact, deterministic results through rigorous analytical methods. Any reference to noise, fluctuations, uncertainty, probability, fuzziness is therefore banned from the start. An important part of this Chapter, is a short, although somewhat technical, exposition of the main findings of Dynamical Systems Theory, upon which all traditional methods are based. The topics dealt with include concepts such as stability, bifurcation, chaos and hierarchical systems. Ample space is devoted to the theory of Prigogine's Dissipative Structures, as well as to the theory of solitary waves and of models of pattern formation based upon differential equations. It is shown how all these theories are unable to describe intrinsic emergence, owing to the fact that they lack the tools for taking into account the role of fluctuations and of uncertainty. Nevertheless, they show remarkable potential for describing pattern-formation phenomena at a macroscopic level.

Chapter 5 is, obviously, devoted to a presentation of non-traditional models. It includes topics such as Synergetics, phase transitions, Quantum Field Theory, Symmetry Breaking, to cite only the idealized models. Even a bird's-eye view of non-idealized models is included, with references to topics such as neural networks, Artificial Life, cellular automata and fuzzy sets. The Chapter even contains a discussion about possible relationships between idealized and non-idealized models. It is shown how these models effectively allow a description of intrinsic emergence, even though in most cases the latter is too simple to account for emergence phenomena observed within biological and social systems. We also discuss the possibility of generalizing these tools to account for biological emergence and, as a final goal, for the emergence of Collective Beings.

Chapter 6 introduces the third new idea proposed in the book, related to the usage of ergodicity to detect emergence and to manage Collective Beings. The idea is based on the fact that during the process of the emergence of collective behaviors within a Collective Being the agents are not assumed, of course *with reference to an observer*, to all have the same behavior nor to be distinguishable from one another due to the fact that each one plays a different and well distinguishable role (as in organizations), which is constant over time. In emergence processes of this kind the agents can take on the *same roles at different times*, and *different roles at the same time*. Namely, as we are dealing with autonomous agents, the latter may behave by deciding at any given time which cognitive model to use or by using the same model at different times, that is with different parameters. This is why the possibility of an index for measuring the dynamics of usage of cognitive models may be very helpful for detecting emergence processes and the establishment of Collective Beings. The concept of ergodicity is proposed for such a purpose. In the Chapter we discuss how this concept, initially proposed within statistical mechanics to describe the behavior of physical systems consisting of identical particles, can be generalized to more complex systems, such as Collective Beings.

Chapters 7 and 8 deal with the application to Social Systems of the concepts and tools previously introduced. The topics considered include:

- *Growth, Development and Sustainable Development.* We discuss the problem of representing development, of describing development as a process of emergence, and of development for a Collective Being.
- *Ethics.* This topic includes the emergence of ethics, its crucial role for inducing and maintaining the emergence of social systems, its relationships with quality as well as its crucial role in keeping strategic corporate profitability.
- *Virtual systems.* Here the focus is on all those company devices (virtual and non-virtual, as specified in the text) which process virtual goods, such as money, shares, stocks, insurance products and information. Real goods are processed in these companies through "abstractions, information and images" as happens in e-commerce and in *Industrial Districts*.
- *Knowledge.* This topic deals with the fact that the production, management, distribution, application, transmission, approachability, classification, memorization, protection, representation and marketing of knowledge as well learning technologies will become more and more the core business of the Post-Industrial Society. The subject of knowledge

also refers to knowledge representation, knowledge management and organizational learning.

- Finally we discuss *Industrial Districts* as a typical example of emergence of Collective Beings in the economy.

Finally, the concluding Chapter 9 is devoted to a discussion about the application of the concepts introduced above to the study of cognitive systems (the essential feature of each autonomous agent belonging to a Collective Being) and, more in general, of Cognitive Science. The systemic approach sketched above entails overcoming the traditional computational approach used so far within this domain. The subject of this Chapter, therefore is mainly related to the conceptual tools available for going Beyond Computationalism.

