The Double Challenge: Toward a Better Understanding of Systemic Risk Management

Alberto Gandolfi

Department of Management and Social Sciences, University of Applied Science of Southern Switzerland, CH-6928 Lugano-Manno, Switzerland
alberto.gandolfi@supsi.ch

Abstract

This paper sets out to present a new approach to a better understanding of the challenges of risk management in socio-technical systems. It is an integrated approach, in that it attempts to bring together, in a systemic way, two fundamental and, so far, rather unconnected lines of research: systems thinking and complexity science on the one side, with behavioral psychology and decision making on the other side.

Our model claims that human beings or organizational bodies facing complex systems and complex problems must simultaneously cope with a twofold challenge: the highly nonlinear, surprising and unpredictable nature of complex systems, and the limitations and biases of decision making processes (at individual, group and organizational levels).

This paper will focus the discussion of this integrated approach on the perspective of a management system which has to manage the strategic risks of a (complex) socio-technical system, such as an organization, a project, a government, or a society. We argue that a sustainable improvement in strategic risk management capabilities can only be achieved by simultaneously taking into account both aspects of the "double challenge".

Introduction - The Nature and Evolution of Complexity

Much has been written on the concept of complexity, but even now it appears that no consensus has been reached in the research community, either on a precise scientific definition of complexity or on a set of indicators to measure it. Scholars and professionals have suggested several definitions of complexity, often by trying to define the peculiar features of a complex system (see for example Homer-Dixon, 2002; Reither, 1997; Jervis 1997, Casti, 1994).

The research community working at the Santa Fe Institute coined the term *Complex Adaptive System (CAS),* meaning a dynamic network of many agents (which may represent cells, species, individuals, firms, nations) acting in parallel, constantly reacting to what the other agents are doing. The control of a CAS tends to be highly dispersed and decentralized. The overall behavior of the system is the result of a huge number of decisions being made every moment by many individual agents (Holland, 2000).

According to Casti, complexity is a multidimensional concept. Complexity includes several aspects (Casti, 1979), which can be grouped into two basic dimensions:

1) *structural complexity*, which refers to the (static) elements and the connectivity patterns among them, and includes:
    - variety (of elements and states);
    - hierarchical structure;
    - connective patterns;
    - strengths of interactions.
2) *dynamical complexity*, which addresses the system's dynamical motion or behaviour, e.g.
    - nature of the interactions (deterministic vs. random; linear vs. nonlinear);
    - time scales and rates of change.

From a risk management perspective, the most cited approach, proposed by Perrow, distinguishes two system characteristics that are particularly relevant in making a socio-technical system more complex and error-prone: nonlinearity of interaction and tightness of coupling among components (Perrow, 1999).

The Evolution of Complexity

For the sake of this paper it is also very important to briefly consider the evolution of complexity over time. It is often said and written – and our daily life experience would confirm – that our world is becoming more complex over time. But, unfortunately, to *scientifically* test this hypothesis would require the availability of a precise and widely accepted measure of complexity; as we have seen, this is not the case.

More empirical approaches show, however, that almost all partial or putative indicators of complexity show an increase in socio-technical systems (Berry, McKenna, Martin-Smith, 2005; Homer-Dixon, 2002). Several suggestions about the underlying mechanisms have been made, (Homer-Dixon, 2002); interestingly, all of these authors mention *technological progress* – and especially Information Technology – as a major force for increasing complexity. Hence, in the remainder of this paper we will assume that socio-technical systems (e.g. organizations, societies, governments, Internet) are actually becoming more complex over time.

The First Challenge: The Surprises of Complex Systems

Why is it so difficult to control and manage a complex system?

In the cybernetic approach, control is viewed as the ability to minimize or to block the flow of variety from environmental perturbations to a system's essential variables, thus enabling the survival of the system (Ashby, 1956). In other words, the controller must act as a buffer or a filter, absorbing any disturbance which might push the system away from the desired behaviour while also keeping the essential variables within a "safe" range. In this paper, we will identify those disturbances with the concept of risk (Malik, 1984).

