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■ *Research Paper*

Model-based Management: A Cybernetic Concept

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The purpose of this contribution is to elaborate an integrative framework for model-based management, drawing on the concepts of cybernetics. This conceptual frame should enhance managers' understanding of structures that give rise to patterns of system behavior, helping them to design more effective policies and improve their practice in general. We flesh out the commonalities between technical, biological and social cybernetics. An analysis is undertaken to make the available concepts fertile for the social domain. These are then synthesized into an integrative framework for a model-based, cybernetically grounded management. Copyright © 2014 John Wiley & Sons, Ltd.

Keywords model-based management; cybernetics; organizations; integrative management framework; transdisciplinarity

INTRODUCTION

Since its beginnings in the 1940s, cybernetics—the science of 'control and communication in the animal and in the machine' (Wiener, 1948)—has turned towards multiple fields of application. A clear distinction differentiates technical, biological and social cybernetics. In addition, cybernetic schools have evolved in medicine, psychology, pedagogy, anthropology and epistemology.

The conceptual differences between the respective contexts of application are often ignored (Ackoff and Gharajedaghi, 1984). This leads to improper transfers of concepts, models and methodologies between the technical, biological and social domains. A paradoxical situation results, namely, that concepts and methods are often unduly transferred while adequate and fertile transmissions are not carried out. Generally, at least the domains of technical, biological and social cybernetics have differentiated and segregated themselves in a way that communication among them is rare. There is a 'red thread' that is often neglected—the generic concepts that are applicable to any one of these domains. We believe that in a time of growing dynamic complexity in organizational settings, new ways of management are necessary. As demonstrated elsewhere, the effectiveness of managers and leaders will increasingly depend on the use of formal models. Therefore, a model-based management has been advocated (Schwaninger, 2010; Grösser *et al*., 2014). This idea is fundamentally linked to the concepts of cybernetics, which

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are in principle an invaluable pool of knowledge to be tapped by the community of managers and leaders.

The purpose of this contribution is to elaborate an integrative framework for model-based management,[1] which makes the variety of cybernetic concepts fruitful, helping managers to reflect upon and improve their practice. Frameworks of this kind are needed and can empower executives, leaders, entrepreneurs, politicians and so on—in short, *managers*—to be more effective. This has been demonstrated recurrently in the realm of general management, which is of interest here (e.g., Ulrich and Krieg, 1972; Bleicher, 1996; Ulrich, 2001; Rüegg-Stürm, 2005; Martin, 2007). The novelty about our approach is twofold. First, the framework to be elaborated here is based on a survey of the principles of cybernetics from its beginnings to the present. Second, this framework is directed to the specific needs of a model-based management.

We will explore the basic concepts available from cybernetics, and how they emerged. The understanding of these concepts—the heuristic power of which is undisputed—should enhance their fertile use whenever applications to complex issues or problems are at stake.

The aim of elaborating a cybernetic framework for model-based management begs for a solid theoretical–conceptual foundation. We have decided to build the argument starting with the origins of cybernetics. We then proceed to sketch out the evolution of cybernetics across the different fields of application. On that basis, the conceptual building blocks for model-based management will be introduced, with a view to their relevance and embodiment in the different application fields. Consequently, these components will be synthesized into an integrative cybernetic framework for model-based management. Instead of delving into the details of examples on how to use the framework, we restrict ourselves to highlighting its function as a diagnostic device, and its enabling function for the transdisciplinary inquiry necessary in a context of complexity and change. Or, in brief, the framework provides a transdisciplinary 'code', by which management can be improved. The leverage here is based on the enhancement of managers' understanding of the system they manage.

ORIGINS OF CYBERNETICS

To shape the future, we must first understand the past. The word 'cybernetics' stems from *kybernetiké*, the ancient Greek expression for the art of steersmanship; *kybernétes* names the steersman. Already, Plato used cybernetic ideas when he characterized the statesman as the steersman of society.

Later on, various precursors of modern cybernetics showed up, particularly in the 19th century. André-Marie Ampère (1843) developed the idea of a science, which he titled *cybernétique*. That science embodied, within an overall system of *connaissances humaines*, the general knowledge about governance in political space. James Clerk Maxwell (1868) with his centrifugal governor laid the cornerstone for control theory. Modern cybernetics was founded by several actors:

- Rosenblueth *et al*. (1943), with an article about 'Behavior, Purpose and Teleology', in which the concept of feedback was operationalized.
- The Macy Conferences (1946–1953), which assembled the leading members of the cybernetic research community, including McCulloch, Wiener and von Foerster, among others. These gatherings were dedicated to the topic 'circular causal, and feedback mechanisms in biological and social systems'.
- Norbert Wiener, with his opus 'Cybernetics or Control and Communication in the Animal and the Machine' (1948), which is considered the basic opus of cybernetics.

That last title conveys the insight that the processes of control and communication are equally present in the technical world, nature and the social domain, and structurally equivalent in a specific sense. Already, in his quoted work of 1948, Wiener includes society as a universe of information processes in his analysis (pp. 155ff.).

Contemporaries and colleagues of Wiener develop cybernetic concepts and apply them in the

[1] By 'model-based management', we understand a management of organizations, that is, governance, control and leadership sustained by formal models (see also Section on An Integrative Framework for Model-based Management).