The book also includes two Appendices. Appendix 1 lists brief descriptions of and information about some crucial theoretical concepts dealt with in the book. Appendix 2, on the other hand, discusses some general theoretical questions, supported by typical real-life examples, with proposed answers, related to the ideas, methods and concepts introduced in the book.

From this short description, it can be seen how the main scope of the book is to introduce new ideas for the control and management of human systems, in turn based on a lot of technical material, deriving from different approaches and different disciplines. It is evident how such a synthesis has been a very difficult enterprise. While aware of the intrinsic limitations of our effort, we hope that in some way it will be useful to all those rethinking in a critical way the very foundations of the systemic approach. Dealing with the problems related to Collective Beings is certainly necessary, but we consider that it cannot be the subject of a particular discipline (even though disciplinary knowledge is essential), owing to its transdisciplinary nature. We would consider this book as successful if the readers could include it within the category of transdisciplinarity.

Gianfranco Minati

Eliano Pessa

Foreword

In their impressive book, Gianfranco Minati and Eliano Pessa, introduce the concepts of Collective Beings in order to propose a conceptual tool to study collective behaviors. While such behaviors play a fundamental role in many scientific and technical disciplines, the authors focus their attention on socio-economic applications to be used, for instance, to increase corporate profitability and productivity. To this end, they provide the reader with deep insights into modern conceptual tools of economy based on systemics.

Collective behaviors are shown by systems composed of individual parts or agents. Minati and Pessa illuminate the interplay between system and individual in a remarkable new way: their collective beings give rise to systems having quite different behavior, namely that of the group and that of the individual agent. The authors always take all the various aspects into account - for instance the components of one system may be simultaneously the components of another system as well. They stress the importance of cognitive models used by the interacting agents, of the role of the observer and of the dynamic use of many cognitive models. They deeply penetrate into the concept of being virtual in contradistinction to being actual. They underline the role of ethical agreements, jointly with a careful discussion of different concepts of ethics as well as their relation to quality. I fully agree with their view on systemics as a cultural framework crossing disciplines. Their book is coined by a profound humanitarian attitude, for instance when they state that often technological solutions are designed for problems rather than for people having these problems. I have found the two appendices on systemics characteristics and on various critical questions concerning systemics, e.g. on systemics as a discipline, on the possibility of its falsification, etc. highly informative.

I have read this book not only with the utmost interest, but also with great delight and I can recommend it highly to all those who are interested in the modern and fascinating field of systemics.

Hermann Haken

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Chapter 1

THE BACKGROUND TO SYSTEMICS

1.1 Introduction

This book is devoted to the problems arising when dealing with emergent behaviors in complex systems and to a number of proposals advanced to solve them. The main concept around which all arguments revolve, is that of Collective Being. The latter expression roughly denotes multiple systems in which each component can belong simultaneously to different subsystems. Typical instances are swarms, flocks, herds and even crowds, social groups, sometimes industrial organisations and perhaps the human cognitive system itself. The study of Collective Beings is, of course, a matter of necessity when dealing with systems whose elements are agents, each of which is capable of some form of cognitive processing. The subject of this book could therefore be defined as "the study of emergent collective behaviors within assemblies of cognitive agents".

Needless to say, such a topic involves a wide range of applications attracting the attention of a large audience. It integrates contributions from Artificial Life, Swarm Intelligence, Economic Theory, but also from Statistical Physics, Dynamical Systems Theory and Cognitive Science. It concerns domains such as organizational learning, the development or emergence of ethics (metaphorically intended as *social software*), the design of autonomous robots and knowledge management in the post-industrial society. Managers, Economists, Engineers, as well as Physicists, Biologists and Psychologists, could all benefit from the discoveries made through the trans-disciplinary work underlying the study of Collective Beings.

From the beginning, this book will adopt a *systemic* framework. The attribute "systemic" means that this framework fits within *Systemics*, a thinking movement which originated from *General Systems Theory*, proposed by Von Bertalanffy and from *Cybernetics*, introduced by Wiener and developed by Ashby and Von Foerster (Von Foerster, 1979). A systemic framework is characterized by the following features:

- Focus is placed upon the global, holistic properties of entities qualified as *systems*, which, in general, are described in terms of elements and of their interactions;
- the role and the nature of the *observer*, as well as the *context*, are taken into account, as far as possible, within the description and the modelling of each and every phenomenon;
- the goal is not that of obtaining a *unique, correct* model of a given behavior, but rather of investigating the *complementary* relationships existing between *different* models of the same phenomenon.

