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von Bertalanffy's General System Theory and the adaptive governance of social- ecological systems

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Abstract
Based on biological insights Ludwig von Bertalanffy coined General System Theory (GST) and later expanded his perspective, exploring what GST could mean for other disciplines and other types of systems. We make a case for the relevance, or rather, the importance, of GST for coming to a new understanding of the resilience of social-ecological systems and the possible forms of adaptive governance which might increase such resilience. After analyzing the conceptual structure of the resilience paradigm and of GST we identify concepts in resilience thinking where GST provides new confirmation or modifies the perspective: complexity, evolution, self-organization, adaptation. We discuss post-Bertalanffy developments in the inter-disciplinary and twinned fields of systems theory and complexity studies which can provide bridging concepts between GST and resilience thinking. Concluding, we emphasize the need for both cognitive and institutional resilience to foster adaptive governance. We highlight the management of couplings between systems and the switching between forms of understanding and forms of organization, where self- organization and more centralized forms of steering can alternate and combine.

1. Introduction

We argue that Ludwig von Bertalanffy's (LvB) general system theory (GST) still provides valuable insights for contemporary theories of the social and the ecological and their connections. It is therefore useful for theories of social-ecological systems and of the resilience thinking which has been the dominant form of sustainability thinking for some time (Armitage et al., 2008; Folke et al., 2007, 2002; Lebel et al., 2006; Levin et al., 2013; Olsson et al., 2004). We analyze resilience thinking as a paradigm, meaning that we emphasize the unity in resilience thinking, while acknowledging its internal diversity. That diversity, however, we consider less important because in the literature all concepts which feature as coupled in our understanding of the paradigm do appear in all possible combinations and permutations in the literature, effortlessly bridging the initial differences between authors.

The key concepts in the paradigm are resilience, social-ecological systems, adaptive governance, complexity and the distinct local/expert knowledge. Each of these concepts has a unique lineage and each had a different disciplinary and inter-disciplinary history, but they came together cohesively in the resilience paradigm, ushered in by C.S. Holling in the 1970s. Resilience of ecological systems transformed into resilience of social-ecological systems, a capacity to bounce back from shocks. From analysis of external events the attention moved to analysis of systems we are part of, and systems we can influence, by means of resource management and more broadly, by governance. As environments change, management and governance have to be adaptive, and as governance then has to be more sensitive to environmental change, knowledge and learning are essential. Diverse sorts of knowledges have to be combined to maximize sensitivity, and the same inclusion that enables diverse knowledge is expected to enable broadly supported interventions in the social and/or ecological environments, when required by adaptive governance. Even so, this will never be easy, as both social and ecological systems are complex systems, marked by non-linear responses to intervention, yet also offering the possibility of new solutions and adaptations emerging through self-organization.

We elaborate and refine this sketch in the following sections on the paradigm and its genealogy. Then, we introduce Ludwig von Bertalanffy, and the key concepts making up his general system theory. Von Bertalanffy was a biologist and keenly interested in metabolic processes that keep going and seem to create and maintain structured complexity in and through that process. He developed a concept of open systems which are, as we shall see, not entirely open, but depend on sophisticated mechanisms of boundary formation and maintenance. From there, his perspective itself developed more complexity, and allowed to grasp coupled and embedded systems, while it produced a new understanding of evolution and co-evolution. LvB thus reformulated key insights in what he considered to be the most basic conceptual and physical structures constituting and studied by the discipline of biology (he spoke of 'theoretical biology'). After which he started expanding his systems perspective outside biology and exploring what it could mean for other disciplines and for a theory of everything, of social and ecological systems.

In a next section, we then zoom in on key concepts in or highly relevant for the resilience paradigm, and how they appear in the light of GST. Von Bertalanffy's insights in evolution itself, in the evolution of complexity, the nature of adaptation, self-organization and the possibilities and limits of steering were all inspired by studies of biology and ecology. Through generalized systems thinking these insights became transposable to the world of the social-ecological environment; in many ways they confirm the resilience paradigm, and in some cases offer extensions and modifications. We believe such interrogation of GST is useful not only because of the ambitions of GST, but also because of the ambitions of the resilience paradigm and its sprinkled references to an origin in systems thinking.

Rather than limiting ourselves to the question 'What can von Bertalanffy do for us (resilience thinkers)?', we believe it is more productive to add another question, representing another strand of investigation, i.e. 'What can we do for Bertalanffy (so he is more useful for resilience thinking)?'. The answer to that question has in principle no limits. We will define a number of possible extensions of GST, linking to ideas already present there, to resilience ideas and to its practical embodiment, adaptive governance. These extensions we do not have to invent, as they already exist, and in most cases came about in discussion with GST.

After thus re-analyzing resilience, von Bertalanffy and possible extensions, we concludingly argue for a re-invigorated discussion and deepened awareness of the systemic conceptual infrastructure of resilience thinking. This, we believe, is essential for reinforcing those foundations and for the enduring relevance and, yes, adaptive capacity, of the paradigm itself.

