Chapter 6
Perspectives

Abstract. Integrative points of view are presented with reference to the classification of sciences, cybernetics and its extensions, and to the categorification as the new wave of transdisciplinarity, coming after complexity.

The cyclic view of sciences is correlated to different orders of cybernetics approach.

Intra, inter, and trans disciplinarity are presented as natural steps in problem solving.

The polystochastic modeling place and the correlation with other methodologies and research directions is evaluated.

A table offers a synthetic view of the cognitive frameworks and of methodologies, proposed in the book as conceptual tools capable to manage different degrees of complexity for different domains of reality and of science.

This may be of help to see where future studies might be going and to promote new domains of applications.

6.1 Cybernetics and Classification of Sciences

Creating common methodologies and languages for discussing and solving problems for a wide range of systems making use of different disciplines is critical for complexity studies. In practice, one of the main questions is how the languages of different sciences and methodologies result in scientific interventions and actions into the real world.

Answering such questions one can start by referring to cybernetics.

Cybernetics studies the assumptions and procedures of different particular disciplines as for instance modelling, controlling and predicting (Wiener 1945).

The interdisciplinary character of cybernetics was explicit from its founding.

The cybernetic approach is correlated to the study of levels of reality and also to the classification of sciences problem (Hartmann 1952, Piaget 1972, 1977, Poli 2001, Nicolescu 2002).

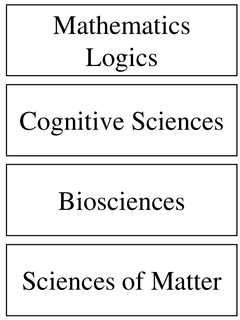

Fig. 6.1 Hierarchy of sciences

According to Hartmann there are four main levels of reality: physical, biologic, cognitive or psychological, and intelligent or spiritual. These levels correspond to the four main domains of sciences: sciences of matter, biosciences, cognitive sciences, and lastly logics and mathematics.

The usual view on systems and related sciences classification is a linear and hierarchical one. Fig. 6.1 shows a hierarchical view of sciences.

Numerous researchers disagree with this linear model of sciences. According to Piaget (1967) the sciences are cyclically related since there is nowhere to look for an explanation of logical and mathematical phenomena other than in psychological or cognitive activity. The Piaget circular model of sciences goes as follows: psychological that is cognitive phenomena are dependent on biological phenomena, that in turn depend on physical and chemical phenomena that, in their turn are stated in mathematical and logical laws and with these laws we are back at the beginning namely at the cognitive phenomena (Fig. 6.2, Table 6.1). The concordance between the mathematical and the experimental science would not be the product of an accident but rather it would be because mathematical knowledge and empirical knowledge are both weaved from the same psychological or cognitive cloth.

The field of cybernetics is usually described as developed in two stages namely the 1^{st} order and the 2^{nd} order cybernetics.

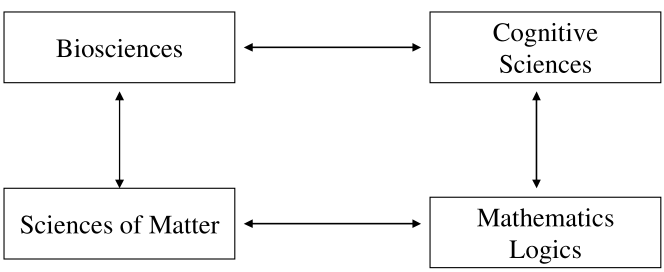

Fig. 6.2 Cycle of sciences

Table 6.1 Cycle of sciences and cybernetics

Biosciences Biology Anatomy	**↔2nd order** Reflexivity. Self-organization	**Cognitive sciences** Psychology. Sociology Engineering Design
↕ 1st order Homeostasis Feed-back		**↕ 3rd order** Virtual. Anticipative
Sciences of mater Physics Chemistry	**↔ 4th order** Embodiment. Evolvable	**Mathematics** **Logics**

The 1^{st} order cybernetics developed as the science of control and communication for machines and animals outlines the feedback concept. It focused on the idea of homeostasis, the ability of systems to maintain steady states despite disturbances in the environment. The concepts and the applications of 1^{st} order cybernetics are interdisciplinary between the sciences of mater and biosciences (Table 6.1).