In order to better specify the domain under study, we will introduce, distinctions (which could even be considered as hierarchical) between different kinds of systems:

- *simple systems*, where each component is associated (in an invariant way) with a single *label* (which could even be a number), specifying its nature and allowed operations ; a limiting case of simple systems is given by *sets*, in which the individual components cannot perform operations, but only exist;
- *Collective Beings* (Minati, 2001), where each component is associated (in a variable way) with a *set of possible labels*; the association between the component and the labels depends upon the *global behavior* of the system itself and can vary with time; a typical case is a flock of birds, within which each bird can be associated with a single label, specifying both its relative position within the flock and the fact that its operation consists only of flying in such a way as to keep constant its distance with respect to neighboring birds. Such an association, however, holds as

long as the flock behaves like a flock, that is like a single entity; as soon as the flock loses its identity, a single bird becomes associated with a set of different labels, specifying different possible operations such as flying, hunting, nesting and so on; this new association can define a different Collective Being, such as a bird community;

- *Multi-Collective Beings*, characterized by the existence, not only of different components, but even of different levels of description and of operation; each component and each level is associated (in a variable way) with a set of possible labels; the forms of these associations depend upon the relationships existing between the different levels. Examples of multi-Collective Beings include the human cognitive system and human societies.

This book principally considers the study of Collective Beings and, in addition to a review of the existing approaches for modeling their behaviors, we will introduce a general methodology for dealing with these complex systems: the DYnamic uSAge of Models (DYSAM) (Minati, 2001). The latter will be applied to cases in which it is manifestly impossible, in principle, to fully describe a system using a single model.

This chapter will introduce the reader to some fundamental concepts of Systemics, by starting from a short history of Systemics and of the associated evolution from the concept of 'set' to that of 'system'. Several examples will help the reader in this introductory approach. The distinctions between sets, structured sets, systems and subsystems will allow the reader to better understand new theoretical concepts, introduced in subsequent Sections of this book, such as those of Collective Beings, of DYnamic uSAge of Models (DYSAM) and of Ergodicity, within the context of the tools used to detect emergence.

In the second part of this chapter reference will be made to some technical tools of Systemics both to complete the historic overview and because they serve as an introduction to Chapter 4, where we will deal with the problems of managing emergence.

1.2 What is Systemics ?

The father of Systemics was Ludwig von Bertalanffy (1901-1972). He was one of the most important theoretical biologists of the first half of the Twentieth Century. His interdisciplinary approach (researcher in comparative physiology, biophysics, cancer, psychology, philosophy of science) and his knowledge of mathematics allowed him to develop a kinetic theory of stationary open systems and General Systems Theory. He was one of the founding members and Vice-President of the Society for General Systems Research, now renamed as the International Society for Systems Sciences (ISSS). The "Society for General Systems Research" (SGSR) was formally established at the 1956 meeting of the American Association for the Advancement of Science (AAAS), founded in 1848. The SGSR was born under the leadership of Ludwig von Bertalanffy, the economist Kenneth Boulding, the neurophysiologist Ralph Gerard, the anthropologist Margaret Mead, the psychologist James Grier Miller and the mathematician Anatol Rapoport.

Von Bertalanffy held positions, to mention but a few, at the University of Vienna (1934-48), the University of Ottawa (1950-54), the Mount Sinai Hospital (Los Angeles) (1955-58), the University of Alberta (1961-68) and the State University of New York (SUNY) (1969-72).

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. 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*.