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physiological context (Ashby, 1952, 1956) and especially in neurophysiology (McCulloch, 1965). In later works by Wiener (1954) and other authors (e.g. Beer, 1959; Deutsch, 1969; Luhmann, 1984), cybernetic concepts are also transferred to social systems. For that purpose, the application of perception and epistemology is made (Powers, 1973; von Foerster, 1984) to man–machine systems, conversations and learning (Pask, 1975).

In the offing at that time, a distinction between a *first-order cybernetics* and a *second-order cybernetics* emerges. Heinz von Foerster in that context draws a distinction between 'cybernetics of observed systems' and 'cybernetics of observing systems' (von Foerster and Rebitzer, 1974). In the first case, concepts such as information, feedback, adaptation, homeostasis and control or governance occupy the centre of attention. In the second case, the observer becomes part of the observed system; interest falls on phenomena such as self-organization, self-reference and the construction of realities.

The early cybernetic studies broach mainly two aspects that are crucial for dealing with complex, dynamic systems: communication (via language and information) and control or governance (with its components of regulation and steering). In addition, the cybernetic perspective makes possible the inquiry into invariant structures not only in a descriptive sense but also in a prescriptive one, and in a way that transcends disciplines. Here, two insights of the early cyberneticians were path breaking: first, that one and the same structure can be ascertained in biological systems (living beings and organisms), in technical systems (power plants, energy networks, etc.) and in social systems (organizations and societies); second, that the knowledge of these structures can be used for the design of technical, biological and social systems. The term *socio-technical system* therefore became widely adopted in language use.

These new insights were congruent with an idea stemming from general systems theory: the idea that systems of any kind can be described and explained with one and the same formal apparatus (von Bertalanffy, 1968; Rapoport, 1986). In this way, structural invariances ('isomorphisms'), the same principles that rule different kinds of systems, should be uncovered. For example, a law of exponential growth can be located equally in colonies of bacteria and in human populations, in the latter with behavior patterns such as conflict and cooperation or the progression in the number of scientific publications. A similar case is the logistic growth curve ('S-curve'), which maps the process and the limitation of growth. It is applied in biology, ecology, economy and sociology, for example, to technological substitution processes and population development. Cyberneticians were the ones who were able to explain dynamic phenomena of that kind as a result of feedback processes.[2]

Feedback is used in virtually all scientific fields, from physics, chemistry and ecology to the social and economic sciences, as a principle for the explanation of system behavior and the design of systems. This is also the case in applied disciplines such as engineering and management.

Cybernetics takes insights and concepts from individual disciplines (e.g. Boltzmann's entropy formula from statistical mechanics) and brings it into a larger context. In other words, it opens these insights or concepts by means of generalization into new fields of application. For example, in the information theory by Shannon and Weaver (1949: 51), an equation for the computation of entropy that is practically identical with the Boltzmann formula can be found.

Cybernetics has also made a topic accessible to scientific analysis, which, up to that point, had been reserved to metaphysics—teleology, that is, the study of goal orientation. Feedback is a mechanism that provides goal direction, as Rosenblueth *et al*. (1943) showed in conceptual terms.

TECHNICAL, BIOLOGICAL AND SOCIAL CYBERNETICS

In this section, we sketch out how the three application domains of cybernetics—technical, biological

[2] Feedback is that process in a system by which an outcome variable is redirected—normally via a control system (regulator and governor)—as an input, such that the object system's behavior changes. Hence, the system changes itself. The complementary concept of feedforward denotes an information process by which a disturbance is registered *ex ante*, before it impinges on the object system, and the respective information is directed to the control system, which thereupon can change the system anticipatively (Figure 3).

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and social—have evolved and differentiated themselves (Figure 1). The focus will be on the middle column, named 'cybernetic thread'. As cybernetics also has ramifications into the other fields of the systems approach, the other two columns will be put into play, also.

Technical Cybernetics

Cybernetics in the first place became very prominent in the technological domain. Its principles became the fertile soil for breeding technical applications. An outstanding development in that domain is control theory (Figure 1, left strand). This discipline is practised today in almost all areas of technology. It plays a crucial role in most disciplines of engineering. Its domains of application encompass not only simple machinery (e.g. thermostats and mechanical governors) but also sophisticated systems of propulsion technology, safety engineering (e.g. antilock braking systems (ABS) and power plant control), energy and transportation technology (e.g. wind turbines, trains and signal technology), aircraft and space technology, computer and communication technology and robotics. In the automation of production, control and information processes, a huge increase in model building, simulation and algorithmization has occurred (von Känel *et al*., 1990).