2. Resilience and adaptive governance of social ecological systems

Understandings of resilience at first revolved around the adaptive capacity of an ecosystem to maintain certain of its features despite and through sudden changes, without the latter leading to collapse or to internal restructuring of the system. Besides resilience as returning to a stable state after shock, resilience was presented as the capacity of an ecosystem "to absorb change and disturbance and still maintain the same relationships" (Holling, 1973, p. 14). While initially conceptualised in reference to ecosystems, resilience increasingly became thematised in reference to socio-ecological systems or 'people and nature as interdependent systems" (Folke et al., 2010, p. 2). This enlargement of meaning had become necessary because of the perceived reductionism in its initial formulation: a focus on ecological systems captured 'only a part of reality' and neglected the social dimension, which was now understood to be irreducibly intertwined with the former (Folke et al., 2010, p. 2). Anthropologists, for instance, borrowed the ecosystem concept from the biological sciences to describe how people adapt in different ways to the demands of their immediate environment (Haenn and Wilk, 2006). Along these lines, Holling's concept of 'ecological resilience' became tightly coupled to the idea that the social and natural are inherently intertwined and that it would be 'irrational to continue to separate the ecological and social and to try to explain them independently, even for analytical purposes' (Folke et al., 2010, p. 2).

The idea of social- ecological systems does show up with Holling early on (Holling, 1978) much later with the oft quoted Ostrom(Ostrom, 2009), but has older roots going back to Chicago School sociology of the 1920s and 30s, to social ecology thinking dating back a bit earlier, and ultimately to humanist biology considering humans part of a global ecosystem (Dale, 1970; Krebs, 2001; Meyfroidt and Lambin, 2011; Myers, 1950; Richerson, 1977; Selznick, 1948; Wenke, 1981). We find in this lineage – of which Alexander von Humboldt is undoubtedly the great precursor (Wulf, 2015)- a similar testing of ideas, a similar scrutiny of ecological and biological thinking for explanatory value in social issues, and vice versa. Von Humboldt inspired Darwin, who inspired social darwinism, later the field of socio- biology, and the evolutionary thinking since Darwin inspired systems theories of all kinds, including GST and complex adaptive systems (CAS) (Hempel, 1951; Myers, 1950; Phillips, 1976; Thompson et al., 2010; Von Bertalanffy, 1950).

With the inclusion of the social into resilience the meaning of the term was increasingly widened (Fig 1) with a component of self-steering or active adaptation. Resilience increasingly referred not only to adaptability, but also to transformability, the capacity of a socio-ecological system to learn, combine experience and knowledge, adjust its responses to changing external drivers and internal processes (Folke, 2006; Hahn et al., 2008). The guiding idea is that resilient systems are social-ecological systems which are undergirded by policies that can enhance the capacity of such systems to absorb sudden changes of states and constantly renew themselves in the face of unexpected changes. (Berkes and Folke, 1998; Chapin et al., 2009; Folke, 2004; Levin et al., 2013; Liu et al., 2007). Such policies need to address issues at multiple scales and require a multi-level, and poly- centric governance system itself (Folke et al., 2002; Lebel et al., 2006; Ostrom, 2010). Adaptive governance ideas took a more prominent place in the resilience paradigm in response to growing concerns over climate change, over the need to make environmental decision making more inclusive, and as an expression of growing awareness of failure of previous governance arrangements and tools for nature conservation and environmental quality (Booher and Innes, 2010; Plummer and Armitage, 2010; Van Assche et al., 2017a; Voß and Bornemann, 2011)

In line with academic and other discourses on participation as rejuvenation of democracy, and as a way to bring more local knowledges into governance systems, and in line with discourses on traditional communities causing far less damage to their environments than nation states and a globalized economy, resilience thinkers paid more and more attention to the combination of self-organization and diversity of knowledges in governance, where one would reinforce the other, and both together are expected to enhance resilience. Recent resilience thinkers drew the conclusion that multi-level governance is a sine qua non, as this increases observational capacity of internal and external environments, and as it can provide correctives for initiatives overly focusing on the issues observed in one scale. Polycentric governance adds a new source of diversity in observation and possible adaptation, since the locus of decision-making at the larger scales is more distributed, and because the relations between scales can differ and shift, allowing for seemingly marginal places to become the origin of possibly important adaptation moves, and potential power centres enabling implementation of the ideas.

[HERE FIG 1]

3. von Bertalanffy's General System Theory

According to Niklas Luhmann, von Bertalanffy's concept of an open system was a watershed in the development of a general systems theory. In his Social systems (Luhmann, 1995, p. 7) Luhmann argued that LvB's thinking constitued a shift from an ontological to a more functionalistic systems concept, i.e. from thinking in terms of wholes as unchangeable substances to systems that maintains themselves in a dynamic exchange with their environment. By proposing the notion of the 'open system' the traditional difference between whole and part was replaced by the distinction of system and environment. Like any paradigm change, Luhmann notes, this implies a conceptual broadening. What has been conceived of previously as the difference between whole and part, was reformulated by this new schema as system differentiation and thereby built into the new paradigm. Systems differentiation can be understood as the repetition within systems of the difference between system and environment.