The second phase of developing cybernetics, focused on the attempt to incorporate reflexivity into the systems, that is, to acknowledge that the observer is part of the observed system. This led, to the deep study of reflexivity and self-organization concepts. The concepts and applications of the 2^{nd} order cybernetics are interdisciplinary between biosciences and cognitive sciences (Table 6.1).

Possible 3^{rd} order and 4^{th} order cybernetics will confront higher levels of complexity that arrived in science and technology.

The idea of emergence is fundamental here-the thought that complex systems, when recursively structured, can spontaneously evolve in directions their designers did not anticipate. It is the case of some proactive or evolutionary methods and devices. The virtual is a key characteristic of 3^{rd} order cybernetics. According to 3^{rd} order cybernetics some systems can change goals without pre-programming. This means that the observer is considered as a proactive or anticipative component that not only observes but also decides and acts. Noticeably, the observer is not necessary a human one.

The focus of 3^{rd} order cybernetics is beyond cognitive sciences level and includes virtual, conceptual, proactive, anticipative technologies, and cyberspace. The 3^{rd} order cybernetics concentrates on virtual systems, on building information systems. The concepts and applications of the 3^{rd} order cybernetics are interdisciplinary between cognitive sciences and the logical and mathematical sciences.

The 4^{th} order cybernetics should confront and surpasses the challenge of high complexity in technology and sciences. The 4^{th} order cybernetics may be one of the embodied, fully evolvable, creative and autonomous systems. It implies that a system will immerge into its environment, of which it is part. A 4^{th} order cybernetic system is embedded, integrated into the context and context aware. As outlined by Table 6.1 the 4^{th} order cybernetics can be understood and described in terms of the complement of the first, second and 3^{rd} order cybernetics considered as a whole.

The 4^{th} order cybernetics may be linked to emerging new scientific domains as synthetic biology (Endy 2005), artificial life (Bedau et al. 2000), and organic computing (Würtz 2008).

Synthetic biology, studies the design and construction of new biochemical systems, such as the genetic circuitry. Just as the engineers design electrical circuits based on known physical properties of materials and then fabricate functioning circuits and processors, the synthetic biologists design and build biological circuits.

Artificial life studies the life as it could be, while organic computing studies the life-like computing structures and processes. Programmable artificial cell evolution is a project illustrating such innovative research directions (Chemnitz et al. 2008).

Organic computing starts from the principle that the problems of organization in different domains as molecular biology, neurology, computer science, manufacturing, ecology and sociology can be studied scientifically in a unified way (Würtz 2008). Technical usage and embedding of general principles observed in natural systems is the long term objective of organic computing.

Elements of higher order cybernetics have been outlined in the study of the regulations due to Piaget (Piaget 1977), third-wave cybernetics (Hayles 1999), social systems (Luhmann 1997), conceptual systems and cyber semiotics (Brier 1998) and of viable systems (Schwarz 1997, Yolles 2006).

It should be observed that any new type of cybernetics embeds elements of the previous ones. The higher order should be inclusive and self-aware on previous levels.

After the integrative closure, the material embodiment of logics, mathematics and computing capacity will allow operating the material realm at multiple levels simultaneously. This may support the emergence of another type of sciences of mater, of biosciences and so on. Consequently a spiral of sciences instead of cycle of sciences and associated systems may be taken into account as a more appropriate image of knowledge development (Iordache 2009).

6.2 Transdisciplinarity

It has been argued in many ways that the problem solving for complexity domain is an activity which cannot succeed on the basis of one point of view, or the knowledge of one discipline, but that it needs cooperation of a number of disciplines to develop valid knowledge.

Researchers still respect the idea that each discipline has its own level of explanation. It is considered that assembling parts from a system does not give the whole since the whole of each system needs its own point of view. Each level of explanation has it own long-established background and from that there seems to be a natural hierarchy between the disciplines. Confronted with an explosion of new disciplinary knowledge, it is difficult for any specialist to understand more that the tiniest fraction of his specialized domain.