Correlated with the concept of risk is the concept of *surprise*: a generally unwelcome and unpredicted event. It is clear that the joined occurrence of both concepts, i.e. a surprising, unpredictable risk, represents the worst scenario from a risk management perspective. This is exactly the point where we believe that a complexity oriented approach can deliver a new and refreshing view on systemic risk management (i.e. risk management at the level of a whole system). In fact, a rich and consistent body of research from different scientific and professional fields now allows us to classify the main surprise- and risk-generating mechanisms of complex systems.

The following features in particular have been found to generate surprise, risk and unpredictability:

- Feedback – the web of causal interactions among components which creates feedback loops;
- Nonlinearity – nonlinear behaviour, threshold effects and critical mass phenomena, hysteresis;
- Network dynamics – topology effects, power law dynamics;
- Delayed effects, inertia;
- Emerging properties, system effects, self-organization, synergetic behavior;
- Openness to outside environment and influences, coevolution with other systems;
- Indirect, unintended consequences; side effects.

We should briefly discuss these features and understand what kinds of risks they might breed in socio-technical systems, and consequently what kind of challenges they pose for management, as well as for risk management.

Feedback - The Web of Causal Interactions Among Components Creates Feedback Loops.

If the behaviour of each system's component is strongly influenced by the behaviour of the other components, such as in social, organizational, or ecological systems, then an extremely nonlinear behavior may emerge, resulting in dramatic, seemingly inexplicable (and thus unpredictable) fluctuations in the essential variables (Ormerod 1998; Jervis, 1997). As Schelling put it, for social systems, "what we typically have is a mode of contingent behavior – behavior that depends on what others are doing" (Schelling, 1978, p.17).

Interdependence means that the combined effect of changes in two or more of a system's components differs from the sum of their individual effects – a form of nonlinear behavior (Homer-Dixon). Similarly, in interconnected systems, effects and results cannot be predicted by examining the individual inputs separately; the effect on one variable often depends on the state of another: e.g. each of two chemicals alone may be harmless, but exposure to both can be lethal (Jervis, 1997).

Feedback loops are also very important for system behavior; while negative (balancing) feedback leads to stabilization and equilibrates the system, positive (reinforcing) feedback usually destabilizes the system, leading to uncontrollable amplifications of relatively small fluctuations (Sterman, 2000; Jervis, 1997). In systems with strong interdependence, changes and disturbances in one part of the system may be propagated throughout the system. Particularly relevant – and worrisome – for risk management are the so-called *cascading failures*, a phenomenon which can arise in systems where a specific positive (reinforcing) loop becomes dominant, so that the likelihood that an event will occur again is increased after each occurrence of the same event.

So, we see that interconnectedness leads to nonlinear behavior, which we will discuss in the following section.

Non Linearity – Non Linear Behaviour, Phase Transitions, Threshold Effects and Critical Mass Phenomena, Hysteresis

Generally speaking, nonlinearity means that a change (input) in a system can produce an effect (output) that is not proportional to its size and direction. Moreover, complex systems can exhibit a sharp shift in behavior when one or more variables cross a critical threshold (Ball, 2005, Jervis, 1997). Schelling has discussed a number of cases and models of so-called *critical mass phenomena*, in which the components' behavior depends on how many components are behaving in a particular way (Schelling, 1978). Ormerod (1998) has found that even relatively simple dynamical models can display an unstable and unpredictable behavior, with hysteresis. A system with hysteresis exhibits path-dependence; in such a system, the status of the system at a particular point depends not only on the state of particular variables, but also on how that state was reached. This means that it is necessary to know the path that the variables or the input followed before they reached their current value. The macroscopic dynamics of large natural and socio-technical systems shows strong nonlinear patterns: long periods of a relatively stable state or incremental evolution are "punctuated" by unpredictable collapses and bursts, as disturbances and fluctuations encounter vulnerabilities in the dynamical cycle (Holling, 2001). Jervis (1997, p.39), addressing political and social systems, claims that

> "jumps rather than smooth progressions often characterize operations of systems, some goals can only be reached by quick and drastic changes; the direct response to a small alteration in a policy or input may tell us very little about either the delayed effect or those that would follow from a large change. Similarly, many people […] believe that problems develop slowly and that it is wise to alter policy and behavior only after difficulties have revealed themselves rather than trying to anticipate long run consequences, which would require relying on speculative theories and evidence. Unfortunately, however, when variables interact in a non-linear manner, changes may not be gradual. Instead, for a prolonged period there may be no apparent deterioration, followed by sudden collapse or transformation".

