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Original research article

Wickedness and the anatomy of complexity

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ABSTRACT

Traditional scientific policy approaches and tools are increasingly seen as inadequate, or even counter-productive, for many purposes. In response to these shortcomings, a new wave of approaches has emerged based on the idea that societal systems are irreducibly complex. The new categories that are thereby introduced – like "complex" or "wicked" – suffer, however, by a lack of shared understanding. We here aim to reduce this confusion by developing a *meta*-ontological map of types of systems that have the potential to "overwhelm us": characteristic types of problems, attributions of function, manners of design and governance, and generating and maintaining processes and phenomena. This permits us, in a new way, to outline an inner anatomy of the motley collection of system types that we tend to call "complex". Wicked problems here emerge as the product of an ontologically distinct and describable type of system that blends dynamical and organizational complexity. The framework is intended to provide systematic *meta*-theoretical support for approaching complexity and wickedness in policy and design. We also points to a potential causal connection between innovation and wickedness as a basis for further theoretical improvement.

1. Introduction

Out of discontent with the performance and adequacy of traditional approaches, which may be described as embodying a top-down rather than a bottom-up approach to understanding and acting, and that are largely based on prediction, planning and control (e.g. Castree et al., 2014; Haasnoot et al., 2013; Leach, Scoones, & Stirling, 2010; Loorbach, 2010), an alternative view of socio-eco-technological systems is taking shape. This view emphasizes qualities related to ideas about complexity, such as multidimensionality, path-dependency and unpredictability (e.g. Bai et al., 2015; Beddoe et al., 2009; Berkhout, 2002; Byrne and Callaghan, 2013; Folke, Carpenter, Walker, Scheffer, & Chapin, 2010; Gunderson & Holling, 2002; Rip & Kemp, 1998). These qualities are seen as irreducible root causes of problems – not least ones related to sustainability – *and* of our persistent inability to predict, prevent and deal with them. They are also seen as key to the development of a new generation of approaches to understanding and tackling these problems.

These approaches are based on partially overlapping sets of ideas, which is promising for a future integration and synthesis, and deep new insights into the workings of societal systems. Such a development is, however, hindered by a lack of shared understanding of foundational concepts, arguably most importantly complexity and wickedness. Depending on whether a person has a background in social or natural science, whether he or she is trained in quantitative or qualitative methods, a person's idea about what complexity and allied concepts mean is often strong, intuitive and treacherously different from other people's ideas. This may be less of a hindrance for productive work *within* the fields where these ideas emanate, but it becomes a real problem in inter- and

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transdisciplinary settings. General foundational knowledge about the *meta*-theoretical nature of these concepts, and the systems that they concern, would aid the formation of the shared understandings that are necessary for productive and cumulative work on a larger scale.

Toward this goal, we here sketch a map of ontological categories as an open-ended and flexible *meta*-analytical tool. Our focus lies on furthering our understanding of "wickedness" which denotes a certain flavor of complexity in societal problems seminally described by Rittel and Webber (1973). An attribution of wickedness to a problem illustrates a feeling that the problem almost seems to avoid resolution and/or that attempting to solve it keeps generating hosts of other and seemingly unrelated problems. Within this "Spectrum of Overwhelming Systems" (SOS), we find, however, not only wicked systems. We also find complex and complicated systems (Érdi, 2008), as well as additional now-discernable sub-classes. All of these are critical to understanding and delimiting wickedness as a distinct type of complexity (Andersson, Törnberg, & Törnberg, 2014a), but they are also important in themselves. In describing these sub-categories, we will discuss how they are related, what may cause systems in these categories to arise, what their characteristic properties, problems and potential functions are, how they may arise, what theories and methodologies that are suitable for dealing with them, and so on.

We propose that the SOS-diagram is useful for enabling a more focused and specific debate by structuring, visualizing, for revealing points of fundamental contention, and by raising concrete questions about how different types of systems and problems interact. We have found this useful in particular in *trans*-disciplinary settings when partners with different backgrounds and experiences must collaborate and align their thinking and actions. Our results are thereby intended to contribute on two different levels: (**i**) Methodologically by enabling detailed debate and alignment between people and ideas, in general and specific settings, and (**ii**) theoretically by providing some initial and provisory insights gained by our own application of the framework. Most importantly, we argue that innovation – in a broad sense, and understood as a distributed process of competitive diversification and adaptation – may describe the generation of the qualities associated with of wickedness.

2. Worse than complex

We continue in the direction taken by Andersson et al. (2014a) and develop wickedness by mining its super-category of "complexity" (as ubiquitous as it is elusive) for internal structure and tensions that can be used to organize the picture.

No single definition of complexity has attracted a majority of followers (e.g. Érdi, 2008) and this anarchy is reflected also in how the concept is used in the literature. "Complexity" usually does not point at any particular idea about complexity, nor at any particular generating process, but works mostly as a catch-all term for problems that *overwhelm* us in some sense; things like massive parallelism, multi-level hierarchization, heterogeneity, tangled "seamless webs", emergence, non-linearity and sensitivity to disturbances, or combinations thereof.

Complexity thereby lumps together a motley collection of causal processes and types of organization. But can we find a representation that usefully separates and clusters this space? Is there an inner anatomy to the set of all things that are complex? To make a first cut we employ a distinction that is often used to explain the scope of *complexity science*[1] (Andersson et al. 2014a:146–148): that *complexity is not complicatedness.*[2]

More specifically, we observe that if we take the popular understanding of "complexity" (i.e. "overwhelmingness"), and factor out the *complicated*, the residue corresponds quite closely to the type of systems that complexity science is best adapted to deal with. We henceforth refer to this residue as complexity, referring to the broader "folk-category" of complexity by the more descriptive term "overwhelmingness"

This seems to provide a separation of the sought kind: complexity is something like a shoal of fish[3] while complicatedness is more like a computer. Indeed, these categories correspond to whole distinct paradigms in systems thinking (Andersson et al. 2014a: 149).

In Fig. 1 we illustrate this move by splitting "complex/overwhelming" into complex and complicated (Fig. 1), expanding thereby an axis between *simple* and *complex/overwhelming* into a plane (the SOS diagram). The most immediate effect is that systems that "work" similarly now cluster similarly, forming the basis of a potential causal taxonomy.

Wicked systems and problems now become separated into a specific part of the SOS diagram, namely the upper right-hand part where both qualities are mixed. Societal systems are something like Necker cubes in this respect: they can be described both as somewhat like a shoal of fish, *and* somewhat like the organization of a computer,[4] depending on how we are primed to look at them.

Since we may not only place systems, but also problems, methods, models and so on into this diagram – also together if we like – we also see this as a possible generalization of wickedness as a general quality of systems, just as we are accustomed to apply complexity and complicatedness.

So what processes and circumstances generate these combinations between complexity and complicatedness? Is wickedness an emergent and irreducible category, possible to study and develop methods for dealing with in its own right?

[1] Or more precisely of what Andersson et al. (2014a) term "mainstream complexity science".

[2] A Google search on "complex vs complicated" will provide an ample selection of examples.

[3] "Complexity" thereby corresponds closely to what Morin (2007) refers to as "restricted complexity", and to what calls "dynamical complexity"; see also Andersson et al. (2014a).

[4] The former has been argued by complexity scientists (e.g. Ball, 2012; Sawyer, 2005; Castellani & Hafferty, 2009) and the latter view of society is ubiquitous, embodied in countless "traditional" methods and theories.

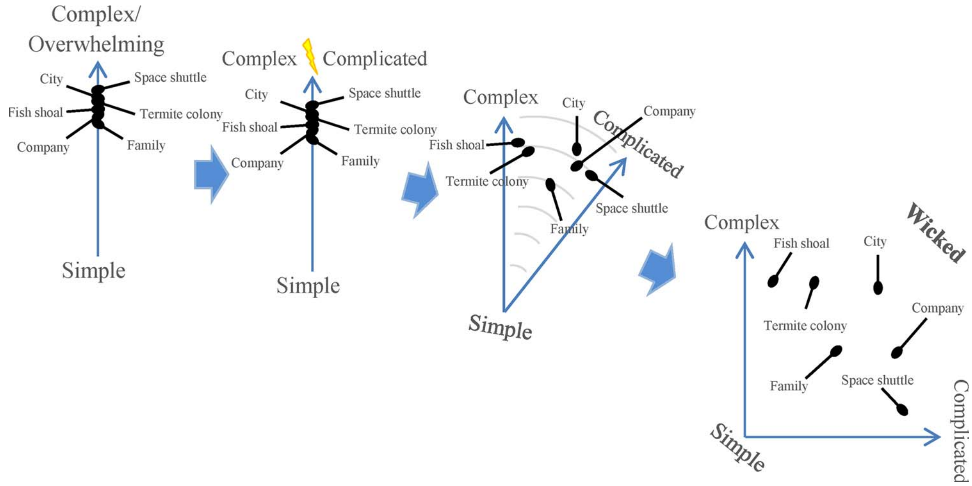


Fig. 1. We obtain the 'Spectrum of Overwhelming Systems' (SOS diagram) by splitting "complex/overwhelming" into (i) a stricter remainder that retains the label "complexity", and (ii), complicatedness, which is a different quality altogether. Although placing examples remains hard and potentially contentious, the strong feeling of comparing apples and oranges dissipates, and the task becomes much more straightforward and potentially interesting.

3. Wickedness in context

To consider wickedness in the context of systems that it may resemble, be mistaken for, or that it partakes in, generates and interacts with, we now postulate some more highly resolved categories; see Fig. 2.

In the following Sections (3.1–3.3) we take a closer look at each of these sub-categories. Each non-wicked sub-category will be described: (i) *generally* in Tables, and (ii), *specifically* with respect to features of particular importance for understanding wickedness. The two wicked sub-categories will be described more in detail. We will then use this image of the structure of the space of a "spectrum of overwhelming systems" to analyze how we might go about better understanding and intervening in wicked systems.