Also inspired by technical cybernetics, several pragmatic (inter)disciplines have emerged, such as micro-system technique, man–machine systems and systems engineering. These disciplines have in common a commitment to the holistic design of complex systems, following an interdisciplinary approach. The field of man–machine systems, for example, rests on ergonomy, cognitive science, software and control theory (Johannsen, 1993). Bionics, which is also fundamentally influenced by cybernetics, is bound to learn from nature for the formation of technical

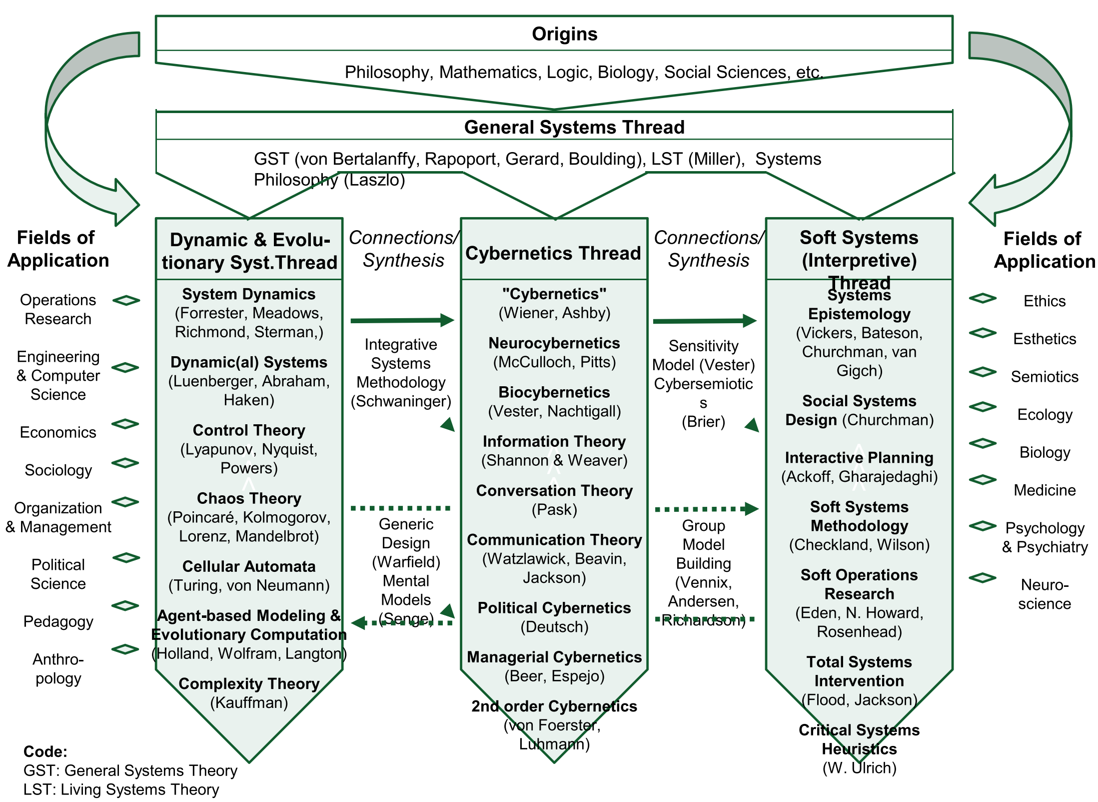

Figure 1 Overview of the systems approaches. An earlier version of this diagram was published in Schwaninger (2009b)

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systems, and recently also for the organization of social systems (Figure 1, middle). Disciplines such as the last mentioned are rooted in technical cybernetics, but beyond the technological context, they also include humans in their design approaches.

Biological Cybernetics

After technology, cybernetic thinking has also spread throughout biology, physiology and ecology. Prominent applications are in neurophysiology (McCulloch, 1965; Figure 1, middle) and medicine (Brown, 1985; Tretter, 2005). The biocybernetician Frédéric Vester, originally a physician, succeeded in applying cybernetics to physiological processes (Vester, 1976). Later on, he opened new paths to coping with ecological issues concerned with cybernetic methods, fuelled by his transdisciplinary approach to systems analysis (Vester, 1999). Finally, Maturana (a physician) and Varela (a biologist) have to be mentioned, who carried out cybernetic research in the area of biology (e.g. Maturana and Varela, 1973) and accomplished studies in epistemology (Maturana and Varela, 1987; Varela *et al*., 1991).

The design of social systems, including the socio-technical systems, can learn from the functioning of higher-order ecosystems. Their functioning can inspire planners, politicians and managers in bringing about a livable world.

Social Cybernetics

The application of cybernetics to social systems also developed after the cybernetics of technological systems. A foundation was laid by Stafford Beer with his pioneering work 'Cybernetics and Management' (1959). Beer (1979, 1981, 1985) is the father of management cybernetics. He expanded his ideas concerning the application of cybernetic principles to the management of organizations and framed his viable system model, which specifies the necessary and sufficient preconditions for the viability of any organization. Beyond that, Beer (1994) came up with the Team Syntegrity protocol—a model for the organization of social processes that enhances the effectiveness of collaboration in large groups ('infosets'). In the wake of Beer's work, many application-oriented and methodological contributions to organizational cybernetics have accrued, which often refer to the viable system model (e.g. Gomez, 1978; Espejo and Harnden, 1989; Clemson, 1991; Espejo *et al*., 1996; Hoverstadt, 2008; Malik, 2008; Türke, 2008; Schwaninger, 2009a; Espejo and Reyes, 2011; Pérez Ríos, 2012) (Figure 1, middle).

Gordon Pask with his conversation theory (1976) and his work on learning (1975) made important contributions to the cybernetics of human, social and socio-technical systems. Gregory Bateson (1973, 1980) in his oeuvre connected studies that are epistemological in nature with other inquiries into human and social systems (Figure 1, right strand).