Network Dynamics - Topology Effects, Power Law Dynamics

Complex systems can be described as *networks*, with nodes (the components) and edges (the relationships or interactions among components). Several lines of research have investigated the structural and dynamical features of networks, as well as the emergence of *network effects*. Barabasi has observed that most natural and socio-technical systems have a scale-free network topology with a *power-law distribution* of connectivity. This property has been observed in systems as diverse as Internet, power grids, metabolic pathways, neural networks, genetic codes, social networks, and protein interaction (Barabasi, 2002).

Scale-free topology has important consequences in determining the network's behaviour, also from a risk management perspective (Albert, Jeong, Barabasi, 2000): scale-free networks seem to be much more resilient against random disturbances or failures – such as the breakdown of a node, or several randomly chosen nodes – than are random networks or other network topologies (e.g. so-called "small world" networks). But scale-free networks are extremely sensitive, and fragile, if the most closely connected nodes are eliminated by a targeted attack: in this case the network connectivity collapses rapidly. In the case of Internet facing the risk of cybercrime, for example, this means that a random attack on its nodes (computers) has little chance of significantly damaging the network, but an intelligent, targeted attack on the few highly connected nodes, or *hubs*, might cause a disproportionate amount of harm (Albert, Jeong, Barabasi, 2000). Scale-free topology and power-law dynamics are also a decisive factor in understanding how disturbances or failures spread in a system. For example, the Internet appears to have a complex scale-free connectivity, which is very efficient for a communications network, but at the same time favours the unrestrained spread of computer viruses, due primarily to the absence of an "epidemic threshold" (i.e. the minimal spread rate for a virus in order to survive in a network; epidemic thresholds are instead present in other network topologies and its associated critical behaviour (Pastor-Satorras, Vespignani, 2001)

The power-law dynamics observed in complex networks has a dramatic impact on risk assessment and risk management. Power-law probability distributions don't discriminate

against extreme events, as Gaussian fluctuation does: fluctuations or perturbations of all magnitudes are possible,
or even unavoidable, in the long term.

Reports from practitioners underpin these academic findings as well. For example, Rosenoer and Scherlis (2009) point out that "technology-enabled extreme events", that is, improbable, hard-to-foresee disasters, in which IT often plays a central role, once considered infinitesimal and therefore a negligible risk, are becoming increasingly common in our world.

Delayed Effects, Inertia

Delays can be defined as processes whose output lags behind their input in some fashion (Sterman, 2000). They are a critical source of dynamics in nearly all systems, and represent subtle but extremely dangerous decision traps, for they hinder effective adjustment and impede learning from previous actions (Sterman, 2000). In socio-technical systems, delayed effects might arise when it takes time for actors to adjust to what others have done (Jervis, 1997; Reither, 1997). To mention only one practical example, delayed effects and the presence of positive feedback loops among the different components of a supply chain might create a logistic risk known as the "bullwhip effect" (Lee, Padmanabhan, Whang, 1997; Sterman, 1989): moving up the supply chain from end-consumer to raw materials supplier, each supply chain participant has a greater observed variation in demand and thus a greater need for secure stock. In periods of rising demand, down-stream participants increase orders. In periods of falling demand, orders fall or stop so that inventory may be reduced. The effect is that variations are amplified as one moves upstream in the supply chain, resulting in the hazard of stock-outs, poor customer service, the ramifications of failed fulfillment, and the hiring and firing of employees in order to manage the demand variability.

Emerging Properties, Self-Organization

In socio-technical systems, it often appears that a lot of unmanaged, uncoordinated individual activity leads to an aggregate behavior which is unpredictable and irreducible (Holland, 2000): markets, social capital, the "intelligent" behavior of ant colonies, consciousness, revolutions, are all emergent properties of systems. A property of a complex system is said to be 'emergent' when it arises out of the properties and relations characterizing its simpler constituents; it is neither predictable from, nor reducible to, these lower-level characteristics.