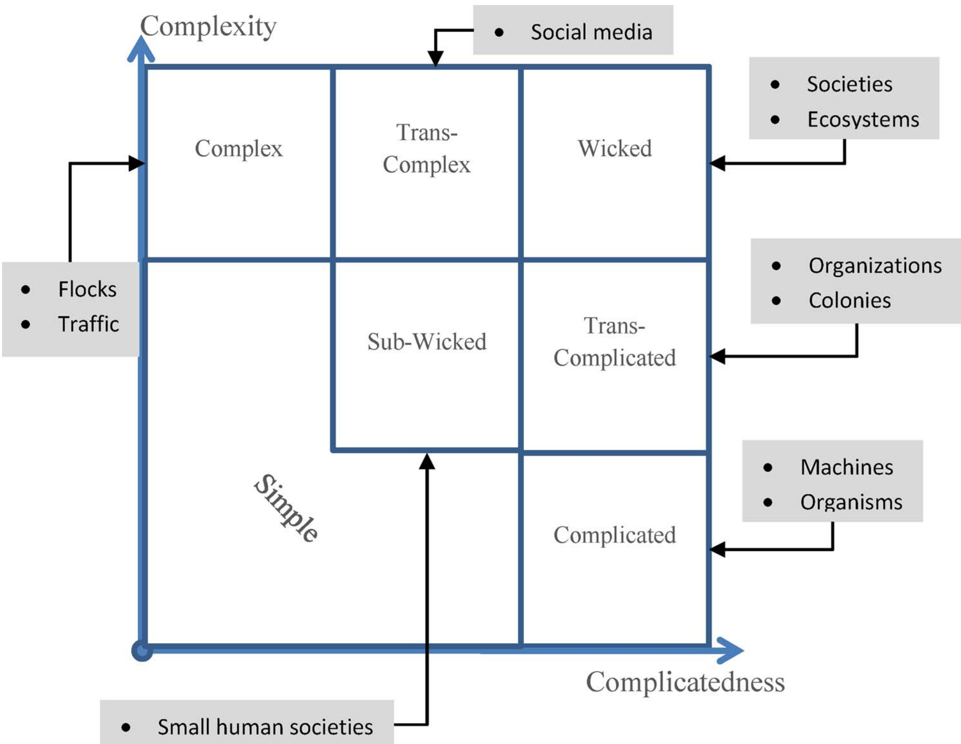
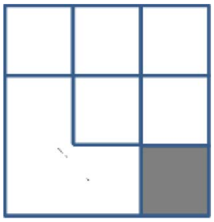


Fig. 2. The resolved SOS Diagram is intended to facilitate differentiation between problems, systems and approaches on the basis of how degrees-of-freedom are organized in different types of systems. The basic relevance is that this organization determines what tools we need for designing, governing and understanding systems. In brief, the idea is to move beyond a tacit and very vaguely differentiated concept of "complexity".

Table 1
Complicatedness.



Complicated

Central examples: Technology, organisms
Main signifying features:

1. Scale-separated level hierarchies.
2. Potentially very tall hierarchies, spanning from small to large scales.
3. Components have relatively few sub-components.
4. About as many component types as component instances.
5. Sub-components are co-adapted to specific complementary functions in a whole with emergent affordances and functions.
6. Low redundancy: components cannot generally take over the roles of other components.
7. Sub-components are "slaved": they often make no sense separately.
8. Near-Decomposability essentially resets the number of degrees of freedom between sub-component and component.
9. Phased lifecycle:
   - Assembly: System assembled/developed with high precision in protected space, free from functional demands.
   - Use: Systems expresses intended set of functions, may undergo diagnostics and repairs to maintain function.
   - Transition between phases may be gradual, as in organisms.

Simplicity hook: The full system may pack very large numbers of components into delineable compartments organized in a level hierarchy. This strongly structures the patterns of permitted interactions and enables strong simplifying assumptions; see Appendix A. We hardly need any knowledge about the embedding system to operate locally on its components.
Desirable adaptive affordances: Allows systematic exploration of design spaces: innovation and assembly may act in a strongly distributed and layered fashion; detailed designs (strong specialization), controllability, repeatability, scalability, precise and economic assembly, division-of-labor.
Main challenges:

1. Controlling and predicting the External Environment.
2. Alignment of goals and aims of components ("slaving").
3. Fine-tuned, non-redundant organization causes sensitivity to breakdowns and is an obstacle to dynamic use-phase adaptation.

Main approaches: Engineering, early "waves" of systems theory (cybernetics, operations research, control theory etc.; Sawyer, 2005), overall the "standard way" we think about design and governance.
Generation/maintenance: Complicated systems are assembled or, in biology, developed in morphogenesis (Slack, 2005).

3.1. The basic qualities: complexity and complicatedness

Complexity and complicatedness represent the two principal ways in which large numbers of degrees of freedom can become stably organized into large systems. Systems close to either ideal class are dominated by either one of these two organizational principles, enabling strong simplifying assumptions, and thereby powerful formal theory.

We will make reference to concepts from Herbert Simon (1962) model of Near-Decomposability. Readers unfamiliar with Near-Decomposability are referred to Appendix A, and (Andersson et al., 2014a, 2014b).

3.1.1. Complicated systems

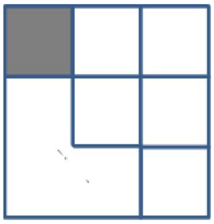
An easily overlooked pre-condition for the construction of stable adapted systems is that their components must be "slaved." Perfectly symbiotic components lack any incentive to undermine the function of the systems that they form parts of. This makes them malleable and enables the design, assembly and governance of delicately fine-tuned systems. Open-endedness in possible designs is the main adaptive affordance of complicatedness, and the basis for adaptation in biology as well as human culture (Table 1).

Slaving applies so automatically to technical systems (try to imagine the exhaust manifold competing with the engine) that in order to illustrate its general role and significance we will consider three recursively linked biological examples where we may trace the genesis of new complicated design spaces from the establishment of alignment and slaving among initially autonomous components. In all three cases, whole new universes of adaptive complicate designs resulted.

All three examples describe a full such transition: first from *wickedness* (competitive interactions) to *trans-complicatedness* via increasing cooperation, then on to *complicatedness* via co-adaptation of components.

1. The "endosymbiont hypothesis" (Margulis, 1970; Archibald, 2011) explains the complicated organization of eukaryotic cells as the result of increasing symbiosis between autonomous bacterial precursors. As symbiosis deepened, these bacteria mutually adapted to form the eukaryotic system of organelles within a single physical enclosure. Entirely co-dependent – also for reproduction – they collectively constituted a much more versatile component on a new level of organization.
2. This versatility importantly included the potential for forming a yet higher level of organization: somatic cells of multicellular organisms are co-adapted differentiated forms of unicellular precursors. Incapable of separate existences, they can procreate only via germline cells (e.g. eggs and sperm), and so there is no possibility for internal competition (Hanschen, Shelton Deborah, & Michod, 2015; Johnson, Richardson, Bachvarova, & Crother, 2011; Michod, Viossat, Solari, Hurand, & Nedelcu, 2006).
3. Finally, social insects (e.g. bees and ants) take this symbiotic principle yet one more step: their organism-level components are slaved under a colony-level Interface in an equivalent manner (e.g. Oster & Wilson, 1978; Moritz & Southwick, 2012).

Table 2
Complexity.

 Complex	**Central examples**: Herds, traffic, social networks **Main signifying features**: 1. Many (even immensely so) components on same organizational level. 2. Many components but few component classes. 3. High redundancy: components may step in for other components of the same class (compare removing an ant with removing the liver). 4. Loose exogenous constraints on formation and dissolution of interactions between components. Exogenous structuring constraints apply to interactions between types of components; e.g. how do cars and trucks behave in traffic. 5. Strong endogenous structuring of component interactions (emergent patterns) may arise from the dynamics (shoals, traffic jams, paths, etc.). **Simplicity hook**: If we deal successfully with emergence among very large numbers of interacting entities (which e.g. simulation helps us do) then, from the view of component classes, complex systems are much simpler than they may appear. Emergent patterns can be explained in those terms. **Desirable adaptive affordances**: 1. Resilience (dampening of disturbances, redundancy) 2. Adaptation 3. Distributed action, monitoring and processing provides affordances unavailable to complicated systems. 4. Self-assembly/organization as path to building adapted systems. **Main challenges**: 1. Chaos in massively parallel dynamics: (i) unpredictability; (ii) amplification of disturbances. 2. Emergence (e.g. macroscopic patterns) in strongly parallel and distributed dynamical systems. 3. Harnessing complex systems for adapted purposes invokes the same demand for "slaving" components as for complicatedness. **Main approaches**: Computation and dynamical systems theory (e.g. chaos theory, synergetics). Simulation crucially allows mass dynamics to play out explicitly "in silico". **Generation/maintenance**: Generally, emergent complex patterns arise "suddenly" as interacting components come together, and dissolve if components seize to interact.

But there is also a tradeoff between delicate fine-tuning (optimality) and robustness. Complicated Systems must have dedicated sub-systems or external scaffolds to constantly guard and repair them in the face of internal and external disturbances; e.g. diagnostics, repairs, materials with high durability, and so on (e.g. Michod & Nedelcu, 2003).

3.1.2. Complex systems

Complexity has two strong sources of relevance for wickedness: **(i)** As a source of *adaptive affordances* that correspond to classical Achilles' heels of complicated systems. **(ii)** As sources of *uncertainty* and *emergent problems* as large numbers of adapted systems interact (e.g. vehicles, or people walking, trading etc.) (Table 2).