According to von Bertalanffy (1968), classical science suffers from a mechanistic worldview which prevents it from giving an adequate explanation of the attributes of organized complexity such as wholeness, evolution, self-regulation and equifinality. To Bertalanffy (ibid), these phenomena could only be accounted for in the model of 'open systems, namely, systems that maintain themselves 'in exchange of materials with environment, and in continuous building up and breaking down of their components' (Von Bertalanffy, 1950, p. 23). The concept of the 'open system' was for him the truly 'general system' concept enabling the integration of all the sciences into a general system theory. The general systems theory (GST), which was co-created by von Bertalanffy with economist Kenneth Boulding and others (Pouvreau, 2009; Von Bertalanffy, 1968), did find inspiration not only in biology, but also in thermodynamics, in systems engineering, and early computer science. It also reflected extensively on the conscious and unconscious use of non-biological models and metaphors in the explanation of biological phenomena - machines, and computers (von Bertalanffy, 1952; Von Bertalanffy, 1968, 1967).

The crucial but often misunderstood idea of *openness* needs to be clarified here: open systems for LvB are open to interaction with the environment, and this can over time lead to adaptation (a term he disliked) yet, this is an openness understood against the background of a continuous self- reproduction, as in the human body all cells are replaced, all organs renew themselves (von Bertalanffy, 1952; Von Bertalanffy, 1950). In his understanding of psychology, a psychic system does not need to be stable and 'well adjusted' to a particular environment, but able to make sense of itself and that environment (Von Bertalanffy, 1967). Insights from development biology, cell biology and evolutionary biology slowly combined and transmuted into a general systems idea which is in essence *metabolic*, based on the understanding of self- stabilizing processes, yet allows for the study of increasing complexity. As bodies are conceived as systems in systems (cells in organs in bodies), hierarchy is understood as one way of enabling stable complexity. The notion of 'the steady state' LvB put forward as an opposite of thermodynamic equilibrium. In his own words, "living systems, maintaining themselves in a steady state, can avoid the increase of entropy, and may even develop towards states of increased order and organization" (Von Bertalanffy, 1968, p. 41).

For LvB, the understanding of unity in diversity, e.g. of shared systems logics in a variety of disciplines, deserved more attention for several reasons. GST could not only produce new insights in many existing fields, it could also connect them in a way that avoided replication of work, multiplication of blind spots, elongation of blind alleys. Moreover, the trans-disciplinary challenges which faced society already in LvB's time, were clearly not addressed by the existing framework of disciplines. In his later career, environmental problems start to draw attention, while earlier on, questions of war, peace, conflict control were center of attention. Both entail ideas of shocks, of destabilizing external events, of loss of gradually built complexity, of both ecological systems and social systems. Both required, in his view, the analytical tools of a general systems theory to come closer to a resolution.

4. von Bertalanffy on concepts close to resilience

It is no longer the entropic disorganization, but rather the generation of extreme shocks, that emerges to be the key environmental challenge which the social-ecological systems are called upon to meet. The systemic capacity to absorb shocks without the undesirable regime shifts does entail the maintenance of a steady state, but in the sense different from "developing towards states of increased order and organization" (Von Bertalanffy, 1968, p. 42). LvB's nuanced insights suggest that self-organization may entail radically divergent evolutionary paths. Through self-organization, social systems may run themselves into the ground yet social and biological systems may also maintain steady state which in turn rests on numerous homeostatic mechanisms and negative feedback loops.

In this section, we discuss LvB's view of complexity, adaptation, evolution and self-organization, to increase our understanding of GST, while coming closer to the pre-occupations and conceptual structure of the resilience paradigm. We will conclude the section with a brief recapitulation of the implications for concepts of social-ecological systems, which do not feature directly in LvB's work, but are compatible with it.

4.1 Complexity

For LvB, inspired by developmental biology, systems can increase complexity by absorbing other systems (think of early evolution, where organisms incorporated others). In unpredictable processes of *emergence,* the interplay of elements at system level can produce a higher order entity and logic, which cannot be reduced to the constituting elements, yet cannot survive without that substrate either (Corning, 2002; Lewis, 2016; Von Bertalanffy, 1968). Internal complexity can increase adaptive capacity, as the number of possible responses expands, and it can just as well imbue the system with new fragilities, as more complex metabolic processes have more entry points for disturbance. It has to be stressed that the relation between a whole and its elements, as well as the layering or hierarchy of systems often invoked by LvB (as in the case of the human body) also embodies a form of co- evolution, where the emergence of higher coordination functions (such as the brain) does not undo the interdependence of the parts (Gray and Rizzo, 1973; Hofkirchner, 2005; von Bertalanffy, 1952).