In this book, instead of using terms such as *Theory of General Systems* or *General Systems Theory* we will use the word *Systemics*, widely used in English language systems literature (see par. 1.3, point i), keeping in mind the distinction mentioned above, and emphasizing that the reference is not only to the scientific domain, which is the topic of this book, but to an overall, general approach towards understanding phenomena in an interdisciplinary manner. The meaning adopted for the word Systemics, therefore, will be that specified in the introduction to this chapter, with the proviso that such an approach to the study of scientific questions will need the design of suitable methodologies and technical tools, which will be described in this book.

1.3 A short, introductory history

In this chapter a short introductory history of systems thinking will be outlined. The reader, by using some of the keywords and consulting a history of philosophy and science and encyclopaedic sources, some of which are listed in the bibliography, will be able to reconstruct a disciplinary framework adequate for his/her interest and background. Information about the history of systems thinking evolution is available in the literature in many books and papers (see, for example, Von Bertalanffy, 1968; Umpleby and Dent, 1999). References and key concepts are also described in Appendix 1.

a) The concept of System as a **mechanism** and as a **device**. From the idea of system as a configuration of assembled components, producing a *working* mechanism, based on the concept of *machine*, in its turn based on many concepts of classic physics, it is possible to extrapolate the powerful abstraction of *device*. The latter concept still makes reference to assemblies of components working as a whole, but having non-mechanical relationships among the components themselves; typical examples are given by electronic devices or software programs. In these cases we may refer to abstract entities, such as procedures, and within this context we will deal with *systems control*, *automata theory*, *control techniques*. This context is known as *Cybernetics*, a term coined from the Greek "pilot of the boat" (Ashby, 1956). This approach provided the basis for modern **systems engineering** (Porter, 1965).

b) **Cybernetics** has been very important in the process of establishing systems thinking. It has been defined as the science of behavior, communication, control and organization in organisms, machines and societies. One of its salient features was the introduction of the concept of *feedback*, viewed as a sort of self-management or self-regulation. Cybernetics as a scientific discipline was introduced by **Norbert Wiener** (1894-1964) in the Forties (Wiener, 1948; 1961), with the goal of studying the processes of control and communication in animals and machines. Initially, (Ashby, 1956; Heims, 1991) it was identified with information theory. A very well- known stereotyped example of a cybernetic device, often used in a metaphorical way, is Watt's centrifugal regulator designed for steam engines (see Figure 1.1): it is based on a feedback process able to keep constant the angular velocity of a steam engine. As can be seen in

Figure 1.1 the base R of the regulator moves upward or downward, its direction of motion depending on the rotation speed of the shaft A. If the base R of the regulator is connected to a regulating valve, the device is able to self-regulate by keeping the shaft rotation velocity constant.

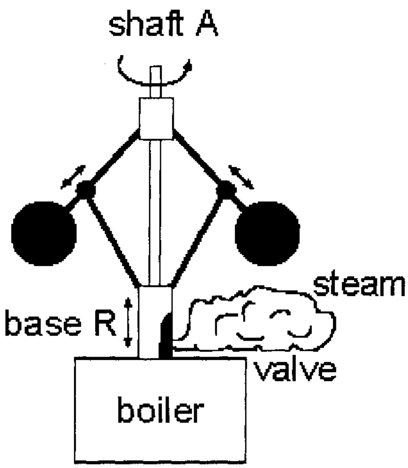

Figure 1-1. Watt's centrifugal regulator.

The behavior of Watt's centrifugal regulator can be easily described in mathematical terms, through the equation of motion:

$$m\ddot{\phi} = mn^2 \sin\phi \cos\phi - mg \sin\phi - b\dot{\Phi} \qquad (1.1)$$

where:

- ϕ is the rotation angle of the axis,
- m is the mass of the revolving pendulum,
- n is the transmission ratio,
- Φ is the rotation speed of the motor axis,
- g is the gravitational constant,
- b is the dissipation constant depending on the viscosity of the pivot.

Cybernetics allowed the creation of relationships among regulation models operating in different fields, such as those describing the operation of animal sense organs, where self-regulation processes are identifiable. One example is the eye which, when hit by light, automatically reduces the aperture in the iris thus regulating the amount of light entering the eye.

Another example may help to characterize the domain in which the concepts of Cybernetics can be applied.