The management of the cooperation of different disciplines for complex problem solving is the main concern. Consequently, it is necessary to find ways to radically simplify and unify knowledge about problems and problem solving.

Piaget and Garcia (1989) methodology starts from the bold hypothesis that there exists a parallelism between the particular problem solving and the historical development of the involved sciences. The short history of an individual problem solving that is the ontogeny, is considered as parallel to the evolutionary long history of a lineage that is, the phylogeny. Piaget explained the isomorphism between psychogenesis and the historical development in sciences by the general equilibration based on assimilation accommodation mechanism and instantiated as the so-called intra-inter-trans process.

The intra-inter-trans process is the functional mechanism that proceeds from simple object analysis, the so-called “intra” step, to the analysis of relations between objects via transformations, that is the “inter” step, and to the building of cognitive structures, that is the “trans” step.

This general mechanism is relevant to both particular problem solving and to scientific activity itself. Piaget considered that the general intellectual development involves the same sequence of steps. In particular he reconstructs intellectual development from pre-operational thinking, the “intra” stage, via concrete-operational thinking, the “inter” stage, towards formal-operational thinking, that is the “trans” stage.

In a broader Piagetian view, the claim is that this kind of stages can be traced in different domains and at all levels of development.

The intradisciplinarity step corresponds to single disciplinarity or to multidisciplinarity realm. It represents the first step of the problem solving.

Disciplinary research is not able to fully cope with complex problems because these problems do not fit into the system of scientific disciplines. Energy, health, ecology, security and financial problems can’t be solved by disciplinary approaches. A scientific understanding of complex problems is mandatory but the increasing specialization and fragmentation of scientific disciplines prevents disciplinary research from working.

Multidisciplinarity makes use of different disciplines and suppose that studying complex problem is not just in one discipline only, but in several, at the same time. Any issue in question will be enriched by incorporating the perspectives of several disciplines.

Multidisciplinary approach brings a benefit to the disciplinary study, but this benefit is still in the restricted service of the source disciplines. The multidisciplinary approach overflows disciplinary boundaries while its goal remains limited to the frameworks of disciplinary research.

It should be noted that multi-scale models are often multidisciplinary. There exists a growing number of tools and methods for engineering systems but little fundamental conceptual analysis leading to general frameworks that help guide modeling of multi-scale systems.

The next step to be considered in problem solving is that of interdisciplinarity. This involves cooperating disciplines and has a different goal than multidisciplinarity. It concerns the transfer of methods from one discipline to another. Like multidisciplinarity, the interdisciplinarity run over the disciplines. Confronted with problems between two disciplines the interdisciplinarity has even the potentiality of generating new disciplines.

The next step in problem solving is that of transdisciplinarity. The definition of problems to solve is, for this step, relatively independent of disciplinary perspectives.

Transdisciplinarity concerns that which is at once between the disciplines, across the different disciplines and beyond disciplines (Nicolescu 2006). Transdisciplinarity was considered not as a discipline but rather as a process of problem solving able to increase knowledge by integrating and transforming different perspectives (Klein et al. 2001).

Highly complex problems do not belong to only one of the three main types or disciplinarity sketched above but contain elements of each type. The focus is on providing technical solution to a given problem rather than on gaining scientific knowledge. There is no opposition between intradisciplinarity (including disciplinarity and multidisciplinarity), interdisciplinarity and transdisciplinarity. In fact, there is no transdisciplinarity without interdisciplinarity and this in turn without multiple disciplinarity. Disciplinary competence remains the essential precondition for transdisciplinarity tasks but it alone does not suffice to deal with complexity.

Fig. 6.3 shows an illustrative problem solving cycle (Murase 2008). It makes use of the analogy with n-graphs (Appendix A5). The disciplines are represented here by signs as "•", for primarily theoretical part and "o" for primarily experimental part.

Initially the parts are separated but start to form well defined disciplines in the 1^{st} order stage, "intra". They may be coupled in the 2^{nd} order stage, "inter" to form interacting disciplines. The 3^{rd} order stage, "trans" corresponds to the coupling of two or more sciences in wide-ranging frameworks going beyond disciplines and solving disciplinary isolation.