Early in his career, LvB is inspired mostly by biologists (yet equipped with a thorough knowledge of philosophy), but his friendship with chemists and physicists working on thermodynamics (as his friend and later Noble prize winner Ilya Prigogine (Gray and Rizzo, 1973; Pouvreau, 2009)) contributed to his thinking on open systems which could ‘beat’ the second law of thermodynamics. Such negation of entropy was only possible by continuous activity, continuous maintenance and reproduction which takes energy, and which implies import from an environment (Von Bertalanffy, 1968). This energetic need underlying the capacity to maintain and increase complexity (hence adaptive capacity), is the main meaning of ‘openness’ for LvB. Internal complexity is therefore always linked to external complexity and external resources. For the understanding of complex system evolution, the environment as in *other systems*, and the environment as a combination of *internal and external* environments, deserves special attention.

For LvB, complex systems indeed display features of non- linearity, with small initial changes in a system provoking large and unpredictable changes later on in the same system, or in coupled systems (Holling, 2001; Schmidt, 2015; Wenke, 1981). Yet he would present the opposite as likely more typical of complex systems, i.e. the relative indifference of many of its metabolic processes to initial states (within a certain range). LvB would speak of *equifinality* as a key feature of self- organizing open systems (Von Bertalanffy, 1968, 1949). The concept means that the same outcome can be achieved through different routes, leading to the same state of the system. Certain systems can tend towards certain steady states, from different starting points. LvB thus anticipates the idea of *attractors* of later complexity theory, as well as non-linearity (see also below).

Equifinality is a form of finality, a form of dependence on the future. For the consideration of social systems, and questions of governance, LvB’s category of *purposive finality*, assuming a capacity for strategy, becomes more important (Von Bertalanffy, 1968). Purposive finality does not imply that the purpose is always reached, and purposive finality contributes to complexity creation in two ways: by multiplying possible pathways of development, and by introducing new non-linear affects, in the form of unanticipated consequences.

4.2 Evolution and adaptation

The evolution idea underlying GST is not entirely Darwinian. For GST, evolution is not necessarily driven by a survival of the fittest, and neither is evolution as development of complexity always a matter of testing alternatives, as in complex adaptive systems theory, or CAS (Hammond, 2010; Hofkirchner, 2005; Von Bertalanffy, 1952). GST foreshadows the evolutionary theory of Chilean biologists Varela and Maturana (Vanderstraeten, 2019; (Gaines, 1978; Von Bertalanffy, 1950), who were familiar with LvB’s work. For LvB and the later Chileans, self- organization is radical self-organization, with processes, structures and elements of a system producing all later processes, elements, structures (Maturana and Varela, 1991; Von Bertalanffy, 1968). Varela and Maturana will speak of *autopoiesis,* a term later redefined by Niklas Luhmann for social systems. Evolution is adaptation to changing environments but those environments are internal and external, and both observation of environment and responses to change are filtered and structured through what is possible in the system. And what is possible is the set of possible responses given the particular structures and processes of the system.

Systems emerge as autonomous operative chains that extend themselves by continuously redrawing the distinction between internal operations and external events. That means that adaptation is never direct or perfect adaptation, but a matter of satisfactory fit with an environment which is only known and responded to via the existing structure of the system. Moreover, following von Uexkull, for von Bertalanffy (hence GST) each system has its own environment, which it continuously responds to (von Bertalanffy, 1952; Von Bertalanffy, 1955, 1950). Adaptation is always there, as long as the system survives, yet conscious adaptation, in the sense of reflexively considering an environment and adapting to it with more than incremental or short-term responses, is not given to all organisms (Hofkirchner, 2005; Von Bertalanffy, 1952). Adaptation through evolution is a different matter altogether; it does happen, but is possible only through the impact of environments on essentially self- referential systems (Pouvreau, 2009; Von Bertalanffy, 1968, 1967).

4.3 S*elf- organization; emergence*

Systems are thus self-organizing per definition*, as there is no other way of organizing*. A boundary and an identity are only possible by continuous reproduction of the elements of the system through other elements; inputs that do not disturb the system can only be integrated through the existing structures and processes (Von Bertalanffy, 1972, 1952). LvB offers the useful insight that, just as all systems root in the biological, they all root in self- organization. To use later terms for a quintessential GST insight: the autopoiesis of biological systems enabled autopoietic emergence of other systems. The social-ecological as a system has therefore to be understood as a product of contingent processes of emergence.

LvB would add that even at the biological level, self-organization at some point in evolution, leads to the formation of closed causal chains, to differentiation of units with a stronger identity of function, to what he calls *mechanization* (Von Bertalanffy, 1972, 1952). For him, this is a correlate of increasing complexity, but it also comes with the price of *less direct or central steering* (Von Bertalanffy, 1968, 1967). Units become more specialized, routinized, operationally closed, hard to read and steer from a control center. Self-organization and central steering are thus only paradoxically compatible for LvB. Complex systems can be both self-organizing and centrally steered, as steering functions enable metabolic processes to continue and maintain the steady state. Yet there is a complexity threshold, beyond which the steering unit has to deal with other units, rather than only elements and processes. The central steering unit might be more clearly defined, recognizable, complex itself, yet together with increased functional specialization and power of steering comes a new opacity of the internal environment. One could say, in a Foucaultian analogy, that power engenders it counter-power.