The problem of computing the trajectory of an artillery shell, starting from the knowledge of all initial factors determining the shell's motion, cannot be considered as a cybernetic problem. On the contrary, it becomes cybernetic when the missile itself is capable of continuously correcting its trajectory, as a function of the information about the nature of the trajectory and the position of the target.

Other approaches to Cybernetics were introduced by:

- **Warren McCulloch** (1898-1968), neuro-physiologist, introduced the mathematical model of Neural Networks and considered cybernetics as the study of the communication between observer and environment;
- **Stafford Beer** (1926-), researcher in management, considered cybernetics as the science of organization (Beer, 1994);
- **Gregory Bateson** (1904-1980), anthropologist, introduced a distinction between the usual scientific approach, based on matter and energy, and cybernetics, dealing with models and forms (Bateson, 1972).

c) **System Dynamics (SD)**, in which a system is identified with a configuration of regulatory devices. The expression "System Dynamics" actually denotes a methodology introduced by **Jay W. Forrester** (1918-) in 1961, in his book "Industrial Dynamics" (Forrester, 1961) to study and implement systems of feedback loops (an example of a single feedback loop involving two elements A and B is shown in Figure 1.2), associated with configurations of interacting elements. A system consisting of interacting (through feedback) elements can exhibit global emergent behaviors, not reducible to those of the single individual elements nor to the feedback among them. Such behaviors, for instance, occur within electrical networks and traffic flows. This approach was assumed to be the most suited to describe the interactions among industrial departments which emerge within companies.

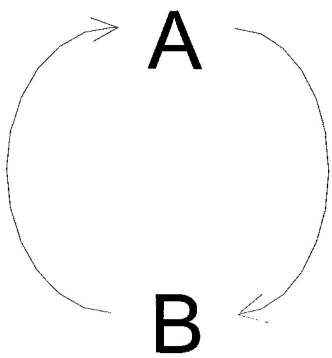

Figure 1-2. System of feedback loops

To summarise, Systems Dynamics deals with conceptual networks of elements interacting through feedback loops. This approach is mainly used for software simulations of corporate dynamics and social systems (Forrester, 1968), but also to model organized social systems (Meadows *et al.*, 1993).

d) **The theory of dynamical systems**

System Dynamics (SD) must be not confused with *Dynamical Systems Theory*. In the mathematical literature often a *continuous dynamical system* in an open interval w is described by an autonomous (i.e. whose right hand members are time independent) system of ordinary differential equations which hold for a vector of dependent variables x:

$$dx/dt = F(x) \qquad (1.2)$$

The theory of dynamical systems, implemented on the basis of the fundamental intuitions of **H. Poincaré** (1854-1912), showed the coexistence of ordered and chaotic behaviors in the study of almost any kind of system which can be represented in mathematics and physics. Simple systems, such as a pendulum or the Moon moving along its orbit, can be described by using the equations of motion of classical mechanics. A dynamical system is associated with two kinds of information:

- One which deals with the representation of the system's state and with basic information about the system itself;
- Another specifying the dynamics of the system, implemented through a rule describing its evolution over time.

The time evolution of a dynamical system may be geometrically represented as a graph in a multidimensional space, the so-called *phase* *space*. It should be noted that by looking only at the form of the orbits in the phase space, we do not describe the geometrical movement of the system, but only the relationships among its independent variables (see Appendix 1).

e) **Gestalt Psychology** introduced an important new approach, related to systems thinking. It originated in Germany, in 1912, under the name of *Gestaltpsychologie*. In the same period in the U.S., *Behaviorism* (Skinner, 1938; 1953), holding an opposite view of psychology, was born.

The German term *Gestalt* refers to a structure, a schema, a configuration of phenomena of different natures (psychological, physical, biological and social) which are so integrated as to be considered an indivisible whole having different properties from those of its component parts or of a subset of them.

Gestalt Psychology is part of the anti-mechanistic and anti-reductionistic movement deriving from the crisis of positivism.