A milestone on the way from first-order cybernetics to second-order cybernetics is the first opus about principles of self-organization (von Foerster and Zopf, 1962). Studies published therein (in particular Ashby, 1962) opened a new perspective: the postulate was—similar to the new physics (Heisenberg, 1959: 93)—to include the observer in the cybernetic system. The protagonist of this conceptual innovation was Heinz von Foerster, the director of the Biological Computer Laboratory at the University of Illinois. Von Foerster formulated the lead difference already mentioned between 'observed systems' (cybernetics I) and 'observing systems' (cybernetics II; von Foerster and Rebitzer, 1974), which would be seminal for the investigation of social systems.

The most comprehensive project for the grounding of a system theory or cybernetics of social systems was undertaken by the sociologist Niklas Luhmann. In his opus 'Social Systems' (1995/1984), a detailed blueprint for a theory system was presented, which would be conferred to the various functional subsystems of a society (e.g. Luhmann, 1990, 1994). In line with the programme of cybernetics II, autopoiesis, self-organization and self-reference were among the topics recurrently addressed by Luhmann. Luhmann's pupils have pursued his argument and have translated it mainly into the organizational context (e.g. Willke, 1996; Baecker, 2003).

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Finally, under the term 'soft systems', diverse methodologies have come about, which were developed for applications in the realm of organizations (Figure 1, right strand).

The three domains of reality just discussed exhibit very different features. Even so, cybernetics is applicable to all of them, owing to its abstract nature and focus on the invariances inherent in all kinds of systems. We will now try to elicit the concepts by which these invariances are captured.

CYBERNETIC CONCEPTS—BUILDING BLOCKS FOR A FRAMEWORK OF MODEL-BASED MANAGEMENT

If it is so that the science of cybernetics is applied to all three phenomenal domains, two questions spring up: which cybernetic concepts are used the same way in all three object domains? And then, are any concepts specific to single domains and therefore cannot be used in transcending the domains?

In science and in practice, differences between the three domains are often negated. As an example, men and machines are often equated, that is, they are understood as interchangeable system components that react deterministically to external impulses. Consequently, this position is prominently represented in the dawning modern era by LaMettrie, the French exponent of a materialistic, mechanistic world view and author of the opus 'L'Homme Machine' (1748). This stance is also present today among certain decision theorists, for example in their idea that organisms, organizations and adaptive machines are not only similar but also functionally equivalent (Crowther-Heyck, 2005). In economics, the mechanistic metaphor has had a paradigmatic significance from the era of mercantilism (17th century) until the neoclassical era (Ötsch, 1993). In our day, the inclination to design and steer organizations as if they were trivial machines is less a problem of theory than of the practical world.[3] However, these forms of reductionism have been refuted. For both the human and organizational realms, the non-trivial agent who can react to impulses in unforeseeable ways is a more appropriate concept (after von Foerster, 1984). Russell Ackoff and Jamshid Gharajedaghi (1984) have argued cogently for a distinction between the domains mentioned earlier.[4] They differentiate them as follows:

- **The mechanistic model**: It implies that a system can be understood completely, if one understands the relationships between its parts. These are considered as sufficient for the explanation of the connection between cause and effect. The system behaves deterministically. Applied to organizations, the mechanistic model conforms to the image of a hierarchically structured system governed centrally by a totally autonomous authority.
- **The organismic model**: It is based on the idea of a system that depends on its environment. In order to survive, it must adapt and learn. Survival is the highest goal, for the attainment of which growth is essential. Shrinkage is a synonym for degradation and decay. An organismically conceived organization is structured hierarchically, but as thinking and sensing are separated from each other, governance is not completely centralized. Some parts show certain measures of self-control, but they cannot control the functions they must perform.
- **The model of social systems**: In contrast to an organism that can change its structure only to a limited extent, but nevertheless survives, a social system exercises nearly full control over its structure. The effective management of a social system does not require the control of the mutually independent parts, but rather of the interactions among these parts and the interactions between the system and its environment. Analysis alone is insufficient for the study of such a system; it must be complemented by synthetic thinking. As the parts of an

[3] The ubiquity of bureaucratic controls and hurdles (Kanter, 1983: 56f.) and the re-engineering movement (Hammer and Champy, 1993) are prominent manifestations of mechanistic design.

[4] Formal analytical methods enable one to describe systems of very different types—nonliving systems, organisms and organizations—by one and the same set of formulas (Rapoport, 1968). Even so, we still face the aforementioned differences between the types, independent of our belief, whether or not they can be eliminated in principle and therefore will be outdated sooner or later.

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organization have their own goals and values, the deterministic model, according to which the causal relationships are exhaustively known, is useless in this case.

This brief account of the distinction between the characteristic models of different domains leads to the conclusion that distinct ideas of governance have to be employed. Neither the mechanistic nor the organismic model is sufficient for dealing with social systems. Oft-heard ideas such as 'the organization must function like a machine' or 'the company is like an animal' are inopportune.