Emergence as the appearance of a new higher- level logic and identity can, for GST, be the appearance of a new system, or the transformation of a system. Emergence without systems would dissipate, and systems without emergence would not evolve towards higher complexity. Emergence is not necessarily a result of adaptation, yet what emerges has, evidently, be adapted to survive. Higher complexity, indeed, does not necessarily entail better adaptation or higher adaptive capacity, yet the possibility of emergence opens up entirely new horizons of possible adaptations. Indeed, for Luhmann (see below), the emergence of social systems (engendering along the way social-ecological systems) made a variety of new understandings of, thus adaptations to, different times and environments possible.

4.4 Social ecological systems

For LvB, openness and closure of systems allow for a co-evolution in two directions, horizontal and vertical (Gaines, 1978; Pouvreau, 2009). Ecological systems are the result of co-evolution of ecosystems, of species in systems, while each individual making up an ecosystem consists of other systems. Or, systems always exist in and besides each other, and their functioning can only be explained in reference to some of the systems besides and inside. Not all systems influence each other, and co-evolution has to be restricted to phenomena of tight coupling, where changes in one system trigger changes in the other, to remain meaningful. Social ecological systems certainly feature this co-evolution in two directions, while the vertical one is the primary one in evolutionary terms, as the substrate of all systems biological, without them being reduced to it. The ecological is thus the environment of the social in a double sense: internally and externally. It forms a substrate and a boundary at the same time.

LvB does not translate the concepts of self- organization, adaptation, emergence directly to social systems. Thinking direction adaptive governance, his ideas do not warrant that the necessary degree of self- awareness and the required power to steer the system in a different direction is ever present (Von Bertalanffy, 1968). Adaptation as the result of purposive finalities, adaptation transforming social-ecological systems towards resilience, has to calculate the web of co-evolutions constituting the realm of the social-ecological (Von Bertalanffy, 1967). His interpretivism, inspired by von Uexkull, according to which each creature and each system has a limited construct of an environment, and a limited world in which to act, presents a second layer of obstacles to easy steering of social ecological systems towards resilience (Von Bertalanffy, 1955).

A third potential obstacle for this is the afore-mentioned evolutionary process of mechanization. Differentiation and black-boxing are necessary to manage internal and external complexity yet bring in new limits. In social ecological systems there are bound to be a multitude of autopoietic forms, and a great many forms of mechanization. If the social ecological system is a system of systems, it nevertheless remains a system itself, meaning that we can attribute a degree of mechanization to the system as a whole, and state that balancing self-organization and mechanization in that overarching system, is a sine qua non for building adaptive capacity. This is the case because both are needed for observation, for adaptation, for coordination of response, yet both are internally fragmented, potentially harmful, and entirely context- dependent, that is, the positive or negative effects emerge only in a particular social-ecological system with a unique history (Gray and Rizzo, 1973; Luhmann, 1989; Von Bertalanffy, 1952). Adaptive capacity starts to look here as the capacity to manage the couplings between systems, and to manage the degree of mechanization within systems.

LvB does not differentiate between social and other systems in terms of self-organization and steering. This, we believe, is an issue which renders it difficult to apply his insights directly to the issue of adaptive governance for resilience. In the following section, we bring in a set of bridging concepts which can remediate this issue and others. In other words: which conceptual extensions to the GST framework can make that framework even more useful in the analysis of the limits and possibilities of adaptive governance of social- ecological systems? The nature of the social seems under-analyzed in both GST and the resilience paradigm.

5. Useful extensions for resilience analysis: Building on Bertalanffy

Extensions are a tricky thing. There are in principle no limits to extensions, in the case of buildings and theories alike. For both of those, the limits have to come from the design and the requirements of structural integrity. In our case, the main question is: if not an application of GST to the analysis of the resilience paradigm is the goal, what is? Our answer would be: this is the case, yet more than a literal application of GST principles, we aim at bringing out the potential of GST, and claim that a few additions can maintain the integrity of the theory while bringing it closer to our analytical goals.

5.1 Luhmann/ Varela & Maturana

Varela and Maturana coined the term *autopoiesis* for processes of metabolic self-organization already described by GST. They were familiar with GST and found new evidence for autopoiesis and its key features (such as the combination of openness and operational closure) in cell biology (Maturana and Varela, 1991). Meanwhile they did further develop the concept of evolution which LvB hinted at, a non- Darwinian history of many non-adaptations. GST theorists in the 70s and 80s were aware of this refining of the theory (Gray and Rizzo, 1973; Midgley, 2003).

In the 80's, Niklas Luhmann was the person who most clearly recognized that autopoietic self-organization and system formation for social systems had to be different from biological and other systems (Luhmann, 2006, 1990, 1989). Drawing on various versions of constructivism (including post- structuralism), he designated *communications,* not people nor actions, as the elements of social systems. And largely drawing on Talcott Parsons, he understood increasing complexity in social systems as a matter of *differentiation,* in the first place the differentiation between function systems in society (law, politics, economy, etc). This structural difference between social and ecological systems brings in a fundamental asymmetry between the two: knowing and steering the other is mostly a one-way street, from social to ecological.