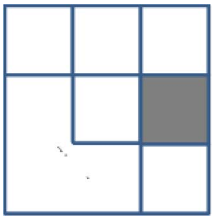
Natural selection is a prominent example of complexity-based adaptation: sets of competing components ("populations;" e.g. Andersson, 2011; Aldrich et al., 2008; Hodgson & Knudsen, 2004; Mayr, 1993) that are mainly similar but that, crucially, exhibit minor variations that affect competitive success and carry over to derivative versions. "Distributed computation" is another example, seen e.g. among social insects, in biologically inspired optimization methods (Wahde, 2008), "crowd wisdom" (e.g. Surowiecki, 2004) and peer problem solving (e.g. in web forums; Liu & Tsai, 2008).

3.1.2.1. Self-assembly/self-organization. Affords a powerful and economic method for assembly of microscopic components and the potential to realize designs that are not feasible with traditional assembly (e.g. Sacanna, Pine, & Yi, 2013). Described as "…the autonomous organization of components or structures without human intervention" (Whitesides & Grzybowski, 2002: 2418), a particularly interesting potential is that of designing microlevel components such that they dynamically assemble "themselves" to realize some intended functional macrolevel Interface.

3.1.2.2. Problems caused by complexity emanate chiefly from chaos and emergence.

1. *Chaos* is the flip-side of the resilience coin: non-linearity may dampen disturbances but may also *amplify* them (e.g. Cvitanovic, Artuso, Mainieri, Tanner, & Vattay, 2005:149). Responses of Complex Systems to interventions are therefore often unpredictable, both quantitatively and qualitatively, which has:been conceptualized in sustainability contexts as e.g. "attractors", "tipping points", "bifurcations", "basins of attraction" etc. (e.g. Holling, 2001; Helbing, 2013; Lenton et al., 2008).
2. *Emergence* is macroscopic qualitative novelty arising from interacting components (e.g. Bedau, 1997; Corning, 2002; Holland, 1998); summarized in the adage "more is different" by Anderson (1972). Although not unique to complex systems, emergence in complex systems is particularly "surprising" due to our inability to intuitively follow complex dynamics. Although by no means inherently maladaptive, they are hard to foresee, and they therefore often appear as negative externalities, such as congestion in communication networks (e.g. Yan, Zhou, Hu, Fu, & Wang, 2006).

Table 3
Trans-complicatedness.

	*Trans*-complicated	Central examples: Organizations with human components, or biological individuals (e.g. of different species) with separate channels of procreation Adaptive rationale: Tapping into adaptive affordances of complicatedness for systems whose components have "an agenda of their own." Main approaches: Organizational and political theories and practice. In general, the art of organizing humans. Main challenges/limitations: 1. Alignment must be actively maintained (monitored, policed, enforced) by dedicated systems. This is costly and carries the risk of failure. 2. Insufficient alignment brings "component rebellion", breaking Near-Decomposability if components adapt to their own aims and goals at the expense of the whole (e.g. corruption; "defection" in game theory). 3. Controlling and predicting the External Environment is hard, expensive and faces decreasing returns to investment in terms of effectiveness. 4. Duplication/assembly much harder than for complicated systems since component innovativeness generates "tacit" processes and organization, which become crucially necessary for function (e.g. Polanyi, 1967).

3.2. The trans-qualities

Trans-qualities arise as adaptive responses to facticities, most importantly the construction of complicated systems using components that are hard to align (humans and organizations thereof), but also to reap adaptive advantages. Generally, we seek *complicatedness* to build adapted organization and impose control, and *complexity* to achieve resilience, adaptability and low management overhead.

3.2.1. Trans-complicated systems

Trans-complicatedness represents the complicated organization of components with separate agendas. Complexity enters as an increased density, and lower regularity, of interactions: while an exhaust manifold is precisely an exhaust manifold, a human component will connect a system to just about all sectors of society and in a wide variety of ways (a seamless web; Hughes, 1986) (Table 3).

Alignment (Section 3.1.1) here becomes a salient issue, and human organizations are highly preoccupied with the problem of internally aligning interests and actions. By contrast with the biological cases cited above (Section 3.1.1), however, the problem is never *solved*[5] here. Alignment is an ongoing and often highly costly effort of negotiation, persuasion, monitoring, punishment, reward etc.: a struggle to pull organizations away from wickedness, toward the complicated regime where design and governance is more straightforward.

Trans-complicated systems also face the threat of unexpected (even hostile) change from the outside. They are, however, inherently poor at adapting to external changes since they are prone to breakdown if their strongly patterned internal interactions are disturbed. One response is to try, as far as possible, to balance the needs for control and flexibility (e.g. "loose coupling"; Orton & Weick, 1990) and another is to exert control over the Outer Environment (an option whose availability varies with power; see also Niche Construction, Laland, Boogert, & Evans, 2014).

Trans-complicated systems are rarely assembled, but develop/evolve historically; a property they share with the wicked systems that they inhabit. The taller the hierarchies, the tougher the problems outlined here become. First, the taller and broader the hierarchy, the harder it becomes to align its components under directions entering from the top-down, making their internal dynamics more and more ecosystem-like and less and less like an organism. This poses a problem to political control and, more generally, to scaling up organizations. Second, while components *within* nations and global corporations may be under the control of integral systems of alignment (e.g. institutions, shared languages, cultures and narratives), nations and global corporations themselves do not interact under a similarly strong force of alignment.

3.2.2. Trans-complex systems

Trans-complex systems represent the harnessing of affordances of complex systems by adding elements of persistent complicated organization to complex systems (Table 4).

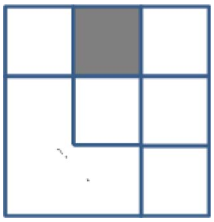
Two main strategies are: **(i)** designing micro-components to collectively behave in a certain way, as described under *complexity* (Section 3.1.2); **(ii)** "herding" – dynamically monitoring and perturbing micro-component behavior.

These strategies are, however, typically combined since herding can be improved if components are primed to respond more appropriately; e.g. the emergence of pastoralism (which, literally, involves herding) may have involved not only herding strategies, but also selection-induced morphological change of animal behavior (e.g. Marshall & Weissbrod, 2011) to improve responses to herding.

Religion, politics and marketing would provide examples of priming micro-components to be responsive to "herding". Two factors

[5] Many utopian visions imagine precisely a state of society where all forces of dis-alignment are eliminated and where alignment becomes automatic.

Table 4
Trans-complexity.



Trans-complex

Central examples: "Sharing economy" (e.g. AirBnB, Uber), smart grids, forums, social media movements (Arab Spring, Avaaz, etc.), guerillas, terrorist networks. Organizations based on disseminated designs, shared views, norms etc. (e.g. in religion and politics).
Adaptive rationale: Tapping into adaptive affordances specific to complex systems; e.g. organizing with scarce resources, organization in hostile/repressive environments; designing, or increasing the level of control, specificity and alignment of, an adaptive complex system.
Main approaches: Two (often combined) main approaches: (i) designing micro-component classes such that a desired feature emerges as many components interact; (ii) dynamically scaffolding the behavior of components ("herding the system").
Main challenges/limitations:

1. Hard to achieve detailed designs due to highly non-linear mapping between specification and resulting system.
2. See corresponding points 1–2 or Table 3.

have, however, limited our ability to accurately design *detailed* outcomes: (i) high cost and low bandwidth of the required mass communication; (ii) lack of theoretical understanding of non-linearity and emergence in complex systems.

Complexity Science, and Information and Communication Technologies (ICT), allowing large-scale dynamical monitoring, information sharing and processing of large amounts of data, has alleviated these limitations greatly. Coordinated collective action using ICT is today becoming increasingly commonplace, varied and sophisticated; e.g. the emerging "sharing economy" (e.g. Hamari, Sjöklint, & Ukkonen, 2015) and "smart grids" (e.g. Clastres, 2011).

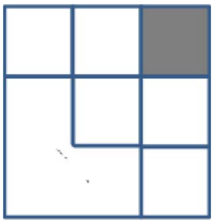
3.3. *Wickedness*

Wicked systems are arenas where adapting systems interact and compete over limited resources.

3.3.1. *Wicked systems*

Simply put, if self-organization generates complex systems, and assembly/development generates complicated systems, then *innovation* generates wicked systems: wicked systems are arenas of and for innovation. Note that innovation is here invoked, without its common positive valance, as a *causal process of change* without regard to whether the change is good or bad, or with respect to whom or what (Table 5).

Table 5
Wickedness.



Wicked

Central examples: Large human societies, ecosystems over evolutionary time.
Main signifying features:

1. Not adapted, but arenas of and for interaction between adapted systems.
2. Components have own agendas and exhibit the full range of ecological interaction modalities.
3. Components are heterogeneous, versatile multi-level interactors, interacting under few constraints.
4. Strongly distributed and pervasive innovation/adaptation.
5. Strongly interconnected "seamless webs": cascade effects and lock-ins (e.g. w.r.t. interventions and technological innovation.)

Simplicity hook: No general avenue for formal simplification.
Desirable adaptive affordances: As arenas for adaptation, they are, hotbeds of innovation: without wickedness, no creativity.
Main challenges:

1. Intermittent, unexpected behavior: (i) lock-ins from jamming between dependent entities; (ii) dramatic transitions as jams break up.
2. Uncertainty and unpredictability, not least "ontological uncertainty"; emergence of qualitative novelty; game changers.
3. Cascades and entrenchment of effects makes for a potentially unlimited horizon (both in time and scope) for consequences of actions.
4. Uncertainty that grows rapidly with time and scope imposes a short foresight horizon.
5. Short foresight horizon and long consequence horizon combine into a propensity for unsustainability in the form of self-undermining innovation pathways.
6. Innovation upsets any level hierarchical organization, ruining prospects for Near Decomposability, constantly rewriting the "rules of the game".
7. Control demands a global overview, but growth and change is local and demands no such overview, so wicked systems may outgrow any capacity for governing them.
8. No two subsystems or problems are likely to be identical: uniqueness hampers learning and generalization.