The 4^{th} order, last stage, shown in Fig. 6.3 may represent an integrative or self viewpoint. After a complete cycle intra-inter-transdisciplinarity the self viewpoint is open towards a new disciplinary approach and a new cycle. This

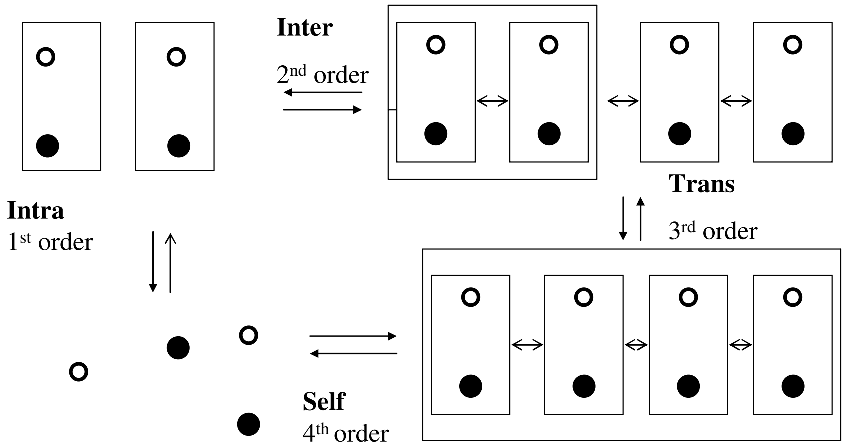

Fig. 6.3 Intra, inter, trans disciplinary

4^{th} order stage and arrow completes the knowledge cycle and the problem solving. It corresponds to the creative stage in intellectual development and supposes the ability to formulate post-disciplinary notions as for instance new goals.

How the integrative or self disciplinary viewpoint turns back into a new disciplinary life is an open problem. A suggestion is that evolvable problem solving could restart and follow the same steps on a higher methodological plane that is at a higher dimension in modeling. This is the categorification way (Appendix A4). New open problems concern the timing of travel back and forth across the levels of abstraction, alternating categorification and decategorification in a specific dynamics for specific problems.

It was observed that the transdisciplinary research tends to be reinvented and reformulated about every one or two decades. In the second half of the last century there have been waves of transdisciplinarity in cybernetics in the 1945s, control systems in the 1960s, chaos theory in the 1975s and complexity theory in the 1990s (Strogatz 2003). It would be of interest to explain why this approach in waves is followed and proves to be efficient, instead of a more constant effort, why each wave of interdisciplinary lost its initial impetus as a unifying force, and what comes after the complexity pulsation.

The transdisciplinary waves are imposed by the social and economic context. The recent history of transdisciplinary problem-focused researches dates from the 1940s, initially in defense research. The 1960s represent the start of increased funding for transdisciplinary research in areas of economic competition as engineering, manufacturing and medicine.

Study of control systems became mandatory. It was evident during the 1975s context of unpredictability and chaos in market and the 1990 context of environmental research that new discourses of transdisciplinary problem solving are necessary and emerging (Klein 2004).

The case studies presented in this book sketched how categorification was imposed by the complexity advent, how it can serve for complex problem solving, and how category theory could serve as a "lingua franca" that lets us translate between certain aspects of different subjects in different domains and eventually, build a general science of systems and processes (Baez and Stay 2008).

Such observations allow us to assume that the categorification may represent the new wave of transdisciplinarity, a new C-theory, coming after cybernetics, control, chaos and complexity (Strogatz 2003).

6.3 Synopsis

At the end of this incursion in complexity domain it is appropriate to evaluate the PSM place and the correlation with other methodologies and research directions presented in the book.

Fig. 6.4 and the table 6.2 offers a synthetic view of the cognitive frameworks and of methodologies, revealed in the book as conceptual tools to manage different degrees of complexity for different domains of reality and of science. The rectangles in Fig. 6.4 represent reality levels or sub-levels. Fig. 6.4 shows that after an increasing number of hierarchical levels, integrative cyclic closure structures limited to three or four realms and sub-realms have to be considered. The integrative closure shown in Fig. 6.4c or Fig. 6.4e is not seen as a final stage. As illustrated by Fig. 6.4f, we may consider a process that can develop self-similar patterns for cognitive architecture.