The increasing complexity-as- differentiation of society means that ever more systems deal with ever more systems in their external and internal environments, while these are never transparent to each other (Luhmann, 1995). Differentiation is thus proliferation of blind spots, and of boundaries hampering coordination. Politics and administration are not understood as the center of society and cannot be expected to have a full overview of society and a sufficient power to change society according to its wishes. Purposive finality, therefore, can never be reduced to 'implementation' of policies, and neither can it be the sole prerogative of politics (Luhmann, 1990). Luhmann himself showed considerable pessimism regarding the capacity of modern society to rise to the challenges of environmental deterioration (Luhmann, 1989).

With additional insight in the nature of the social, hence the social-ecological, and into possibilities of purposive adaptation, came thus a considerable skepticism regarding the possibilities of steering. We do not entirely share this skepticism, and, even when thinking *with* Luhmann, emphasize that new sources and forms of adaptation become visible in his theoretical perspective (Beunen et al., 2014; Van Assche et al., 2013). While self-organization in a political sense (distinct from the general concept of autopoiesis) cannot carry the weight of complex problem solving in differentiated societies, and while the now old alternative of central steering and comprehensive planning also does not work, Luhmann shows a myriad of adaptation mechanisms, linked to different forms and sites of observation (Luhmann, 2012; Van Assche et al., 2017b).

Although different systems necessarily remain partially blind for each other's logic, there are, nevertheless, possibilities to create a 'unity in diversity' (to use a LvB term); through shared semantics (likely similar to Snow and Benford's understanding of framing devices), bridging organizations, the differentiation of specific roles functioning as brokers or connectors, the renewal of communication between far removed social systems are all examples of coordination and problem-solving which are compatible with autopoetic, self-steering systems (Brans and Rossbach, 1997; Van Assche and Verschraegen, 2008). More fundamentally, Luhmann's distinction between social and psychic systems (people), and between organizations, function systems and interactions (conversations). Which means that each coordinated response to an environmental problem, even if struggling to find the form of comprehensive and implementable policy, can draw on this multiplicity of systems for contributions and corrections. People are members of organizations, participate in conversations, in various function systems, but are irreducible to them, while that same irreducibility applies to all other systems. Differences cannot be excluded, differences multiply and shifting between perspectives and gradually building composite perspectives towards new adaptation remains possible (Luhmann, 2006).

Most fundamental, we argue, is the possibility of *second order observation* (Luhmann, 1995; Von Bertalanffy, 1955). This is the observation of observation, seeing how other systems make distinctions and develop an autopoietic logic from there. This is only possible within social systems (one aspect of the one-way street mentioned). Contemporary functional systems highly depend on second-order observations, such as comparison of prices, public opinion conditioning politics, scientific publications, mediated communication, which all provide opportunities for second-order observations and allow for flexible adaption to an ever changing environment (Luhmann, 2012). To the extent that functional systems have adapted operationally to second-order observation, there is no possibility anymore of a binding presentation of society, nor of the natural environment. The system of the mass media, for instance, can only report on climate change by reporting on specific scientific findings, presenting them in such a way that they becomes comprehensible for non-scientists, yet flawed and overly simplified for scientists. Politics, in turn, can try to capitalize on the public concern that emerges, with businesses, however, possibly trying to lobby to limit the costs. Albeit modern society, based on second-order observing, loses a direct access to reality, it wins the possibility of flexibly adapting to ever changing descriptions of reality.

5.2 Complex adaptive systems/ complexity thinking

Complex adaptive systems (CAS) thinking largely developed at the Santa Fe institute in the 1980's and 1990's (Gell-Mann, 1994; Jost, 2004; Rammel et al., 2007), drawing on a variety of intellectual traditions. Most of the founders were natural scientists, yet much less influenced by, and familiar with, the systems theory which had started in biology and ramified from there, i.e. GST. Its concepts of system, evolution, and complexity, therefore were, despite shared terminology, genuinely different. We cannot get deep into the discussion of the genealogy of CAS here, and its entanglement with the (competing) genealogies of systems theory and complexity thinking, but believe it is fair to say that CAS protagonists routinely understated its indebtedness to older systems theories and ideas (such as GST, and its early embrace of thermodynamics), while correctly stating their great influence on the broader field of complexity studies, which is, logically, even broader in its field of antecedents and sources (Midgley, 2003).