Main approaches: Approaches based on complicatedness and complexity; the former include "traditional" approaches. Narrative approaches with "thick" historical descriptions and analyses. Harnessed Innovation approaches emerge increasingly today.
Generation/maintenance: Open-ended innovation – "creative destruction" – in an "arena" where adapting systems interact ecologically. Wicked systems are deeply historical: identifiable initial conditions may be ancient and qualitatively very different.

Open-ended innovation generates powerful interactors, organized primarily as complicated or *trans*-complicated systems. These are capable of maintaining vast and heterogeneous arrays of interactions where every node is densely connected to just about all domains of the web (society as a "seamless web", Hughes 1986). Innovation both *integrates* the seamless web by weakly constrained interaction, and *separates* it, through specialization.

Interactions have a strong enveloping competitive component but display the whole spectrum of ecological interactions (competition, symbiosis, neutralism, parasitism, commensalism and amensalism; see Sandén & Hillman, 2011). Symbiotic interactions may give rise to self-organized systems toward the *trans*-complicated and *trans*-complex regimes; e.g. bundles of value chains as described by Sandén and Hillman (2011). Parts and levels may over time co-adapt to become increasingly co-dependent; compare with examples of symbiotic origins of complicated systems; Section (3.1.1). The boundary between wickedness and *trans*-qualities is thereby porous.

Components act and react within neighborhoods in the seamless web, and, since each is part of many neighborhoods, change is liable to propagate across the system. Dynamically and macroscopically, this leads to two dialectical dynamical regimes: transition and lock-in.

Transitions are self-propagating waves of qualitative "reconfigurations" of and by components, traveling across neighborhoods in the seamless web (Geels, 2002; Lane & Maxfield, 1997). These may form potentially system-wide cascades of change (Geels, 2011; Lane, Maxfield, Read, & van der Leeuw, 2009; Lane, 2011, 2016; Schiffer, 2005). However, if locally beneficial reconfigurations cannot be made, change will be resisted, and if such criteria, posed by large numbers of strongly interconnected components, are combined, the range of actually viable innovations will be strongly constrained and channeled. The result is a *lock-in*, such as by a dominant design (Utterback & Abernathy, 1975) or a sociotechnical regime (Geels, 2002; Rip & Kemp, 1998), or gene regulatory networks (e.g. Davidson & Erwin, 2006).

Historical case studies embodying compatible accounts include Geels (2005) on automobility, Rödl and Andersson (2015) electrification, Geels (2002) on steamships and Lane (2011) on book printing. But, for demonstrations of generality, see also Andersson, Törnberg, and Törnberg, 2014b on prehistorical cultural evolution, Erwin and Valentine (2013) on the emergence of modern life forms in the "Cambrian Explosion" (~543 Ma), and Laubichler and Renn (2015) on the emergence of equsociality.

Consequences of action in such a system is shrouded in deep uncertainty, described by Lane and Maxfield (2005) as an *ontological uncertainty*: not about the truth or meaning of well-defined propositions but about what entities that inhabit the world, how they may interact, and how interactions and entities change through interaction (Lane & Maxfield, 2005:9–10; Bonifati, 2010:755). Uncertainty keeps us from aligning action to respond to future ill effects (game theory; e.g. Gintis, 2000; Ostrom, 1990), but it also (and relatedly,) prevents us from designing effective interventions without high likelihoods of causing unexpected troubles in other domains.

Uncertainty also forces us to be shortsighted by preventing us from building sufficient certainty for large-scale alignment and action. A short foresight horizon, and virtually no bound on the horizon for consequences of actions, makes wicked systems susceptible to self-undermining: what we typically refer to as *unsustainability*. Societal evolution is thereby prone to spontaneously and collectively embark on pathways leading to new dynamical regimes that may be arbitrarily disadvantageous (e.g. the Anthropocene; Steffen, Broadgate, Deutsch, Gaffney, & Ludwig, 2015a, 2015b).

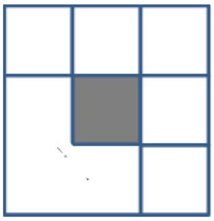
Innovation unfolds distributedly and locally in "the adjacent possible" (Kauffman 1996, 2000), which consists of organization largely created by innovation. *The game* and *the rules of the game* are thereby impossible to delineate in the general case (non-Near Decomposability; see Appendix A). Interactions will cross any postulated Interface boundaries or levels of organization, building impenetrable "causal thickets" (Wimsatt, 1994) rather than the ordered level- and component patterns that adapted (and many physical) systems exhibit. Wicked systems thereby cannot, generally, be simplified along either of the two axes in the SOS diagram: simplicity is not just hard to find, it frequently simply is not there.

Innovation happens around and within (sandwiched emergence; Lane 2006) structures, which are constantly in a state of linked construction and destruction (creative destruction; Reinert & Reinert, 2006; Schumpeter, 1976). The organization of wicked systems thereby never settles down to persistently stable or stationary states: regular and stable patterns of interaction (levels, components) are short-lived, often more local than we think, and constantly threatened by dissolution. Wicked systems will therefore rarely repeat themselves, with instances of what seems to be "the same" problem or system differing treacherously.

This organization is rarely forged through consensus or completely aligned interests, but rather through continuous conflict and negotiation. This can be related to the long-standing sociological tradition around the idea of "negotiated order" (Strauss, Schatzman, Ehrlich, Bucher, & Sabshin, 1963), as it challenges the notion of social orders as innately stable, and instead proposes order and stability as social accomplishments that need to be explained (Strauss, 1978). The central premise is that social order is an ongoing production of the actors involved, and that order is thus temporary and in flux: "a universe marked by tremendous fluidity; it won't and can't stand still. It is a universe where fragmentation, splintering, and disappearance are the mirror images of appearance, emergence and coalescence" (Strauss, 1978). The structures are furthermore important in setting the positions from which individuals negotiate and, in turn, give these negotiations their patterned quality: the structures are created, but also create the context for action (Callaghan, 2008).

While Strauss' work focused on organizations, similar dynamics seem to play out on all levels of wicked systems. In line with

Table 6
Sub-wickedness.

	Sub-wicked	**Central examples**: Small societies; local social contexts, e.g. relatives, close friends or workplaces; early human societies. **Differentiating features from wicked systems**: Smaller in scope. **Simplicity hook**: Smaller scope allows them to fit into the range of human cognition. They exhibit wicked problems, but ones small enough for us to handle. **Significance**: Sub-wickedness is attractive as a basis for dealing with wicked problems since it (as opposed to approches based on complexity or complicatedness) fundamentally matches their ontology.

Byrne and Callaghan (2013), we can regard wicked systems in general "as negotiated orderings at different scales, which have an assemblage character in that additions to and/or deletions from the assemblage 'rework' the negotiated order" (Byrne & Callaghan, 2013).

Open-ended innovation *demands* high complexity and complicatedness:

- Constrained to *low complicatedness*, innovation cannot be open-ended since we need complicated organization to build powerfully adapted and specialized systems. Unstructured system interactions would make for unmanageably high-dimensional spaces, preventing creative processes from efficiently exploring the design space (e.g. Erwin 2015; Stankiewicz 2000).
- *Low complexity* prevents the operation of chief mechanisms of adaptation, such as distributedness, parallelism, multifaceted interactions to provide robust feedback, and exploration of design spaces by testing multiple variations. Such systems are barren since the patterns that their interactions are allowed to take are pre-determined.

But innovation likewise *maintains* high complexity and complicatedness:

- Complicatedness is maintained since it represents our chief way of organizing design spaces. While it is an open question whether complicatedness generally increases or not (e.g. Marcot & McShea, 2007; referred to as "complexity"), complicatedness is clearly *maintained* at high levels; see Andersson (2013).
- Complexity is maintained because the rich interactive capabilities of adapted entities are expressed distributedly in an arena setting. Intense, dynamic and weakly constrained interaction creates "seamless webs" where any node will be in close interactive contact with just about the entire web. This gives us mass dynamics and the phenomena of complexity.

Complicatedness-based approaches do not work well since complicated organization in wicked systems is constantly changing, and complexity-based approaches do not work since interactive populations are strongly heterogeneous and changing in wicked systems.

3.3.2. *Sub-wicked systems*

Sub-wicked systems are wicked systems that have not outgrown our capacity to design and govern them – a capacity that it is no coincidence that we possess: we are adapted *specifically* for dealing with sub-wicked Systems (Table 6).

Human societies emerged out of the intricate politics of groups of versatile and strongly individualist Great Apes (> 10 million years ago; e.g. Moyà-Solà et al., 2009). Acting in such a group demands the ability to deal with constant social innovation: intrigues, new constellations, secrets, lies, and the relations between others and between others and oneself (Read, 2012). An important aspect of the unique evolutionary history of the *Homo* genus (< 2.5–2.0 million years ago; e.g. Antón, Potts, & Aiello, 2014) seems to have been the innovation of ways of organizing ever-larger groups of such individualists to simultaneously reap the rewards of individualism (resourcefulness, intelligence, initiative etc.), large numbers (emergent team functionality, robustness, etc.), and the capability of combining individuals with culturally developed complementary function into an emergent group-level functionality (Read, 2012). This represents the emergence of small seamless webs, wickedness and innovation in the cultural sphere along the lines presented in Section (3.3.1).

Sub-wickedness thereby becomes a route – alternative to theories of complicatedness and complexity – to the crucially important simplicity that we need to build and understand adapted systems. Narratives embody this capability, and so does the capacity to dynamically manage innovation processes – stories under construction; what we with minimal expansion of the concept may refer to as *negotiation*.

4. Conclusions

We may now identify a number of general conclusions – to be read as a sequence of very short aphorisms – about the constraints that exist on understanding and intervening in wicked systems. We will offer suggestions about future pathways for developing such capabilities, as well as integration and confirmation of some existing pathways and insights.