This does not imply that all cybernetic concepts would be applicable to one single domain only. Rather, most of them are relevant to all three of them, albeit with different nuances. We will proceed to a survey of the concepts of cybernetics as they emerged in the evolution of the field. We begin with those concepts that are ubiquitous across the whole range of domains of application:

- **Feedback and feedforward**: These phenomena are found in all three domains. One difference is that social systems show a probabilistic causality, whereas mechanical systems are mostly deterministic.[5]
- **Information**: The concept of information is highly relevant independent of the domain. The cybernetic definition of *information* as 'that which CHANGES us' (Beer, 1979: 283) implies that information and mere data are different things. Information is the component of a message that is new to the addressee. Hence, it always emerges in a receptor that notes 'a difference which makes a difference' (Bateson, 1973: 286).
- **Control, governance**: These abstractions refer to the backward-oriented process of regulation and its forward-oriented counterpart—steering. Both phenomena inhere in all kinds of dynamic systems.
- **Learning**: This refers to the adoption of new behaviors into the repertory of an organism, concretely as the acquisition of knowledge, competencies and skills. First-order learning occurs by regulation in a process of error elimination, whereas second-order learning arises by changing the goals or the mental models. Finally, learning to learn better has been termed 'meta-learning' or 'deutero-learning'. Besides the existence of learning organisms and organizations, learning machines have been established since Turing (1950: 454ff.).
- **Self-organization**: A behavior that emanates from the elements and structures of an evolving system. It gives rise to forms that are neither externally devised nor imported. In line with the principle of redundancy, self-organizing systems show no separation of organizing, designing or controlling parts. Self-organization was identified first in chemistry and biology. In the technological domain, self-organization occurs in multiagent systems. Finally, social systems are self-organizing, as can be shown, for example, in politics and in socio-technical networks.
- **Evolution**: Evolutionary theory deals with the change of the inheritable attributes of a population from generation to generation. Mutations increase the variety of types (➔ *Variation*). Whenever the individuals of a population differ in regard to one or more attributes, a selection mechanism provokes certain individuals to procreate successfully with a higher probability (➔ *Selection*). Survival then is a consequence of fitness. In this process, variation and selection enhance the adaptation of a population in its environment. The concept of evolution stems from biology (Darwin, 1859), but it also pertains to social (e.g. Nelson and Winter, 1974) and technical systems (e.g. Rechenberg, 1973).

Certain concepts are connected mainly with the organismic–biological domain, without excluding technical and social systems applications completely, as follows, for example:

- **Adaptation**: In organisms, adjusting to external influences is an 'automatism'. It manifests itself as changes in structure and behavior following external stimuli. In social systems, adaptation gains an eminently creative component—reaching out to co-produce the environment.
- **Homeostasis**: This refers to the maintenance of a state of equilibrium in an open dynamic system by means of an internal process of regulation.

[5] In causal relationships, determinism refers to the view that cause and effect—due to preconditions—are unequivocally predetermined and predictable. In the probabilistic case, the incidence of a result can only be indicated with a certain probability.

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This principle also functions in social systems, but it does so through the participation of agents with their own goals and values.
- **Emergence**: This refers to the spontaneous appearance of new system properties, owing to the interplay of the system components. In principle, foreseeing the new features of the whole as a function of the properties of the parts is impossible. Emergence surfaces also in organizations; there, unexpected developments can often be anticipated.
- **Autopoiesis**: The process by which an organism (re)produces itself and maintains its existence was ascertained by biologists. It is also recognized as a phenomenon that arises in organizations (e.g. by Luhmann), in the sense that these reproduce themselves by means of operational closure.[6]

Two concepts inherent in human and social systems are as follows:

- **Reflexion**: This is the highest form of self-reference, that is, of the relationship of a system with itself. Basal self-reference and reflexivity are those forms of self-reference that can be ascertained in organisms (Schwaninger and Groesser, 2012). Reflexion, that is, the thinking of a system about itself and its environment, is a function to be found in organizations, for example, in strategy processes: the organization and its interaction with the environment are cogitated.
- **Ethos**: Stemming from the Greek term for character, custom, morals and manners, *ethos* denotes the moral sense of a person or a social system. For organizations, it is the totality of convictions, namely values and norms, that constitutes and stabilizes the unity and identity of the system.

The conclusion from this survey is that ultimately almost all concepts of cybernetics are in some way applicable to systems in all three domains. In other words, most of these concepts are valid across the whole range of domains of application. Even the concepts that are primarily connected to one domain only may lend themselves to being anchored in other domains as well. For example, emergence or even reflexion, two concepts that stem from biology, can also be linked to and implemented in a machine. Think of an abstract multiagent system, which can produce unexpected, 'emergent' features, or a computer system with an inbuilt higher reasoning function.

Nevertheless, a fatal pitfall occurs in applying a concept irrespective of the nature of a domain. An ominous example of inappropriate transfer of concepts is the mechanistic approach to the control of social systems. Although machines are typically controlled by goals defined centrally and outside the system, social systems are governed by values and goals that emanate from both the system as a whole and the components of that system (see the models of Ackoff and Gharajedaghi introduced earlier).

The question of inappropriate concept transfer hinges less on the concepts themselves than on their interpretation and application. For our purpose, the interest lies in the particular nature of social systems.

To take an example, the control function in a social system is by nature fundamentally different and more complex than in technological and organismic systems. It is polycentric and multimedial and embraces multiple autonomous, conscious and reflexive agents. In addition, the organization as a whole is (self-)conscious.