The rows in Table 6.2 correspond to the main domains of sciences as shown in Fig. 6.1.

A supplementary level of transdisciplinarity was included on top of this hierarchical perspective. Periodicity refers to the fact that for the same column we may detect pattern similarities despite the fact that the issues pertain to different domain of sciences.

Column a, in Table 6.2 (Fig. 6.4) refers to low-dimension methodologies and devices. Column a, includes adaptive devices as material systems, genetic code versus amino acids relation, evolutionary algorithms and theoretical concepts as semantic closure for biosystems domain. The multi-agent systems MAS, and theoretical concepts as the modeling relation, illustrates the cognitive domain.

As mathematics, the column a, includes automata, Turing machines and learning systems. All these are low dimensional models of computation that correspond to 1-categories.

The 1^{st} order cybernetics appears to be the transdisciplinary approach associated to the a-frameworks.

It is possible to conceive highest dimension developments for the mathematical concepts shown in column a. Examples are the higher n-dimensional automata, nDA (Pratt 1991) and the n-categories approach for rewriting systems (Johnson 1991, Burroni 1993).

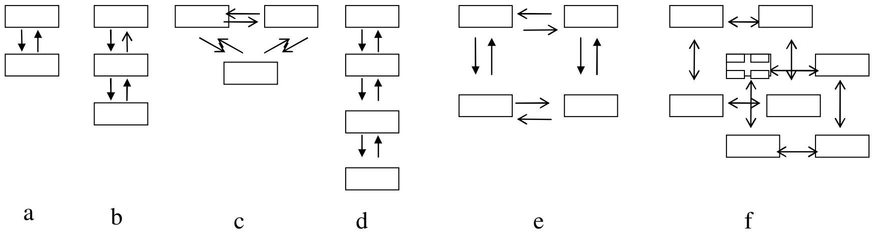

Fig. 6.4 Synthesis of cognitive frameworks

There exists several attempts to define n-categories models but the knowledge about n-categories is still in progress and sometimes controversial (Baez and Stay 2008).

Column b, in Table 6.2 corresponds to the three levels hierarchical, b-frameworks.

Evolutionary devices as Pask's device (Cariani1993) may represent the material systems. For biosystems one may considers the central dogma of biology, structured genetic algorithms-GA (Dasgupta and Gregor 1992), contextual GA (Rocha 1997) and chemical GA (Suzuki and Sawai 2002).

As cognitive systems or models, the von Uexküll functional circle (1973), the mesoscopic cognition frame (Doursat 2007), and the universal modeling language-UML studies may be mentioned.

Table 6.2 Periodic table of methods and cognitive frameworks

	a	**b**	**c**	**d**	**e**	**f**
Trans-Disciplinary	·1st order Cybernetics	·2nd order Cybernetics	·Three realms Ontology	·3rd order Cybernetics ·Four levels Ontology	·4th order Cybernetics	
Mathematics Logics	· 1-category ·Automata ·Turing Machine ·Learning systems	·2-category ·2DA ·Petri nets ·Strings rewriting	·2-category	·3-category ·3DA ·Terms rewriting	·3-category	
Cognitive Systems Sciences	·MAS ·Modeling Relation	·von Uexküll Functional Circle ·Mesoscopic Cognition ·UML	·CBR ·BDI ·SASO	·Symbolic-Connectionism ·K-sets ·Holonic Systems · Autonomic computing ·MOF	·GDT ·EMAS ·IRDS · Organic Computing ·Piaget Schema	·Digital self ·EDOE, PSM ·Nested MML ·Piaget Garcia Schema
Biosciences Bioinspired Sciences	·Genetic code-Amino-acids ·Evolutionary Algorithms ·Semantic Closure	·Central Dogma of Biology ·Structured GA ·Contextual GA ·Chemical GA	·Operons		· Synthetic Biology · Artificial Life	
Mater Sciences	·Adaptive Devices	·Evolutionary Devices	·Evolution in *materio*	·Embryonics Devices		

As mathematical methods, the 2-categorical formulation of the 2-dimensional automata, 2DA, string rewriting systems (Johnson 1991), and the Petri nets may be regarded.