1. Wicked systems are so strongly and heterogeneously connected that it is impossible to exhaust even small portions of them empirically to produce a "realistic picture".
2. "Pictures" must therefore be *perspectives*, rarely subject to universal agreement.
3. Even if we could obtain a "realistic picture", this would frequently not help much since the system changes unpredictably over time – including as a direct result of us interacting with it.
4. Uncertainty includes not only foresight but also e.g. what the problem consists in, what tools are available, what actors to include.
5. "The game" and its rules frequently change dynamically on similar time scales.
6. The usefulness of models and theory hinges critically on whether, how, and to what extent it is realistic to decouple the game from its rules; see "short run" Appendix A.
7. Since this is more likely to be realistic for basic, slow-changing, features (e.g. physiology, logical dilemmas, strongly locked-in features, etc.), useful general regularities tend to be highly abstract.
8. Every wicked problem, however, is critically unique in its details. Interventions to address wicked problems must therefore be designed in the form of *meta*-solutions that scaffold the generation of actual solutions.
9. Navigating innovation pathways in everyday sub-wicked systems is congruous with doing so in wicked systems: an iterative and reflexive process of alignment, integration and problem solving.
10. Policy can be formulated in the likeness of this capacity rather than of our capacity to design complicated artifacts (designed, assembled and launched).
11. *Reducing wickedness to sub-wickedness* is attractive since this preserves more of its ontological and epistemological features.
12. What we need to pay particularly attention to in such a reduction is:
    a Incomplete and biased perspectives on the wicked system from sub-wicked perspectives that reflect how we are embedded into the seamless web (culture, education, roles, interests, power).
    b Wicked systems exhibit more complexity than we can handle: we have an eminently poor – even outrightly misguiding – intuition for complexity.
13. The suggested response is to:
    a Prioritize the integration of different perspectives.
    b Integrate the use of models as crutches for understanding complexity.
14. Also sub-wicked systems are constantly under the threat of misalignment. We need cooperation for aligned and directed action and so alignment should also be prioritized.
15. Alignment is also important normatively (deciding *what* we want to achieve) since, by contrast with engineering problems, goodness cannot be integrated uniquely at a top level with respect to external functions. Wicked systems are good or bad in relation to the components that they contain – components that are, in many ways, in competition – and a "good arena" might have qualities such as sustainability (inequity and other problems do not amplify) and a balance between goodness from local perspectives that is acceptable to most.
16. Narrative and negotiation have strong aligning and integrating functions and can form the "glue" in iterative cycles of sub-wicked approaches.
17. Due to uncertainty and dynamics any propositions and goals should be treated as tentative.
18. Dynamic exploration must include *components* that are actually or potentially part of the process:
    a We cannot know in advance what parties to include or leave out, nor what roles they should or will play.
    b Components in a seamless web are subject to substantial uncertainty; they cannot be sufficiently declared in mission statements, CV's etc.
19. Large black-box models (such as detailed predictive planning models) are hard to integrate into seamless webs: they cannot intermix with the viewpoints, knowledge and experiences of the participants (e.g. Klosterman, 2012).
20. Many wicked problems are so unique and contingent that modeling makes no sense. Complexity remains important, however, and simple, pedagogical models could be important for building a better *intuition* for complex dynamics.

To make these linked points easier to overview, we will now boil them down to three main themes:

1. Uncertainty is intrinsic to wickedness and the issue should not primarily be how we reduce it but how we deal with it. Dealing with uncertainty is at the core of what dealing with wickedness is about.
2. Integration of interests, models, tools, viewpoints, expertise, capacities for action (e.g. authority), and goals is essential, both instrumentally and for normative reasons.

3. Alignment is tightly tied to integration and is essential for maintaining the direction and integrity of efforts.
4. Dynamics/emergence is at the core of innovation and wickedness, giving rise to uncertainty and other wicked phenomena. Interventions must therefore be dynamically intermeshed with the unfolding dynamics.

In Table B1, (Appendix B), we discuss the ten points presented by Rittel and Webber (1973) to describe wickedness from the here developed perspective.

In Appendix C we review, through the lens of SOS, a set of emerging approaches that generally match the description provided in the Introduction (Section 1), and suggest understanding such approaches as sharing a common aim of *Harnessing Innovation*: there is an emphasis on integration and alignment between disciplines, actors and perspectives,[6] and intervention is increasingly conceptualized as directing and supporting iterative processes of innovation. Such an approach finds a strong *meta*-theoretical support in our understanding of the wickedness of socio-eco-technological systems.

Needless to say, a two-dimensional plane representing something "as overwhelming as overwhelmingness" must necessarily be incomplete in numerous ways. But, as Box and Draper (1987) famously stated: "all models are wrong; some models are useful," and the cases where models break down may be exceptionally useful to the extent that they force us to think along new constructive paths (Wimsatt 2002). The point is not to find a "correct model", but a "useful model", which we interpret as a model that helps us make sense of and organize our imagination about systems and problems than otherwise overwhelm us.

Our hope and intention with the SOS model is that, in furnishing a *meta*-ontology – a map of ontologies – it may serve as scaffolding for our imagination: a way of interrogating systems, processes and goals. *In which ways is this a complex problem? Is it complexity placed under control? How does that control work? How could it work? What are controlled complex systems like? What can be achieved? What are the trade-offs we're facing?* When disagreements arise over where to place a system, this will bring points where understanding is not shared to the surface, allowing their resolution. The SOS model hopefully offers some guidance for answering such questions, and, not least for refining and branching the model itself. Wicked problems are never solved in the abstract, and above all we aim to help *posing* them.

In our experience, the SOS model (and in particular diagram) has a particular value as a basis for discussions and exchanges of different experiences with wicked problems. We think the reason is that it allows – and invites – participants to think about their issues, cases, problems, goals, and so on, on a more abstract and domain-free level than the typical wicked-problem-solver is typically inclined to. This inclination to go into detail is quite natural: anybody working with wicked problems must spend a lot of time and energy uncovering, understanding and keeping up-to-date with massive amounts of contingent details. The downside, that we hope to mitigate, is that useful congruencies between cases – a precondition for the ability to compare and learn – risk drowning in these details along with insufficiently elucidated differences in terminology and types of goals.

Theoretically, the SOS mapping suggests commonalities among *meta*-level generating processes of ontological categories: if *self-organization* is the causal origin of complexity and *assembly* the causal origin of complicatedness, then *innovation* would be the origin of the wickedness. This points toward a possible unifying theme among many emerging approaches to sustainability (including the Pathways approach, e.g. Haasnoot et al., 2013; Stirling, 2007, 2010; Stirling, 2007, 2010; Wise et al., 2014, Transition Management, e.g. Loorbach 2010, and adaptive governance, Olsson et al., 2006). This theme is their recognition of the vanity of trying to predict, control or plan-away wickedness, and their shift of focus to embracing and harnessing these troublesome qualities of wickedness instead (see Appendix C). This also means a shift towards seeing humans (and their tools) increasingly as fallible as agents and knowers – the future becomes a historical process where problems, and the tools at our disposal for tackling them, are constantly changing as part of a wider societal innovation dynamics.

Innovation is essentially unpredictable and cannot be understood in the same way as we may understand systems where the rules of the game remain fixed, such as in the design of a technological artifact. Realistically, we may however hope to understand innovation and wickedness on a *meta*-level, similarly to how evolution is understood. For example, even if we cannot understand what the consequences of our actions will be, we may understand what *types of consequences* may arise, and we may use this knowledge to build mechanism for detecting, learning, and handling them specifically *as they arise.* We see establishing a theoretical connection between innovation and wickedness as a promising future direction of research.

In closing, we propose (Fig. 3) six rough mappings of typical generating processes, governance approaches, directionalities of design and governance, and types of organization into the SOS diagram. These mappings are based on the preceding analysis in this paper, and they can all bear elaboration and debate. Indeed, they are there as much to stimulate thinking about how they (and other similar mappings) can be revised and refined as to communicate conclusions about "how things work."

Acknowledgements

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[6] These themes are widespread but specifically in focus in research tracks such as Post-Normal Science; Funtowicz & Ravetz 1993; Turnpenny et al. 2010, and Inter- and Transdisciplinarity Research (Darbellay, 2015; Lawrence, 2015; Ledford, 2015).