As Schelling has vividly shown, the resulting systemic pattern might be (and often is) uncorrelated with the individual intentions or objectives of the components (Schelling, 1978). Moreover, Holland (2000) notes that the context in which a persistent emergent pattern is embedded determines its function, making the final outcome even more unpredictable.

Beadu highlights two admittedly vague but essential properties of emergent phenomena (Beadu, 1997): (1) Emergent phenomena are somehow constituted by, and generated from, underlying processes; and (2) Emergent phenomena are somehow autonomous from underlying processes; an emergent property is irreducible to that of the micro-properties on which it supervenes

Openness to Outside Environment and Influences, Coevolution with Other Systems

Interdependence is not limited to the system, but also extends beyond the system's boundaries: the system is influenced by its environment, and it in turn influences its environment. The phrase "playing a game against nature" usually designates a situation in which the other side is unchanging; but this is a misunderstanding of the nature of socio-technical and natural systems, which in fact do react to people's actions (Jervis, 1997).

This point is particularly important for risk management and governance issues when risks arise from the conscious action of malevolent people who want to damage the system (e.g.

hackers, spies, terrorists, enemies, saboteurs, angry employees, competitors): in these cases, actors consciously react to others and anticipate what they believe others will do, thus increasing the complexity of the interaction (Jervis, 1997).

Indirect, Unintended Consequences, Side Effects

Outcomes in complex systems often don't follow from intentions: actions by a component have unintended consequences on the component, other components, or the whole system (Jervis, 1997). For example, Sterman (2000) has shown that in a dynamic decision-making simulation the aggregate actions of participants, even though all are trying to do their best, might nevertheless lead to a global system failure.

Unintended interactions among system components also breed risks when human actions increase complexity in ecological systems: to mention only one case, it has been shown that the commercial growth of a genetically modified organism (herbicide-resistant oilseed rape) might result in the risk of the inserted gene escaping from the crop and becoming incorporated in the genome of related wild species (Daniels et al., 2005).

The First Challenge – A Summary

To summarize, all of these "complexity surprises" - as mathematician John Casti (1994) calls them - may generate risks for the governance system: in fact, they make the system's behaviour opaque, unstable, counterintuitive, sometimes chaotic, and eventually unpredictable and uncontrollable (Ormerod, 1998; Forrester, 1971,). For example, a survey of large software engineering projects carried out in 1995 found that only between 10% and 20% of all projects met the stated goals in terms of time, costs and functions, the complexity of the projects being recognized as the main cause of failure (Bar-Yam, 2002).

Thus, on the basis of our previous discussion, we argue that an increase in complexity in socio-technical systems generally leads to a shift towards higher levels of uncertainty, populated by epistemic risks ("unknown unknowns": see Homer-Dixon, 2002). In such a situation, new management styles and approaches are required. Risk management is extremely difficult or even impossible to attain; management is not able to identify, control, or prevent all system errors and failures (Choo, 2008).

The Second Challenge: Decision Making Biases and Behavioral Limitations

In the first part of this paper, we have seen (a) that the complexity of our world is increasing and (b) that complexity leads to "behavioral surprises", unpredictable, nonlinear and largely unmanageable events. We shall now consider the other face of the issue (see figure 1), our "second challenge", the ability of such management systems to effectively cope with the complexity challenge. We will show that human decision makers are ill-equipped for this task. This is not at all obvious. Bernstein (1998, p.330) argues that

> "Bernoulli and Einstein were scientists concerned with the behavior of the natural world, but human beings must contend with the behavior of something beyond the patterns of nature: themselves. Indeed, as civilization has pushed forward, nature's vagaries have mattered less and the decisions of people have mattered more."

A number of different lines of psychological, economic and organizational research provide support for the position that the "human side" of decision making under uncertainty and in complex situations is far from rational and coherent. In fact, there are a great many shortcomings to the sources and types of human decision making. In the next paragraphs, we will briefly discuss the most relevant ones from a risk management perspective, distinguishing between three hierarchical levels: the individual level (both cognitive and emotional), the team level and the organizational level.