The 2^{nd} order cybernetics is the transdisciplinary approach associated to the three-level, b-frameworks.

Column c, refers to a cyclic, which is closed version of the previous framework that is to three realms c-frameworks. This corresponds in part to the evolution in *materio* project as biomimetic devices (Miller 2008) and to operon models in genetics (Jacob and Monod 1961). The conventional case based reasoning-CBR systems (Aamodt and Plaza 1994) and the self adapting self organizing-SASO framework (Di Marzo Serugendo et al. 2007) represents examples of cognitive systems. The three realms ontology allows a transdisciplinary study of this three realms cyclical framework linked to 2-categories (Poli 2001).

Column d, refers to four-level hierarchical d-frameworks. This includes embryonics project as biomimetic devices (Mange et al. 1998), some symbolic-connectionist models (Hummel and Holyak 1997), the K-sets models for neurodynamics (Freeman 1995), holonic systems (Valckenaers et al. 1997), autonomic computing (IBM 2005) and meta-object facility-MOF studies, as examples of cognitive systems and models.

For mathematical frames, the 3-categorical formulation of the dimensional automata, 3DA, and the term rewriting systems (Johnson 1991), may be considered. The transdisciplinary studies are associated to 3^{rd} order cybernetics and to Hartmann four levels ontology.

Column e, includes synthetic biology (Endy 2005) and artificial life as biosystems.

The engineering general design theory-GDT (Tomiyama and Yoshikawa 1987), some evolvable MAS, EMAS, information resource dictionary systems-IRDS (Rossiter and Heather 2003), the organic computing studies focusing on embodiment (Würtz 2008) and the four realms schema of Piaget (1980) may represent the cognitive sciences domain. The e-frameworks were proposed in different sections of this book as n-graphs mathematical model inspired by study of computads (Street 1987) or polygraphs (Burroni 1993) and as the coming up 4^{th} order cybernetics corresponding to transdisciplinarity.

The f-frameworks from column f, represent refinements and developments of the cyclic variant of the four level e-frameworks. Potential developments correspond to the splitting of a realm in four sub-realms and to the inclusion of a central realm that may in turn split in four sub-realms and so on. This parallelism allows making use for the new f-framework of the same software support as for the e-frameworks. The column f may include cognitive systems as the digital self MAS developed by Goschnick (2003) on the basis of Jung analytical psychology, some evolvable designs of experiment-EDOE and PSM frameworks (Iordache 2009), nested meta-modeling language-MML (Alvarez et al. 2001), and systems based on the psychogenetic schema due to Piaget and Garcia (1980).

Several f-frameworks have been just sketched in this book as for instance: the evolvable SMB, the creative engineering design, the BGPI and the evolvable manufacturing systems.

Moving from left to right in the periodic table 6.2, means to perform categorification steps, and to increase the system dimensionality and capability to confront higher levels of complexity.

The periodic table 6.2 highlights the interconnection of different theoretical concepts and research directions. This may be of help to see where future studies might be going and to promote applications.

Many of the presented frameworks and methods are based on less than four levels and these levels are incompletely connected.

For instance some evolutionary devices, and also some cognitive tools as the conventional CBR, BDI lack the fourth level. This lacking may explains the difficulties reported with Pask's device, in evolutionary hardware or the deceptive applications of genetic algorithms. Pask's devices and evolutionary hardware are confronted with reproducibility problems. Genetic algorithms work well in some calculations and not in others, but it was not clear why and when this happens. It may be supposed that some artificially constructed evolutionary systems are less evolvable than other.

Embryonics project frameworks, holonic enterprise management systems, autonomic computing systems and MOF, show four levels hierarchies but do not focus the interconnection between top and lowest levels.

The integrative closure of these hierarchies is a necessary next step toward fully evolvable and autonomous technological systems, management systems, enterprises and organizations.

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