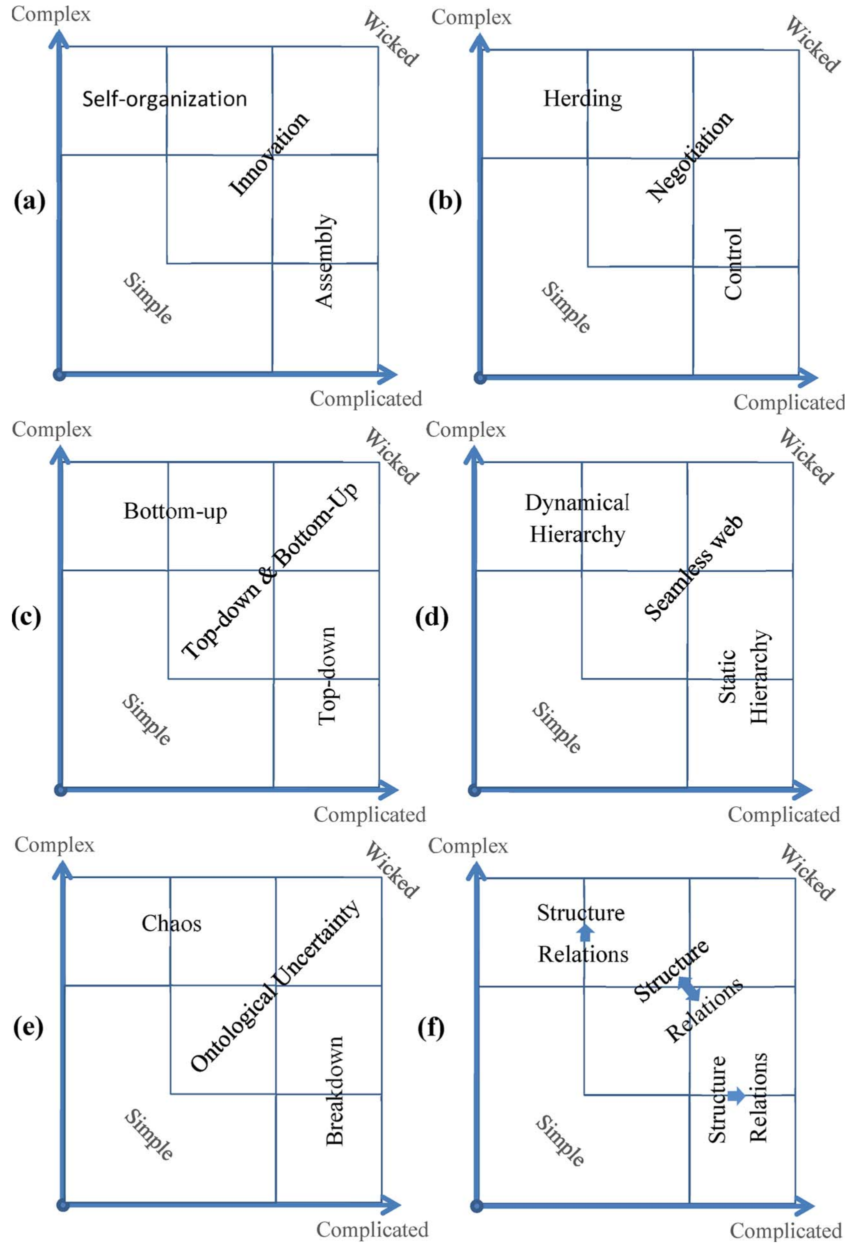

Fig. 3. The SOS diagram allows us to chart system features to relate and differentiate between them. (a) Generating processes; (b) Governance approaches; (c) Directionality of design and governance; (d) Style of system organization; (e) Characteristic sources of risk and uncertainty; (f) Relation between structure and relations.

Appendix A. Wickedness and Near-Decomposability

Herbert Simon (1962) concept of Near-Decomposability, and Rittel and Webber (1973) concept of wicked problems represent takes on the problems of "designing complex systems". The opposition between the two accounts could, however, hardly be stronger (Coyne, 2005). Simon's story is about systematically conquering overwhelming problems following a top-down procedure. Rittel and Webber (1973) story tells us that precisely this strategy is doomed to fail in many of the most important cases – in particular in front of the types of sustainability problems that we are primarily interested in here.

While we agree with the diagnosis of Rittel and Webber (1973), we note that Simon did something that they did not: he provided a generative design space for an important class of problems. Rittel's and Webber's work, by contrast, was essentially negative (a critique) and does not structure the design space in a similar way. They tell us that the design spaces of the paradigm that Simon represents do not work for wicked problems, but do not provide much in way of an alternative.

In our quest to provide new design spaces also for wicked systems we may, however, still benefit from Simon's explicitness: we

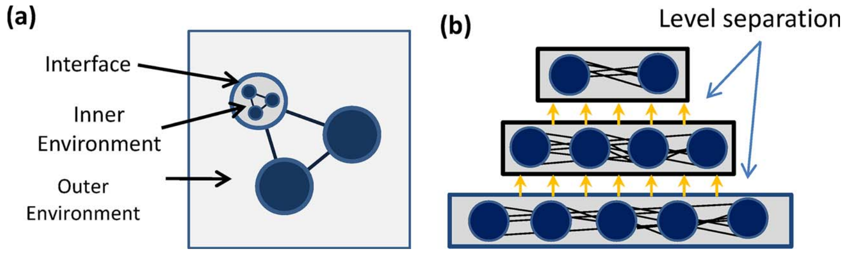

Fig. A1. Illustration of Simon (1962) the concept of *Near-Decomposability*. Interaction in the Outer Environment happens only via component *Interfaces*. If we nest this style of organization hierarchically we obtain a neat level hierarchy where each level may be understood with only summary knowledge about the levels above and below. This is an ideal situation for building models as it allows for strong control and powerful assumptions, and it also allows us (or any adaptive process) to erect an arbitrary number of hierarchical levels, compartmentalizing in principle any number of degrees of freedom, behind a simple interface.

may use his concept of Near-Decomposability to understand why wicked problems are not like the "tame problems" for which Simon's prescriptions work so wonderfully. After all, Rittel and Webber (1973) define wickedness more or less precisely as a stubborn recalcitrance to the type of approach that Simon (1962) proposed.

Near-Decomposability (see Fig. A1a) is a type of patterning of interaction pathways that allows for strong simplifications. Essentially it means that the rate of interactions between sub-components *within* a component (*Inner Environment*) is much higher than the rate of interaction *between* the component and other components on its own level of organization (*Outer Environment*). The Inner and Outer Environments are separated by the component *Interface*, which can be seen as the emergent (designed or evolved) totality of the component: its interaction modalities and pathways of interaction.

The archetypical way in which components are separated is physical distance and/or enclosure (usually in technological components for example), but the separation may be maintained in any manner that achieves the sought structuration of interaction patterns.

Apart from a difference in density of interactions within and between components, the Interface also tends to channel interactions so that they occur in forms that the Inner Environment is adapted to deal with. For example, humans may accept energy from the environment, but exposing us to heat or pouring nutrients over us will not work: energy must enter in very specific forms along very specific pathways if we are to properly make use of it.

The Interface can, for many purposes, be used as a shortcut to everything below its own level of organization: we may use a smart phone or an automobile with virtually no knowledge about its inner workings. The Interface cuts short potential system-wide cascades effects of changes, and the process of creating representations of such systems (on some level, e.g. by gathering empirical data) will converge: more effort yields less and less relevant details to add. Innovation or assembly may therefore focus on one small part of a system at a time.

This mechanism of simplification-by-compartmentalization is so drastic that it may entirely reset the number of degrees of freedom of a system on each level of organization. In principle, we may go on nesting systems in this hierarchical manner forever (see Fig. A.1b). What prevents us from actually doing so is simply that we run out of scales over which to operate. Indeed, opening up new scales to occupy with levels of organization is a premier cause of major transitions in engineering (see e.g. Feynman, 1992).

Near-Decomposability is, notably, valid only over a time scale that Simon refers to as "the short run" (Simon, 1996). If the time scale is too long, then factors outside of the Inner Environment will begin to disturb the dynamics, and assumption that the "enclosure" is constant will become invalid. For example, a suitable "short run" for the study of traffic would be minutes and hours. Over time scales shorter than minutes not much would happen, and if we move to several days, the dynamics would more or less repeat itself. Moving to even longer time scales, roads, types of vehicles, regulations and so on would begin to change. Short runs are not just hard to find in wicked systems, there is no guarantee that there even exists a meaningful short run. *Wicked Systems may be seen as systems that largely lack relevant short runs* and thereby also opportunities for powerful formal modeling.

Levels of organization have been described as "stable foci of regularity and predictability", and as such, the existence of levels of organization in itself must be expected to act as attractors to adaptive processes: they should self-reinforce and self-stabilize over time (Wimsatt, 1994) since adapting systems evolve in such a way as to minimize uncertainty in their environment (Levins, 1968).

However, as Wimsatt (1994) points out, this is only half the story. In a competitive situation (i.e. wickedness,) entities under competition (be they organisms, organizations or humans) will themselves seek to be as *unpredictable* as possible to their competitors, which would make it adaptive to also break up level hierarchies.

Wimsatt (1975:181–185) furthermore argues that Simon's principles take only ease of design and assembly into account, not optimality of function. Optimality of function, of course, may be under strong selection pressure, and when it is we should expect this to cause breakdowns in level-hierarchical organization. The reason is that there is no convincing argument for why a style of organization that simplifies assembly and design would a*lso* make for optimal function. Intuitively this expectation seems to be carried out in reality. Technological artifacts that are mass-produced (strong pressure for adaptability, cheap assembly and easy maintenance) contain more standard components, and are simpler in their architecture, than ones that are highly specialized and produced only in very few numbers. Compare for example a standard laptop to a space shuttle; see example under Point #5, Table B1, (Appendix B).

Simon (1977) own take on "Ill-Structured Problems" is **worth** mentioning as it illustrates the friction between how different paradigms conceive of problems: their specifications and what counts as solutions. He here deals with the fact that many important problems are very hard to specify in such a way that they can be solved following prescriptions along the lines of his famous (1962) paper. He concludes that a dynamical *process* is needed in cases where the problem cannot be posed up-front, and what he describes is a process of dividing-and-conquering: even if the problem as a whole is Ill-Structured, all actual problems fed to the problem solvers remain Well-Structured (i.e. Near-Decomposable).

The process that he proposes takes an initial broad problem specification and goes on to decompose and dynamically explore what it entails (working out sub-problems, locating people with skills, permissions and so on, locating and mobilizing assets, etc.) This includes going back to revise the initial specification if necessary (Simon, 1977:315). The process then slowly works its way into a complete specification that can be agreed upon as a solution.

While this is certainly in the *direction* of a Harnessed Innovation approach, with elements of both integration and alignment, there is a distinct difference between this process and Harnessed Innovation with regard to what counts as solving the problem.

His example of designing and producing a new battleship clearly demonstrate how he misses the mark when it comes to wickedness. *The problem specification tells the problem solving system what the result should be like in terms that are intrinsic to the solution.* In this case that it should have such and such armament, armor, propulsion, and so on. The process then realizes a solution that works out all the nasty little details in how to actually go about doing this, and that can deal with contingencies such as that some criterion is too expensive, impossible to implement and so on.