Despite all their differences, the applications in all domains can learn from one another. For example, this was shown by Beer (1979, 1981, 1985), whose viable system model is inspired by human neurophysiology. Conversely, technologists also learn from the functioning of natural organisms, as in bionics, the application of biological principles to design in engineering (Blüchel and Malik, 2006; Nachtigall and Wisser, 2013).

AN INTEGRATIVE FRAMEWORK FOR MODEL-BASED MANAGEMENT

By *model-based management*, we apprehend an organization's management (governance, control

[6] Operational closure is about the circularity of operations producing operations and must not be confounded with closeness, which implies isolation. An organism keeps all, or a certain part, of the relations between its elements invariant, despite perturbations, which stem from the organism's internal dynamics as well as from its relationships with other systems (Maturana *et al*., 1987: 180).

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and leadership) sustained by formal models. The high and growing importance of such models for the viability of organizations has been expounded elsewhere (Schwaninger, 2010). As cybernetics deals with governance or control in general, it makes sense to support management with cybernetic models, that is, abstract representations of concrete systems. Models are one, if not the, crucial factor for the results that can be attained with the management process (theorem by Conant and Ashby, 1981). If that is so, then the quality of the models used is extremely important. The truth and quality of the models used hinges primarily on the correct match of the model with the concrete ('real') system in focus. These thoughts can be summarized as follows: 'Show me your model and I will tell you what you can reach'. This section embodies an effort to make explicit the role of models in management, and their relationships with the objects of management, namely organizations, and the environment.

Given the diversity of the real systems and in view of the many conceptual components, which we have tried to make comprehensible, an integrative effort is called for at this point. It should make this variety productive by synthesizing the component concepts in such a way that a higher meaning emerges. To this end, we have developed an integrative framework for model-based management grounded in cybernetics. Frameworks are models with a broad scope, and usually of a qualitative type. They have been defined as 'broad schemes which support the orientation within a wide field. A framework offers dimensions and categories, by which a rough overview and a first location, and possibly also a structuring of an issue or problem, can be undertaken' (Schwaninger, 2010: 1422).

The frame presented here visualizes the concepts introduced in the last section, in their relative positions and with their interrelationships.

The framework embodies a synthesis of these cybernetic concepts, all of which are at the service of the viability and development of an organization. The integration of these components opens out into a generic meta-model, which should and can be an enabler for effective management. The rationale that guided the design of this meta-model is expressed in a 'language of integration'—the cybernetic notation used in the following diagrams.

As shown in Figure 2, the building blocks of the framework are as follows: (i) the concrete system to be managed—the organization; (ii) the environment/milieu of that system; and (iii) the model system used by the management.

We now elaborate these components and their interrelationships in a more detailed way (Figure 3).

In an organization ('the system'), technological, biological and social components are integrated on a higher level. That system adapts to its environment, which it can also influence. This is in principle a homeostatic way of functioning. In addition, the system is subject to change processes, which are essentially self-organizing, and it learns. The changes are part of a comprehensive evolutionary mode, in which new system properties can emerge. Although the organization is open in the sense that it can import people, information, energy and matter, it can also be considered operationally closed in that it obeys an internal circular logic by which it produces itself ('autopoiesis').

The model system is coupled to the real system and its environment through multiple information and communication processes. Information is present almost everywhere in the diagram: feedback is an information process, as are feedforward, decision, adaption of the model, reflexion, etc. The concept of control is present in the notion of *control model*. We wish to remind the reader that control or governance, as already

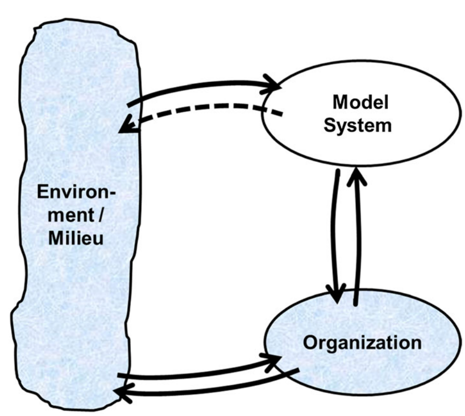

Figure 2 Building blocks of the framework for model-based management

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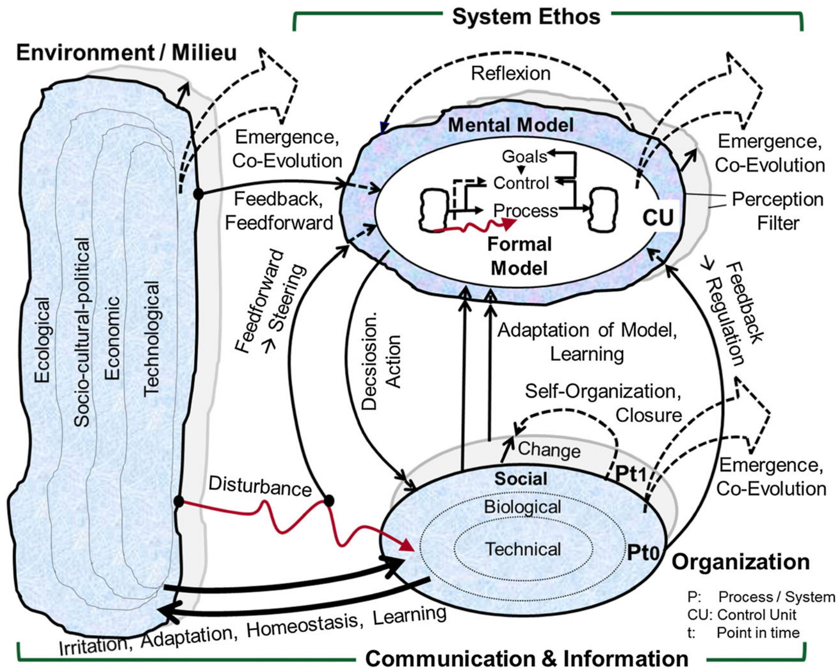