According to this approach it is not possible to reduce psychological phenomena to a chain of stimulus-response associations as, on the contrary, is held by the Behaviorist approach.

Gestalt Psychology triggered a thinking movement, which led to the establishment of systemic psychology.

f) The term **organicism** refers to a view which, in contrast with positivism, assumes that a living system is a finalistic organized whole and not simply the mechanical result of the sum of its component parts. This conception, of biological origin, has been more generally expressed, for instance, by (Whitehead, 1929) who used the word 'organicism' to denote his general philosophical conception. In the field of sociology Compte and Spencer adopt this approach.

g) The term **vitalism** refers to conceptions according to which the phenomena of living beings are so peculiar as to make their reduction to physico-chemical phenomena of the inorganic world impossible. In the second half of the 18th century vitalistic doctrines opposed mechanicism, by hypothesizing, to explain the phenomena of life, a force acting as an organizing principle at the molecular level, separated from the soul or spiritual values. This force, called from time to time 'life force', or 'life surge', is the key aspect of such a conception. This concept began to wobble with the synthesis of urea, representing the birth of organic chemistry, and Darwinism.

Recent advances in genetics and molecular biology have reduced interest in the confrontation between vitalists and mechanicists.

Even today a *theory of living* is still lacking, even though very important progress in the *physics of living matter* has been made (Vitiello, 2001).

h) The term **complexity** relates to problems and conceptual tools (Flood and Carson, 1988) which have chiefly emerged from physics. Brownian motion provides an important historic example. In this case random fluctuations are directly observable, and this circumstance gave rise to the basic concepts of complexity. Brownian motion is the irregular, disordered, unpredictable motion of a speck of pollen in water. The motion is caused by interactions with water molecules, moving in their turn with thermal energy. As a consequence, it becomes impossible to build a deterministic model of this phenomenon. According to classical physics the reason why deterministic models of phenomena like this are not available is because of an incomplete knowledge of all physical features of the components of the involved systems.

On this point, there are two conflicting views:

- The *mechanistic* view, based on the so-called *strong deterministic hypothesis*, according to which we can reach a presumed infinitely precise knowledge of position and speed of all components of a physical system and this knowledge, in principle, could give rise to a deterministic theory of the system itself. Among the holders of this view we can quote Newton (1643-1727) and Laplace (1749-1827). Faith in this conception was shaken for the first time by the failure of classical mechanics to solve the so-called *Three-Body Problem* (Barrow-Green, 1997), tackled by mathematicians including Eulero (1707-1783), Lagrange (1736-181), Jacobi (1804-1851), Poincarè (1854-1912), (see *chaotic* in Appendix 1). Another key principle of the mechanistic view is that of Descartes, according to which *the microscopic world is simpler than the macroscopic one.*
- The view based on the theory of complexity, according to which a complex system can exhibit behaviors which cannot be reduced to those of its component parts, even if it were possible to know with absolute precision their positions and velocities. This view also acknowledges that in most cases it is practically impossible to obtain complete information about microscopic positions and velocities, hypothesized by Newton and Laplace. This circumstance has been proven by many experiments, whose explanation needs more effective conceptual tools. With the term *complexity* reference is made to themes such as (see Appendix 1) *deterministic chaos*, *role of the observer* (Chapter 2), *self-organization*, *science of combined effects* or *Synergetics* (Haken, 1981). A typical example of a complex system, containing a huge quantity of elements and interconnections among them, is the **brain**.