This is not what we mean by a wicked problem, but it can easily be transformed into one by specifying the problem, instead, in relation to the wicked system in which the battleship is expected to act. For example, if "ruling the high seas" would be the goal (which, in the end, it surely was) then the battleship design problem (as specified in Simon's example) could be successfully solved but still fail to properly address the larger wicked problem. And even if it did solve the problem, it would still only be temporary and it would be part of a much larger technological, economic and political process across historical time.

Appendix B. Analysis of Rittel's and Webber's ten points

Table B1
Expressions and causal interpretations of wickedness.

The ten expressions of wicked problems listed by Rittel and Webber (1973)	
Expression	Causal interpretation
1: "There is no definitive formulation of a wicked problem" (Rittel & Webber, 1973).	Two important causal features of wickedness are **(i)** the "seamless web" structure of the web of associations through which causation travels, meaning that entities are widely and strongly interconnected across far-flung domains; **(ii)** the dynamical cascades of qualitative change that travel through and transform this seamless web; and **(iii)** the fact that those that act upon the system are embedded into it, using their particular embedding as a lens through which they see the system (in effect mapping it to a personal sub-wicked model that they can grasp; Sec. 3.3.2).
According to Rittel and Webber, this has to do with the relation between *understanding* a problem and one's ideas about how to *solve it*.	These features pose several problems to any effort to gather information about the system *first* and to then produce a solution based on this information.
They take the problem of *poverty* as an example to illustrate what they mean. "*Does poverty mean low income? Yes, in part. But what are the determinants of low income? Is it deficiency of the national and regional economies, or is it deficiencies of cognitive and occupational skills within the labor force? If the latter, the problem statement and the problem 'solution' must encompass the educational processes. But, then, where within the educational system does the real problem lie? What then might it mean to "improve the educational system"? Or does the poverty problem reside in deficient physical and mental health? If so, we must add those etiologies to our information package, and search inside the health services for a plausible cause… To find the problem is thus the same thing as finding the solution;the problem can't be defined until the solution has been found.*"	The first is that any problem will be entangled between a large number of domains (e.g. economy, education etc.). We prefer to solve problems from the standpoint of domains since our training and expertise, and thereby experience, are based on domains. Information-gathering, almost necessarily, is biased by the domain from the vantage point of which it takes place.
They go on to critique the prevalent systems approaches of that time…	Even if we spend a great deal of effort on gaining an overview, our search outward for more important factors will not converge as neatly as a similar search in, say, a complicated system: we keep finding more and more important factors, across longer and longer time scales, and eventually we may come to the true but rather useless conclusion that "everything is connected."
"*This property sheds some light on the usefulness of the famed 'systems-approach' for treating wicked problems. The classical systems-approach of the military and the space programs is based on the assumption that a planning project can be organized into distinct phases. Every textbook of systems engineering starts with an enumeration of these phases: "understand the problems or the mission,"*	But, as if this would not be enough, it would not help even if we *could* obtain a perfect overview: the system keeps changing qualitatively over time, and it does so partly as a direct result of us intervening in it. The world in which we insert our cleverly designed intervention is not the same world anymore: it

(*continued on next page*)

Table B1 (*continued*)

The ten expressions of wicked problems listed by Rittel and Webber (1973)	
Expression	Causal interpretation
"gather information," "analyze information," "synthesize information and wait for the creative leap," "work out solution," or the like. For wicked problems, however, this type of scheme does not work. One cannot understand the problem without knowing about its context; one cannot meaningfully search for information without the orientation of a solution concept; one cannot first understand, then solve. The systems-approach 'of the first generation' is inadequate for dealing with wicked-problems.	has our intervention in it, and we have very little of an idea about how it will interact with the agents, ideas and artifacts within it.
…and then to point to more "argumentative processes" where ideas about the problem and the solution co-evolve.	The first-generation systems approaches that Rittel and Webber refer to treat wicked systems as if they had been complicated systems: as if the search for information would converge, as if the problem would be delineable, as if the problem would remain the same, and so on.
Approaches of the 'second generation' should be based on a model of planning as an argumentative process in the course of which an image of the problem and of the solution emerges gradually among the participants, as a product of incessant judgment, subjected to critical argument."	Efforts to accommodate wickedness in such an ontological structure will maximally take us into the *trans*-complicated regime: we remain grounded in complicatedness; i.e. we project a wicked space onto a simpler complicated space. The big problem is not the simplification *per se* but the ontological mismatch between model and problem. No amount of empirical detail can help us in that regard.
	Their suggested move to second-generation approaches describes a move that recognizably is in the direction of what we refer to as Harnessed Innovation (Sec. 5).
2: "Wicked problems have no stopping rule" (Rittel & Webber, 1973).	This expression of wickedness has to do with the fact that the time horizon of consequences is potentially unlimited and wholly uncorrelated with our short foresight horizon.
They here compare wicked problems to the problem of playing chess, where a problem solver has definite criteria to determine when the problem is solved. They state: "*because there are no criteria for sufficient understanding and because there are no ends to the causal chains that link interacting open systems, the would-be planner can always try to do better.*"	The result is that *other* factors must determine when projects begin and end.
Termination, instead, happens "*…not for reasons inherent in the 'logic' of the problem. He stops for considerations that are external to the problem: he runs out of time, or money, or patience. He finally says, 'That's good enough,' or 'This is the best I can do within the limitations of the project,' or 'I like this solution,' etc.*"	It may also be noted that wicked problems do not only lack a stopping rule: they also lack a "starting rule." We always enter wicked problems at what seems to be a too late point in time.
	The reason for this is that nobody wants to own wicked problems and they are often hard to attribute to somebody. They arise in an arena, *between* rather than within systems that "belong" to agents, and they are externalities *par excellence*. Consequently, our first reaction in front of them is to think "that's not my problem" and then try to figure out whose problem it probably is instead. Wickedness is likely to cause finger-pointing.
3: "Solutions to wicked problems are not true-or-false, but good-or-bad" (Rittel & Webber, 1973).	As we note in Sec. 4, and as many others note in our examples in Sec. 5, societal problems belong to their own constituent parts.
Related to Point #2, they here describe how solving wicked problems is very different from solving tame problems: their quality is judged from the standpoint of what different actors want (and understand) rather than from objective and universal criteria.	This is highly different from, say, a machine. The notion that an automobile should be "good" from the point of view of its spark plugs is absurd. But imagine what the design problem would look like if a car had to be good for its parts as opposed to its users.
"*For wicked planning problems, there are no true or false answers. Normally, many parties are equally equipped, interested, and/or entitled to judge the solutions, although none has the power to set formal decision rules to determine correctness. Their judgments are likely to differ widely to accord with their group or personal interests, their special value-sets, and their ideological predilections. Their assessments of proposed solutions are expressed as 'good' or "bad" or, more likely, as "better or worse" or "satisfying" or "good enough.*"	We want wicked systems to be good as arenas of interaction for their constituent components: they should be arenas in which interactions do not lead to bad effects for the agents, neither in the short run nor in the long run; akin to a Pareto efficient state, but in a dynamic rather than static sense.
4: "There is no immediate and no ultimate test of a solution to a wicked problem" (Rittel & Webber, 1973).	This point arises due to ontological uncertainty (Sec. 3.3.1), which, in turn, is due to the cascades of qualitative transformation that propagate and interact in the system; the first quoted passage to the left also gives clear evidence that this picture corresponds to how Rittel and Webber understood the underlying mechanics.
"*With wicked problems, on the other hand, any solution, after being implemented, will generate waves of consequences over an extended – virtually an unbounded – period of time. Moreover, the next day's consequences of the solution may yield utterly undesirable repercussions which outweigh the intended advantages or the advantages accomplished hitherto. In such cases, one would have been better off if the plan had never been carried out.*	The consequence is that we must constantly monitor effects and be prepared to alter our strategies and goals according to how realities change. If we remain committed to descriptions of realities in the past, our actions will become increasingly misguided as time goes on.
The full consequences cannot be appraised until the waves of repercussions have completely run out, and we have no way of tracing all the waves through all the affected lives ahead of time or within a limited time span."	
	This point underscores that wicked problems are not engineering problems.

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Table B1 (*continued*)

The ten expressions of wicked problems listed by Rittel and Webber (1973)