CAS was from the beginning deeply engaged with computing, and with mining the supposed parallelism between systems in the virtual world and in the real world (Holland, 2006, 1992). In other words, computer modeling of 'systems' and their evolution could be the way of analyzing and predicting system behaviour in the real world as the main rules of interaction between elements of a system could be sufficiently simulated in the virtual. This description already adumbrates the system idea of CAS: elements with properties interact according to a described set of rules; this can lead to self-organization, which is complexity, and possibly to a new emergent order, yet displaying non- linearities within the course of this evolution. Evolution is the emergence of complexity out of the interplay of elements, and adaptation is adaptation of elements (or actors in social systems) to other elements and of systems to environments. These features add up to (and were rooted in) a deep interest in artificial intelligence (Gell-Mann, 1994; Hahn et al., 2008; Jost, 2004; Obolensky, 2017)

CAS therefore misses the metabolic understanding of systems we find in GST and social systems theory (SST), and it lacks the conceptual openness of GST and SST, in recognizing a variety of systems types, steering types, and contingent co-evolutions. It never produced (as GST), its own successors which could take more fully account of the social world, and, from there, of governance. Yet, we can also observe that the self-organization idea in resilience studies most often derives from CAS. In the resilience school, it is often translated as self-organization in local governance (Kaufmann, 2013; Lebel et al., 2006; Olsson et al., 2015; Poteete et al., 2009). Holling himself (e.g. 1978) was familiar with early CAS ideas, and the general systems theory (mostly implicitly) invoked in resilience thinking seems closer to CAS than to GST.

These observations necessitate us to make the case again for GST as useful for resilience theories, and at the same time to take CAS seriously. We believe that CAS does offer insights which can 'build on Bertalanffy' and which have been attractive for resilience thinkers for good reasons. We distill two notions emphasized by CAS and in our view under- analyzed by GST, useful as bridging concepts towards resilience thinking: *learning and testing*. Learning is the broader concept, testing can be a form of learning.

In our succinct version of CAS in the previous paragraphs, we failed to mention that system evolution for CAS is a matter of testing alternatives (Holland, 1992). This can have two meanings: systems try different options, some fail, those systems collapse, while surviving ones trigger further evolution based on the successful option. This is old Darwinian evolution. The second meaning is that of internalized testing, before undertaking action. Different possible courses of action are cognitively considered, possibly discussed, after which a choice is made(Gell-Mann, 1994). Such internalization of testing requires reflexive distance and freedom of choice; it requires a high degree of system complexity. And it can be a starting point for purposive finalities and adaptive strategy (Gell-Mann, 1994; Jackson et al., 2010; Levin et al., 2013). Such testing idea can already be noticed with Holling (Holling, 1978). Policy alternatives can survive or fail, which can trigger learning elsewhere, and several alternatives can be entertained within one policy system.

For CAS (Obolensky, 2017; Von Bertalanffy, 1955), *learning* became a central concept, and this was productively picked up by the resilience thinkers (Allen, 2001; Armitage et al., 2008; Cundill and Fabricius, 2009; Walters and Holling, 1990). We believe CAS adds to GST here, while GST and its descendants can help to make the point that learning has to be understood differently in social, ecological and biological systems, as it has to be understood differently at the time scale of an individual life, and that of evolution spanning many generations (Allen, 2001; Hofkirchner, 2005; Holling, 2001). In the pursuit of adaptive governance, cultivating an awareness of the double sense of testing, and of the variety of learning (hence adaptation) sites and forms can be a considerable asset.

As mentioned before, CAS came to similar conclusions as GST regarding non- linear behaviour of complex systems and regarding equifinality, or, in CAS-speak: attractors (Gray and Rizzo, 1973; Hofkirchner, 2005; Holling, 2001; Schmidt, 2015; Urry, 2005; Von Bertalanffy, 1952) These CAS concepts gained popularity in broader complexity thinking, which in turn spurred fruitful development in innovation studies, studies of policy and planning and resilience studies. Such bridges between GST and CAS thus open up new conceptual roads and simplify bridging the gap between GST and resilience perspectives.

6. Resilience and adaptive governance: reinforcing the foundations? (Concluding)

Ludwig von Bertalanffy and his General System Theory still have much to offer for the understanding of resilience. In what we called the resilience paradigm, working towards resilient social-ecological systems is understood as working towards their adaptive governance, which is then linked to self- organization as entailing the sharpest forms of local observation. Which light can we shed on the paradigm after revisiting Ludwig von Bertalanffy's GST and expanding it via SST and CAS? Let us treat the elements of the paradigm separately in concluding.

6.1 Social-ecological systems
From LvB, we can derive the idea of a double boundary between social and ecological, an internal and external limit. Systems exist within systems and besides systems, in patterns of co-evolution, and in the case of social-ecological system, this is a coexistence of systems sharing the general features of systems, yet there is enough difference between social and ecological to speak of a one-way street. Social systems are needed to construct images of the ecological, and to intervene in strategic manners. Nevertheless, social and ecological are entangled enough, due to internal and external co-evolution, to make it impossible for social or ecological to have a clear and full picture of each other or of the whole.