i) **Systems thinking** may be dated back to cultural frameworks of different natures, all oriented towards recognizing *continuity* and unity in a reality fragmented and desegregated into different disciplines, languages, approaches and conceptions (Checkland, 1981; Checkland and Scholes, 1990; Emery, 1969; Flood and Jackson, 1991). Thousands of references relating to different domains are available (introductory ones include, Bohm, 1992; Boulding, 1956; 1985; Briggs and Peat, 1984). References to approaches, currently denoted as *systemic*, may even be found in the Biblical theme of the confusion of languages in the story of the *Babel tower*; in the Talmudic way of thinking in Hebrew culture, as told by S. Freud [1]; in Heisenberg's autobiography with the original German title "The share and the whole" (Heisenberg, 1971); and in many others cases quoted by Capra (Capra, 1996), where systems thinking and its birth are discussed. The expression *General Systems Theory* refers to the fundamental work by Von Bertalanffy (Von Bertalanffy, 1968). Von Bertalanffy states in that book (in which, by the way, a sound introduction to the history of systems thinking is presented) that he introduced the idea of a General Systems Theory for the first time in 1937 during a philosophy conference in Chicago. Around the concept of 'system', suitable for generalizing concepts previously formulated within different contexts, intense research activity has grown. The goals of the latter include both the study of invariant system features and the search for conceptual and methodological (Churchman, 1968; 1971) application to different disciplinary contexts, General Systems Theory (Rapoport, 1968; Sutherland, 1973) was introduced to describe a system as a phenomenon of **emergence** (see Chapter 3) (Von Bertalanffy, 1950; 1952; 1956; 1968; 1975). As introduced at the beginning of this chapter, this expression refers to a general cultural approach more than to a real theory. Actually, *theory* is a very strong word in science (Kuhn, 1962). Following the approach proposed by Popper it must be possible to falsify a scientific theory, if we want to adopt a scientific and not a *pseudo*-scientific attitude (see Appendix 2). The hypotheses on which a theory is based must be validated. It must be possible to design an experiment, a validation test which, if a given result is obtained, would confute the hypothesis on which the theory itself is based.

Usually people speak of

- Systemic approach, with reference to a methodological framework;

[1] S. Freud (1908), to Abraham, May 8th , in Correspondence (1907-1926), Paris, Gallimard, 1969

- Production Systems, a term having different meanings in management science and in a logic-mathematical context;
- System analyst, which is a profession in the field of Computer Systems;
- Electronics and telecommunications systems;
- Systemic therapy, in a psychotherapeutic context and so on.

General Systems Theory looks like a cultural framework, a set of disciplinary meanings extrapolated from theories sharing the topic of systems. A structured and formalized organization of this approach may be found in Klir (Klir 1969; 1972; 1991).

For the reasons presented in the previous section, the term **Systemics** (**Systémique** in French, **Sistemica** in Italian and Spanish) has thus been introduced. The term is used not only in academic literature for referring to holistic concepts (Smuts, 1926), but also with reference to other conceptual extensions of the word 'System'. Systems Research Societies, such as the International Society for Systems Sciences (ISSS), as well as a number of national societies, use this term. It is also used in modern expressions when referring to applications in various disciplines, in order to emphasize the complexity, the web of relations, the interdependency between components. Typical cases are net-economy, software development, organizations, medical applications, pharmacology, electronics, biology, chemistry and so on.

At this point it is important to make a fundamental clarification of the terms introduced so far. This will avoid ambiguities and serious conceptual mistakes in assuming Systemics as referring to a traditional scientific domain (the so called "hard" sciences, such as mathematics, physics, biology, chemistry, etc.) rather than to a general cultural approach.

As introduced at the beginning of this chapter, the term Systemics refers to a cultural framework which crosses various disciplines. Disciplinary applications of this crossing within the scientific context, although particularly important, are only a part of the possible outcomes. The systemic contributions from various disciplines are fundamental for the emergence of Systemics. In its turn, Systemics is a source of innovative approaches within each particular discipline.

However, the term Systemics does not mean a particular disciplinary context in which this approach takes place, but a general strategy for approaching problems, emphasizing the need for a generalised view of events, processes and complex entities in which they are interrelated (see Appendix 2). This is not a trivial observation such as: *arithmetic is applicable to apples, people and trains*. The difference is that, when Systemics is applied within a given context, a model designed for the latter is enriched with new disciplinary concepts and becomes a *systemic invariant* (i.e. a concept, an approach which can be used within other contexts) As such, it allows the use of approaches and strategies designed in other contexts. *Systemic invariants* cannot qualify single elements but the behavior of the whole emerged system. General examples of *systemic invariants* identified within individual disciplines are listed in Appendix 1 and *Systems Archetypes* are discussed in Chapter 7. The concept of systemic *openness and closeness* applies for instance to biology, physics and economics. Moreover, even in *multidisciplinary* fields such as **Cognitive Science**, *when science studies itself, its own processes*, there is a continuous enrichment among applications of mathematical models, computer processing techniques based on Neural Networks, psychological experimental activities, modeling, language research and representation. The same circumstance occurs in domains, which are multidisciplinary *in principle*, such as **Environmental Science** which combines physics, chemistry, biology, economy and engineering.