Individual Bias

We will focus first on cognitive aspects, and thereafter on emotional ones. Individual judgment and decision making activities are subject to a number of limitations and biases. Herbert Simon coined the term *bounded rationality*, noting that human behavior falls short of objective rationality in at least three ways (Simon, 1945):

- The complete knowledge of the situation and of the consequences of each choice, which is required for a rational decision, is not attainable in real socio-technical systems.
- Values of future consequences are only imperfectly anticipated.
- People are unable to identify, remember and analyze all possible alternative.

Perhaps the most influential line of research in this area was the “heuristics and biases” school, by Kahneman, Slovic, Tverski and colleagues. They demonstrated that human beings apply a set of judgment and decision heuristics (e.g availability, representativeness, anchoring) which breed cognitive bias (Kahneman et al, 1982).

Intuitively, when dealing with system dynamics, people often expect a linear relationship (Jervis, 1997). In an empirical study, in which subjects had to estimate future trends and developments from a set of historical data, it was found that 86% of all subjects presumed a linear behavior (Reither, 1997). Sterman (1989) has shown that misperception of feedback is widespread, producing systematic errors and biases in decision making. He also observes that the behavior of different people and teams is strikingly similar, despite a great variation in individual responses and attitudes. Nakamura and Kijima (2009) note that IT engineering failure risks are “soft, systemic, emergent and dynamic, i.e. they accommodate multiple stakeholders’ worldviews”. But they also argue that current methodologies for problem solving and managing such system failures use, paradoxically, a reductionist and static approach, which views failures as resulting from a linear sequence of events, focusing mainly on the technical issues and not considering side effects or unintended effects of troubleshooting interventions.

In the face of potentially risky situations, individuals display a predictable bias towards choice alternatives that perpetuate the status quo, and in general, past behavior has been shown to strongly influence future behavior. A good example is what is known as the “sunk-cost” trap, in which past investment of time, money or reputation, although rationally irrelevant, plays an important role in future decision making: the decision maker tends to prefer alternatives that permit him or her to justify past (sunk) choices and investments.

The list of potential human biases in the acquisition and processing of information and in response selection is very long, and almost all of them are relevant from a governance perspective (for an overview see for example: Kahneman et al, 1982; Simon, 1945).

Research has found that human beings present significant bias in critically evaluating their actions, attitudes and cognitive limitations, as well as in acknowledging mistakes and in learning from them. People are often overconfident, putting too much trust in their opinions. Furthermore, when subjects receive more information, their confidence in their own judgment increases, becoming out of proportion to the actual correctness of this judgment (Kahneman et al., 1982). This bias prevents decision makers from searching and seriously analyzing key factual information and leads them to neglect and to discount disconfirming information. Research has also shown that people fail to recognize their own cognitive bias and incompetence, greatly overestimating their real level of expertise and talent.

Learning in risky and complex environments is further hindered by the fact that people:

- interpret their experience and the outcomes of previous decisions in a way that preserves their positive self-image;
- try to avoid *ex post* cognitive dissonance;
- are tricked by hindsight effects (which convey the subtle illusion that there is not a lesson to be learned from past events);
- tend to treat random events as controllable, finding *ex post* causal relationships where none exist, a phenomenon called “illusion of control”.

At an emotional level, it has been shown that positive and negative moods do influence the decision making process, in particular likelihood estimates for risky events. It has been argued that when managers “face complex decision-making processes with high levels of uncertainty and anxiety, according to psychoanalytical theory, they face the prospect of regressing into unconscious infantile behaviors.” (McKenna, Martin-Smith, 2005, p.827)

Bias at Group Level

Similarly to the individual, groups also show biased information search and processing. Group dynamics effects have a strong impact on the decision making process (McKenna, Martin-Smith, 2005, Janis, 1972), although results don’t allow for easy and coherent generalization, as findings for individual decision do. Group decisions depend on a number of variables, such as group size and diversity, distribution of power, incentives, style of leadership, time pressure, task complexity, etc.