Figure 3 Integrative cybernetic framework for model-based management

mentioned, is the umbrella term for steering (via feedforward) and regulation (via feedback), because often this clear distinction is not made. We understand control in an encompassing sense here: it involves more than a mechanistic correction of deviations leading to first-order learning. It also entails creative processes, by which new paths can be discovered and new options invented. This often leads to the revision of goals and mental models (second-order learning).

On the basis of the information provided to the control unit via feedback and feedforward, that unit influences and changes the real system by means of decisions and actions.[7] In a dynamic, high-complexity context, it is essential that delays in this process be minimized. The postulate of 'real-time control' (Beer, 1979; Hetzler, 2010) is in line with this requirement. It is not enough to gather the current system state. Rather, the possible effects on future reality of decisions as well as disturbances and potential emergent phenomena must already be captured. In this connection, simulation is of utmost importance, namely for exploring action spaces and the implications of alternative options, strategies and structures in particular.

Managers and leaders always take their decisions based on their models, the mental model being at least as important as the formal model. Models are always biased, incomplete and prone to error. Physiological and psychological perception filters, whose primary task is reducing complexity via selection, entail such undesired side effects. Management models serve the purpose of compensating these counterproductive consequences of the filters, in such a way that decision-makers may take into consideration even those aspects that would have been ignored. These models should also foster analysis, synthesis and the recombination of ideas, information and knowledge, which is vital to the creation of the new.

Model-based management is aimed at improving the whole decision and implementation process by making available high-quality models. The

[7] The control unit's influence on the environment is indirect, as organization and environment are structurally coupled. Also, feedback and feedforward from the environment do not impinge directly on the organization, but only indirectly via the model. That is probably what Luhmann means when he claims that a system cannot be changed from outside, but only 'irritated'. More exactly, such irritations are internal to the system, emanating from environmental impacts (Luhmann, 1997:118).

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connections between decisions and their effects on the real system/environment as well as the consequent repercussions on the mental and formal models of the manager are critical levers for the upgrading of those models.

The most important component of a model-based management is the meta-level of self-reflexion and ethos. The former denotes the activity of self-reference, including self-observation and what we call self-framing/reframing—on the part of decision-makers: Is the model adequate? Does it answer the decisive questions? Can we learn from it? Which perceptual distortions need correction? Does the system change, and in what direction? Do the rules of the game shift? Does the model need modifications? These are strategic and developmental considerations inhabiting a long-term horizon. Finally, ethos brings in the ultimate, normative component of values and norms that should govern the organization as a whole: Are the governing values and rules still adequate, in light of new imperatives? Do the supreme goals need adjustment? Is a reframing or reconfiguration of the system required? Formally, the ethos is often cast in vessels such as organizational identity, vision and mission. Independent of formal aspects, the ethos can furnish the crucial components that complete an adequate model (as postulated earlier), in that they balance and eventually integrate the following: (i) the internal and external views and (ii) the short-term and the long-term perspectives. The horizon here is very long term if not timeless.

The issues addressed here, namely processes of self-reflexion and the formation of an ethos, call for a holistic, that is, unfragmented approach, despite the division of labour in an organization. Transdisciplinary collaboration is needed. Cybernetics with the integrative framework for model-based management outlined earlier is an enabling basis for such an approach.

MAKING USE OF THE FRAMEWORK

The integrative framework for model-based management supports diagnosis in the first place. Such a diagnostic function can discover if an organization or other social system is managed on the basis of a good model. More exactly, the diagnosis can discover whether the management of the organization is sufficient to ensure its viability and development.

The framework furnishes the checkpoints by which the components of the management that work can be distinguished from those that do not.

This step can be made tangible by looking into the deficits or failures that can occur. We intentionally choose the failures: these are at the core of organizational pathologies, because they tend to reveal more insights than the successes do (Malik, 1982; Vedder, 1992). The pertinent diagnostic points will relate to the following categories[8]:

(1) Structural deficits:

- 1.1 Dysfunctionalities of organizational structure, such as lack of autonomy in business units, too small or too large redundancy/slack, lack of flexibility
- 1.2 Lack of or pathological self-organization

(2) Model and control deficits:

- 2.1 Erroneous mental models
- 2.2 Missing or insufficient or wrong formal models

(3) Perceptual deficits:

- 3.1 Insufficient feedback causing uninformed management
- 3.2 Insufficient feedforward causing lack of forward orientation

(4) Behavioral deficits:

- 4.1 Lack of adaptation, misalignment with the environment
- 4.2 Insufficient change, usually due to barriers to change and defensive routines

(5) Competence and creativity deficits:

- 5.1 Flaws in or erosion of core competencies
- 5.2 Inaptness of reframing and recombination of ideas, knowledge and information

There is a clear limitation to this use of the framework. It provides paragons for the different management functions, but it does not interpret

[8] A more detailed analysis of organizational pathologies in a cybernetic framework has been presented by Pérez Ríos (2012).