Thus, the important relationships between *interdisciplinarity* and Systemics can be emphasized. To summarise:

- *Mono-disciplinary* approaches take place when specific domains are studied by designing specific tools. Different fields of interest deal with individual disciplines, such as mathematics, arts, economics. Education is usually *fragmented* into individual disciplines.
- *Multidisciplinary* approaches require the use of several different disciplines to carry out a project. For instance a project in telecommunications needs individual engineering, economic, legal, managerial competences working in *parallel*. Implementation of projects requires more and more multidisciplinarity. Multidisciplinary education means teaching one discipline while discussing another, i.e. language and history, mathematics and economy and so on.
- *Interdisciplinary* approaches involve problems, solutions and approaches (and not just tools) of one individual discipline being used in another following from systemic concepts such as those listed in Appendix 1. This is different from just using the *same tools*, such as mathematical ones. For instance, the use of the systemic concept of openness in physics, economics and biology allows scientists to deal with corresponding problems, solutions and approaches even using the same tools.
- *Trans-disciplinary* approaches are taken when problems are considered between, across and *beyond* disciplines, in a *unitary* view of knowledge. In this case the interdisciplinary approach is reversed: it is not a matter of an inter-crossing, cooperative use of disciplinary approaches looking for conceptual invariants using the same concepts in different

disciplines, but of finding disciplinary usages of the same trans-disciplinary knowledge. Trans-disciplinarity refers to something beyond individual disciplinary meanings and effects. It refers to the multiple levels and meanings of the world, the multiple levels of descriptions and representations adopted by the observer. While disciplinary research concerns *one disciplinary level*, trans-disciplinary research concerns the *dynamics between different levels of representation* taking place at the same level of description. Examples include multi-dimensional education focusing on the development of different, simultaneous, cognitively and ethically related disciplinary interests (Gibbons *et al.*, 1994; Nicolescu 1996) and in the approach to phenomena by *simultaneously* using different representations, descriptions, languages and models. These aspects are introduced in the DYnamic uSAge of Models (DYSAM) in Chapter 2.

The most significant contribution of the systemic approach is its ability to demonstrate that a strategy based only on the identification and study of the behavior of single, isolated components is ineffective and unsuitable for problems carrying the complexity of emergent processes and systems. At one level, this approach, in systems engineering, is based upon using, designing and controlling input-output and feedback-controlled devices as considered by System Dynamics (Forrester, 1968). In other words, societies, corporations, biological systems, the human mind and even a magnet or a superconductor can not be studied as if they were made up of individual component parts such as: pendula, levers and bolts. The machine paradigm, in short, is adequate only for machines and it is useless and ineffective in all other cases. To recognize this idea implies a very profound conceptual revolution, given that our scientific tools (mathematical, physical, biological, medical, economical models), as well as our legal and social frameworks have all been designed for a world where the machine concept and model is a fundamental element, within a more deterministic than probabilistic context. The mechanistic view is used as a touchstone to represent and design any other kind of operational device. Systemics, on the other hand, produces conceptual tools, devices and methodologies to deal with situations in which classical mechanistic approaches are ineffective.

Attempting to explain everything by using the available conceptual tools is an understandable and unavoidable human attitude. The following story may be illuminating. *In a dark room only one corner is lit up by a small bulb hanging from the ceiling. The light falls on a disordered set of objects. In this narrowly lit area a person is desperately searching for something. A friend arrives and asks: are you looking for something? Yes, the other says, I have lost my keys. The friend asks if he can help. Sure! After some fruitless*