In his seminal work, Janis coined the term “groupthink”, a subtle and dangerous phenomenon which emerges from cohesive, cognitively insulated groups under stress and with a strong directive leadership (Janis, 1972). Groups in these situations show self-censorship and an illusion of invulnerability (and hence the tendency to overconfidence); eventually they fail to consider all alternatives, reaching consensus too quickly. Further, group polarization – i.e. the tendency for a deliberating group to take a more extreme position than its median member took before interaction began – is a common and well-known phenomenon that might be extremely relevant to risk management decisions (Sunstein, 2003).

Organizational Factors and Bias

Many organizational and cultural factors may impede a correct decision making process, in particular in managing complex risks: among them we can mention hierarchy and authority, power, leadership style, incentive systems, communication channels and information systems (McKenna and Martin-Smith, 2005; Nutt, 2002; Simon, 1945).

It is known that the organization fits the individual’s behavior into an overall pattern. Simon (1945) distinguishes two aspects of organizational influence: (a) the stimuli with which the socio-technical system seeks to influence the individual and (b) the psychological “set” of the individual, which in turn determines his reaction to the stimuli. Simon (1945, p.178) points out that:

> “An analysis of organized behavior of all sorts will demonstrate that such behavior results when each of the coordinated individuals sets for himself a criterion of choice that makes its own behavior dependent upon the behavior of others.”

Often, organizations are unable to detect, recognize and act on warning signals and precursor situations. In fact, it has been shown that a number of complex risks often have a latency (or incubation) phase before occurring.

Choo (2007) claims that a major source of errors in socio-technical systems lies in communication and in information processing; he identifies three types of *information impairments* that lead organizations to disregard warning signals. These epistemic blind spots

are: (a) warning signals which don't fit existing decision frames and thus are not recognized; (b) risk denial: organizational and cultural aspects which cause people to discount warning signals; (c) structural impediment: organizational and procedural aspects which hinder an effective and complete response to warning signals.
Organizational politics is a crucial factor which often heavily influences decision making processes. Astley et al. (1982) use the term "cleavage" to indicate the presence of diverse and conflicting views of various interests and claim that cleavage makes the decision process more time-demanding and difficult. Nutt (2002), based on an empirical study of 400 management decisions, identifies three blunders which account for most decision failures:

- Failure-prone practices, e.g. not fostering participation of relevant stakeholders in the decision making process.
- Premature commitments of decision makers, e.g. when answers are complex and not readily available, decision makers often jump on the first alternative that seems to offer an acceptable solution.
- Wrong-headed investments of time, attention and financial resources, e.g. decision makers invest resources for costly evaluations, whose goal is often to support a choice alternative which the decision maker has already committed to.

These blunders might prompt seven different decision traps: (1) the failure to reconcile stakeholder claims; (2) the failure to manage barriers to action; (3) the allowance of ambiguous directions; (4) a limited alternative search; (5) the misuse of evaluation (and confirmation bias); (6) the overlooking of ethical issues; (7) the failure to learn from experience (Nutt, 2002).

The Second Challenge – A Summary
What we have presented is quite an embarrassing (and surely not exhaustive) catalogue of the serious limitations of our individual, group and organizational judgment and decision making processes. Reviewing this catalogue, one even wonders how such a biased and frail mind can work at all in a complex world. A further important question concerns the existence of a causal link between complexity and decision making limitations; in other words, does increasing complexity increase the number and severity of judgment and decision making limitations? Psychological research suggests a positive answer to this question (McKenna and Martin-Smith, 2005; Reither, 1997).

What can be done? Possible Responses to the challenge

What can individuals and organizations do to cope with this "double challenge"? Cybernetics provides a framework for identifying possible solutions. For example, the *Law of Requisite Variety* (Ashby, 1956), applied to the governance of socio-technical systems, tells us that control cannot be certain unless management has at least as many alternatives (or the same variety; or the same level of complexity) as the controlled system can exhibit. This provides a numerical lower boundary on the requisite variety of decisions and actions the controller must have in order to be effective. In this respect, the *Law of Requisite Variety* clarifies the opportunities and the limits of our decisions and actions, showing that we have only two strategic alternatives to cope with our double challenge (Beer, 1981):

- reduce the variety / complexity of the system to be controlled (and consequently the complexity of the systemic risks) and/or
- increase the variety / complexity of the controlling system (governance system).