LvB emphasizes more than other systems theorists the embedding in the material world of all other systems, thus of the interrelatedness of individual, community, ecology (See Figs 2 and 3). He emphasizes the biological roots of humanity and the human roots of social systems, with admittedly a concept of hierarchy and inclusion of one in the other, but at the same time the operational closure and co-evolution of levels. The substrate of all systems is biological, without them being reduced to it

[HERE FIGURES 2 and 3]

6.2 Self-organization
Autopoiesis is not a word we find with Bertalanffy, but his idea of system formation and functioning is autopoietic. For GST, each open system is complex and autopoietic, and therefore, all open systems are self-organizing. Luhmann, not contradicting but developing what was left unexplored by von Bertalanffy, made the crucial distinction between self-organization in biological systems and in social (and psychic) systems. If communications are the elements and meaning is the medium for social systems, then increasing complexity is differentiation of meaning systems, from which other forms of complexity (such as organizational) can be derived. Thus, all open systems are the product of self-organization, both at an initial stage, and continuously. Autopoiesis never stops. Yet, in organizational terms, and, in terms of the function system of politics, affecting how collectively binding decisions are taken, they do not rely solely on self-organization.

What can be recognized as self-organization in governance (as broader politics) is a contextual distinction, a localized semantics, depending on what counts as 'organized', as 'formal' or as 'institutionalized'. Furthermore, which forms of new interactions, of formation of new organizations and institutions -processes often labelled as 'self-organization', are possible and likely to emerge, hinges on the contingent path of co-evolution of a governance system (e.g. on the question what was mechanized earlier), and, more broadly, a social-ecological system. If we invoke again the idea of double boundary and entanglement, we can introduce the idea of material dependencies, with social systems evolving in a particular direction partly because of (unseen) entanglements with natural systems internally and externally.

6.3 Local observation

Social ecological systems, and within them, governance systems, layer a series of opacities, limits to observation. Systems co-evolve and understanding each other would require the deeper understanding of metabolic processes maintaining the system. Within governance, non-linearities render prediction of system behaviour tough, as well as observation of current states, and the unexpected workings of equifinalities (attractors) and of purposive finalities (strategies) add observational obstacles. A history of blackboxing (linked to institutionalizing and mechanizing) can render governance smooth and powerful but comes with its own baggage, including a further reduction of transparency.

The social-ecological cannot be known in its entirety from within the social. Hence there is a need to oscillate between several imperfect perspectives in governance. This is an issue of inclusive governance, allowing a variety of voices, of expert and local knowledges to influence decision-making. And it is a matter (distinct from the previous one) of encouraging the use of and reflection on truly different metaphors, narratives, discourses on the social, the ecological and the social- ecological. Such can engender one form of learning in CAS terms, the development and assessment in governance of truly different policy alternatives. Simultaneously, the other form of learning we distinguished can be promoted, the discussion of experiences elsewhere, as evolutionary experiments.

6.4 Adaptive governance

Adaptation for LvB is always there, yet purposive adaptation is not always possible. Limits to observation and limits to steering reinforce each other. Policy intervention hinges on the insight in the evolution and metabolic logic of the steering system (the governance system) and the system steered (here possibly the whole social- ecological system). Adaptive governance of social-ecological systems requires insight in their particular co-evolution, and in the nature of the finalities at work, or allowed by these coupled systems logics. As strategy, adaptive governance has to calculate the limits of observation, prediction and steering mentioned in previous paragraphs, knowing that such calculation cannot be perfect. Learning in the double sense mentioned above can thus continuously sharpen and switch angles of observation available to governance.

Luhmann made an autopoietic understanding of social systems possible and revealed new limits to steering in a world of co-evolving autopoietic systems, a world adumbrated by von Bertalanffy. The remaining possibilities of steering, through semantics, through organizations, through incorporating second order observations, are tools for adaptive governance. If our aim is adaptive governance of social-ecological systems, the most powerful remaining tool, or generic strategy, is that of *managing the couplings between* *systems*. This can be between social systems, between ecological systems and between social and ecological systems. Managing couplings makes systems more, less or differently responsive to each other, and modifies their effects on each other.

In order to do so, governance might be able to maintain its configuration, and devise new policies from there. This can produce strategic adaptations of governance to changing environments, and possibly adaptations of environments necessary to mitigate risk or avert threat (Figure 4). Some couplings are altered, others not. In other cases, involving other environmental issues and other systems couplings, governance might have to transform itself more radically to achieve those aims. New governance configurations might be necessary, both enabling and embodying different couplings between social systems or between social and ecological systems. Adaptive governance can be a matter of switching between self-organization as mode of governance and more differentiated modes of steering, either centralized or specialized, both captured by LvB under the term 'mechanized'.

[HERE FIGURE 4]

6.5 Resilience

For the understanding of resilience, we draw out one final distinction, between *cognitive and institutional resilience*. (See Figs 5 and 6) Under institutional resilience we understand the capacity of the institutional structures to absorb shocks, by staying the same or adapting itself from within existing patterns of organization. In our view, resilient systems do not stay the same, and in the case of governance systems, they cannot stay the same, as contingent co-evolution does not allow for a return to the past. Under cognitive resilience, we understand the capacity of the governance system to produce ever new understandings of its external and internal environment, including of the social-ecological system as a whole. Both are necessary. Resilient governance systems make resilient communities (Beunen et al., 2017; Deacon et al., 2018; Van Assche et al., 2018).

[HERE FIGURES 5 and 6]

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