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them in terms of concrete soft or hard variables. In principle, the user of the framework must decide how to evaluate each aspect of the organization in terms of both soft and hard aspects. To give an example, if a manager is unskilled in handling the interrelationships with her employees, this is a communication deficit in the widest sense. It could be merely qualitative (e.g. a negative attitude towards people), but it would also have a value (high–low) in terms of information flow, that is, in the feedback and feedforward dimensions.

THE FRAMEWORK AS A TRANSDISCIPLINARY ENABLER

This study has shown that almost all the concepts of cybernetics have their importance in each one of the domains considered (technical, biological and social). The proposition formulated at the outset, that cybernetic concepts are often conferred unduly between domains of application, holds in the following sense: One and the same concept can be applied in different domains, but then it is often interpreted in mistaken ways. In regard to social systems, this is particularly the case with the control function, which in social systems is of another nature and more complex than in the technological and organismic domains.

Social systems are scientific objects of a specific type: if the distinctions made in this text hold, then a specific language is needed to talk about organizations and their management and to study them. Management needs knowledge coming from many disciplines (Ulrich, 2001). Directing an organization is not only an economic problem but also a sociological, communicative and ecological issue. Leading in an organization also has psychological, technological and informational aspects.

Therefore, an interdisciplinary view is frequently postulated: as the problems at hand overtask the individual, the cooperation of experts from different disciplines is called for. Hence, the interdisciplinary approach is supposed to solve the complexity problem. How does interdisciplinarity function? It rests upon the communication between exponents of multiple fields. For that purpose, one person per set of two must know or learn the language of the other person in that set, in order to overcome the language problem at the interface (Espejo *et al*., 1996). Such a strategy can work well only in a context of low variety, for example if two agents cooperate with each other. If several or many exponents of different disciplines have to communicate in a team, the group must agree on a common code. The United Nations and many international schools have settled on English as their standard of communication.

Here, we are referring to the question of selecting a language that solves the problem of communication in multidisciplinary settings. The issue here is making the necessary variety of perspectives productive, which is necessary in dealing with complex systems. When analysing a societal problem, for example, of public health, it is not enough to conduct economic, epidemiological and sociological analyses separately from each other. Rather an integration of perspectives is necessary. The interdisciplinary path as defined earlier then is not functional. It is necessary to pursue a transdisciplinary approach. In such a case, all members of the responsible group use one and the same language.[9] Besides the ethnic languages, the kind of language we are addressing here is a code that facilitates the capture of subject matters of different scientific and professional fields.

In principle, the formal sciences, mathematics in particular, make available such a 'code'. Mathematics is highly precise, but not especially directed to dealing with complex dynamic systems. Cybernetics offers a formal apparatus that was developed especially for coping with complexity. In the sense of General System Theory (von Bertalanffy, 1968), cybernetics is suitable for representing dynamic systems of widely differing contents and whatever degree of resolution or size. Cybernetics is generally better suited for that purpose than mathematics, even if the latter is more precise.

Transdisciplinary collaboration is the operation of a multidisciplinary group on the basis of a shared formal apparatus or language. Hence, the integrative cybernetic framework for model-based management offered in the preceding section is such a vehicle—an enabler for

[9] Professional translators may be necessary to uphold the communication system.

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transdisciplinary inquiry, discourse and collaboration, by which an organization can cope with complexity more effectively. Cybernetic theories and concepts are predisposed to support such communication and cooperation. Therefore, cybernetics is a strong integrative factor for leadership and management. This holds at least for all those cases in which organizations are at stake—systems that have to cope with complexity and change, strive for sustaining viability and evolve over time.

OUTLOOK

The cybernetically grounded integrative framework for model-based management developed in this paper is highly abstract. That is a strong point: it embodies a synthesis of concepts as they might be of interest to academics. As far as practitioners are concerned, this frame can help them better 'understand the world' or, more down-to-earth, make sense of what they are experiencing and doing in their management and leadership work—an important prerequisite for improving managerial skills.

The role of cybernetics in the context of model-based management is in making transparent the structure and behavior of complex dynamic systems, for a better understanding of the following: (i) what is going on in the system and (ii) what is to be done to direct the behavior and evolution of the system on a desirable course. It need not be emphasized that the framework has to be complemented by models and methods to become operational, for example, structural models and methodologies for modelling and dynamic simulation.

In this contribution, a pertinent framework has been developed, on the basis of the conceptual building blocks bred within the history of cybernetics. The presented structure is embedded into an evolutionary process and therefore still developable. But even now, it already has value as a heuristic device for gaining knowledge and improving management.

From the integrative cybernetic framework presented here, one can gather an overarching cue: ultimately, the interaction of environment, control and real systems is the driving force for progress. Model-based management is, by and large, a way of *learning with models*. In this sense, model-based management has an exceedingly high potential for the improvement of management and organization. It will be worthwhile pursuing this path of research further, in order to actualize that potential.

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