If we turn our attention to the concrete realization of these strategic alternatives in real governance systems, we find in literature and practice a vast array of suggestions, which haven't yet been integrated into a coherent model. Although we cannot describe in detail in this paper all of the suggested approaches, we should briefly mention in the following paragraphs those which seem most relevant from a theoretical or practical point of view.

a) Approaches to Reducing the Complexity of the System to be Controlled.
Several authors have suggested empirical rules and strategies for simplifying socio-technical systems. Some popular management fads of the last decades have explicitly relied on system simplification, for example Business Process Reengineering or Lean Management and Lean Production approaches. Furthermore, Stafford Beer (1981) has suggested the adoption of "Variety (complexity) Attenuators", i.e. methodologies and strategies to attenuate the complexity of the environment which is reaching the system – and its essential variables – through a transmission channel (also see Ashby, 1956); according to Beer (1981), variety attenuators might take different forms: structure (e.g. divisionalization, delegation, functionalization); planning (e.g. setting priorities); operations (e.g. management by exception).

b) Approaches to Increasing the Variety/Complexity of the Controlling or Governance System First of all, organizations and decision making bodies can increase their variety by diversifying aspects of their individual members: age, professional or cultural background, cognitive style, race, sex, knowledge of the problem, role in the organization, experiences, interests (Sunstein, 2003).
Historically, the first structured attempts came from cybernetics, which developed several theories and models to enable an effective design and governance of organizations (François, 1999), for example, the *Viable System Model* (VSM) (Beer, 1981) or the *Team Syntegrity Model* (TSM), a systemic framework developed by Stafford Beer to facilitate open, synergetic and creative discussions in large groups (Beer, 1994).
Another approach is through modelling and simulation, which allows a better understanding of the behaviour of complex systems (Sterman, 2000; Brehmer, 1992).
Variety can be increased by exploiting collective intelligence, also known as the "wisdom of crowds" (Surowiecki, 2004) or in a technical setting as "swarm intelligence".
Furthermore, a more complex and diverse decision making process can be attained:

- by removing the bias and cognitive limitations which are observed in people dealing with complex issues (Kahneman , Slovic, Tversky, 1982),
- and by adopting techniques for improving and enriching the decision process.

Conclusion

In this paper we have outlined an integrative model based on two challenges for decision makers from a governance perspective. The first challenge is represented by the increase in complexity in the socio-technical systems, an evolution which has led to a challenging decision environment. To cope with this complexity, individuals, groups and organizations have to activate judgment and decision making processes, which unfortunately have been shown to be biased, inaccurate, and non-rational: this is the second challenge in our model.
The origins of this double challenge might be found (at least on the individual level) in the evolutionary process: biological evolution first, followed later by cultural and technological evolution. As Forrester (1971, p.52) put it,

> "The human mind is not adapted to interpreting how social systems behave. Our social systems belong to the class called multi-loop nonlinear feedback systems. […] Evolutionary processes have not given us the

> mental skill needed to properly interpret the dynamic behavior of the systems of which we have now become a part."

As anthropology has shown (Tooby and Cosmides, 1989), evolutionary pressure has led to an extremely specialized, "modular" mind, well adapted to a competitive environment that doesn't exist anymore.

> "There has not been enough time passed since the dawn of agriculture – which began a mere 10,000 years ago – for any new mental mechanisms to arise in response to our sedentary, urban industrialized life. In other words, we may live in a modern metropolis, but in many respects we still harbour a stone age mind within our skulls" (Allman, 1995, p.35).

As a result, Homer-Dixon (2002) argues that human societies are locked in a competition between an increasing requirement for ingenuity (i.e. the capacity to understand, manage and control complex issues), and an "uncertain supply".

We believe that this widening gap between the world's complexity and our human capacity to govern it might represent one of the most fundamental and crucial challenges of our future, what we have called "the double challenge". Further research should focus on both challenges, for example by helping us to a better understanding (and possibly a quantification) of the different dimensions of complexity and their consequences for the system's dynamics; or to exploring ways to improve our cognitive ability to cope with complex problems.

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