Expression	Causal interpretation
5: "Every solution to a wicked problem is a 'one-shot operation'; because there is no opportunity to learn by trial-and-error, every attempt counts significantly" (Rittel & Webber, 1973).	
Here, Rittel and Webber touch upon the reflexivity of wicked systems, how we are immersed in them, and how, since they cannot be covered by models, and are too large and slow to be replicated otherwise, we cannot address them *vicariously* (Campbell, 1965); i.e. through an "offline" controlled experimental representation.	The difference may be illustrated with a limit case where this problem applies also to complicated systems, which happens when they are particularly overwhelming and expensive – at the limit of what we can pull off:
Games of chess can be repeated, and we can practice different strategies at little cost and consequence. Not so for wicked problems:" *every implemented solution is consequential. It leaves 'traces' that cannot be undone. One cannot build a freeway to see how it works, and then easily correct it after unsatisfactory performance. Large public-works are effectively irreversible, and the consequences they generate have long half-lives. Many people's lives will have been irreversibly influenced, and large amounts of money will have been spent – another irreversible act. The same happens with most other large-scale public works and with virtually all public-service programs. The effects of an experimental curriculum will follow the pupils into their adult lives."*	When the space shuttle Columbia first flew into space April 12, 1981, it was the first time the entire system had been in motion. Indeed, no system remotely like it had even been tested before.
	The leap from unpowered atmospheric flight (with a different prototype vehicle – the *Enterprise*) to launch, space mission, atmospheric re-entry and landing was not a small one. Confidence in success was sufficiently low that most involved were probably highly nervous, but high enough that the crew certainly did not consider it a suicide mission: everybody fully expected them to get home in one piece. The fact that this was at all possible is a powerful testament to the power of complicatedness and Near-Decomposability as a way of organizing design spaces. In most cases, however, we do not have to forego the powerful design feedback we get from testing the entire system under realistic conditions (in particular not with access to high-quality simulation models). Our inability to learn about wicked systems from experience is due to ontological uncertainty and the long time scales over which wicked problems are addressed. Conditions may have changed dramatically, and in unknown ways, as we move to a new problem instance. What we think we have learned may just as well *prevent* success in the future since the suitability of certain past actions may have been contingent on conditions that no longer exist, and that we may never even have been aware of. The unlimited time horizon for consequences also plays here in an important way: experiments do not end when we think they do. Rittel and Webber note that the effects of an experimental curriculum will follow pupils into their adult lives, but in fact, the effects can be traced even further since the pupils will interact with the rest of the system throughout their lives. An effect of complexity in this context is that effects do not even necessarily abate over time: at any time, a downstream effect may trigger a powerful cascade effect.
6: "Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan" (Rittel & Webber, 1973). "…*normally, in the pursuit of a wicked planning problem, a host of potential solutions arises; and another host is never thought up. It is then a matter of judgment whether one should try to enlarge the available set or not.*"	This problem is about the overwhelmingness of the design space of wicked systems. Contrary to complicated (and to some extent complex) systems interactions are not strongly patterned and there is very little to guide us in a systematic search for solutions or problem descriptions. The lesson that can be derived from our work here is that the only viable way of structuring wicked problems is by projecting them onto simplified *sub-wicked* spaces that we may grasp intuitively. We may then design scaffolds for processes in which these sub-wicked representations are developed over time. That is the lowest level on which we can be systematic.
They go on to illustrate how ideas can direct us in qualitatively different directions, each yielding propositions that could not possibly have been conceived within the framework of the other: "*What should we do to reduce street crime? Should we disarm the police, as they do in England, since even criminals are less likely to shoot unarmed men? Or repeal the laws that define crime, such as those that make marijuana use a criminal act or those that make car theft a criminal act? That would reduce crime by changing definitions. Try moral rearmament and substitute ethical self-control for police and court control? Shoot all criminals and thus reduce the numbers who commit crime? Give away free loot to would-be-thieves, and so reduce the incentive to crime? And so on.*"	See also the analysis of Points #1 and #2.
7: "Every wicked problem is essentially unique" (Rittel & Webber, 1973).	The chance that two identical problems would appear in a wicked system is slim. This does not mean that we cannot learn about solving wicked problems,

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Table B1 (*continued*)

The ten expressions of wicked problems listed by Rittel and Webber (1973)	
Expression	Causal interpretation
	but it does mean that we must be wary about trying to learn on a too specific level.
The conditions in a city constructing a subway may look similar to the conditions in San Francisco, say; but planners would be ill-advised to transfer the San Francisco solutions directly. Differences in commuter habits or residential patterns may far outweigh similarities in subway layout, downtown layout and the rest. In the more complex world of social policy planning, every situation is likely to be one-of-a-kind.	As noted in the analysis of Point #5, learning on a too specific level carries the risk of lock-in to operations and strategies that no longer apply. Moreover, even subtly altered conditions may, in an environment of high complexity, produce arbitrarily large deviations in outcomes due to chaos (Sec. 3.1.2)
If we are right about that, the direct transference of the physical-science and engineering thoughtways into social policy might be dysfunctional, i.e. positively harmful. "Solutions" might be applied to seemingly familiar problems which are quite incompatible with them.	
8: "Every wicked problem can be considered to be a symptom of another problem" (Rittel & Webber, 1973).	This is a direct result of the seamless web organization of wicked systems combined with cascades of transformation across this web. It also connects to our observation that "the game" cannot be delineated from "the rules of the game" (Section 3.3.1).
Delimiting a wicked problem is a vain pursuit, and Rittel and Webber here deal both with the multi-domain and the multi-level nature of wickedness as well as with how problems change dynamically if we deal with parts of them.	
Some observations that they make:	
"*The process of resolving the problem starts with the search for causal explanation of the discrepancy. Removal of that cause poses another problem of which the original problem is a 'symptom." In turn, it can be considered the symptom of still another, "higher level' problem. Thus 'crime in the streets' can be considered as a symptom of general moral decay, or permissiveness, or deficient opportunity, or wealth, or poverty, or whatever causal explanation you happen to like best."*	
"*Marginal improvement does not guarantee overall improvement. For example, computerization of an administrative process may result in reduced cost, ease of operation, etc. But at the same time it becomes more difficult to incur structural changes in the organization, because technical perfection reinforces organizational patterns and normally increases the cost of change. The newly acquired power of the controllers of information may then deter later modifications of their roles.*"	
"*…it is not surprising that the members of an organization tend to see the problems on a level below their own level. If you ask a police chief what the problems of the police are, he is likely to demand better hardware."*	
9: "The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution" (Rittel & Webber, 1973).	This point underscores the importance of alignment and integration in interventions in wicked systems, and relates to discussions above (Section 4; Point #3) about the nature of "goodness" in solutions of wicked problems, as well as to the irreducible co-existence of a multitude of perspectives (Section 4; projections of wickedness onto sub-wicked mental models, or formal models with complicated or complex ontologies).
"*'Crime in the streets' can be explained by not enough police, by too many criminals, by inadequate laws, too many police, cultural deprivation, deficient opportunity, too many guns, phrenologic aberrations, etc. Each of these offers a direction for attacking crime in the streets. Which one is right? There is no rule or procedure to determine the 'correct' explanation or combination of them.*"	We cannot do much about the fact that different parties will be linked into a wicked system in different ways. In some cases, such interests may be irreconcilable, but in many cases, negotiation and mutual understanding may open up for more inclusive resolutions where losses in one area are compensated by gains in some other area. If a problem is seen as serious, if responsibility can be accepted, and if trust can be established, willingness to strike compromises will also increase.
Rittel and Webber boil this point down to an interesting observation: "*The reason is that in dealing with wicked problems there are several more ways of refuting a hypothesis than there are permissible in the sciences.*"	What Rittel and Webber says here can be interpreted as follows: compared to in science, where we have a universally agreed-upon (if not always perfectly functioning) system for deciding who is right, we have nothing similarly strong and forcing in policymaking. In other words: we largely lack a crucially important aligning mechanism.
Briefly put, it is hard to push anybody sufficiently into a corner that they logically *must* abandon their hypothesis.	Unless alignment is pursued, the problem-solving sub-wicked systems (e.g. consisting of a collection of persons and/or organizations) cannot be configured and directed. We note in Sections [4 and 5] that alignment is indeed among the top concerns around which Harnessed Innovation approaches are constructed.
"*The mode of dealing with conflicting evidence that is customary in science is as follows*: 'Under c*onditions C and assuming the validity of hypothesis H, effect E must occur. Now, given C, E does not occur. Consequently H is to be refuted." In the context of wicked problems, however, further modes are admissible: one can deny that the effect E has not occurred, or one can explain the nonoccurrence of E by intervening processes without having to abando*n H.'	
The effect is that:	

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Table B1 (*continued*)

The ten expressions of wicked problems listed by Rittel and Webber (1973)	
Expression	Causal interpretation
"*Somewhat but not much exaggerated, you might say that everybody picks that explanation of a discrepancy which fits his intentions best and which conforms to the action-prospects that are available to him. The analyst's* 'world view' is the *strongest determining factor in explaining a discrepancy and, therefore, in resolving a wicked problem.*"	
10: "The planner has no right to be wrong" (Rittel & Webber, 1973).	Rittel and Webber here compare wicked problems to problems in other fields. This point applies not only to wicked problems but to any problem whose solution is "good or bad" for somebody else (e.g. surgery.)
This point deals with the fact that wicked problems are different than other scientific problems. Referring to point #3, solutions are not right or wrong but rather good or bad: they are not just "hypotheses offered for refutation".	The unlimited time horizon for consequences, however, makes this responsibility different in wicked systems. Just like we cannot determine when we are done solving a wicked problem, we cannot determine when it has been successful or not.
"…*the aim is not to find the truth, but to improve some characteristics of the world where people live. Planners are liable for the consequences of the actions they generate; the effects can matter a great deal to those people that are touched by those actions.*"	Historical interventions may have strong and long-lasting downstream consequences that can produce persistent ill effects and conflict. These effects may have been unforeseeable or not of moral concern (even seen as positive) at the time they were caused. Colonialism, eugenics and anthropogenic global warming would be examples of this in different ways.

Appendix C. Harnessing innovation to deal with wicked problems

We now wish to argue that the type of modern intervention approaches that we initially (Section 1) referred to as "Harnessed Innovation" evolves *roughly* along the lines that we just proposed (Section 4). We thereby wish to find and establish links between the here developed foundation of wickedness in innovation and ongoing work for which such a deepened causal understanding could provide integration, alignment and, hopefully, new ideas.

In the SOS framework, Harnessed Innovation can be conceptualized as the design of a controlled sub-wicked innovation process that interfaces with a wicked societal innovation process. It represents a move from traditional complicated and *trans*-complicated systems-oriented approaches – with emphasis on control and prediction – *to a sub-wicked type of organization.*

We here review a small selection of proposed examples of Harnessed Innovation to detect and characterize unifying concerns and responses that can be tied to our causal and *meta*-theoretical understanding.

Nickerson and Sanders (2013) deal with collaboration between large numbers of governmental and non-governmental organizations (an "alphabet soup" Nickerson and Sanders 2013: 1) in the face of emergencies (e.g. the Deepwater Horizon accident, hurricane relief etc.) that are highly urgent, unique, fluid and multi-faceted. A central concern is that of integrating and aligning assets toward achieving a common goal. They develop the concept of an "enterprise leader": an integrating and aligning agent that: **(i)** Spans the boundaries of many agencies through deep knowledge about how they work, what they do and how they see the world. **(ii)** Can act without formal authority, on the basis of skillfully negotiated commitments rather than command (formulating shared interests, a sense of common mission). **(iii)** Builds and leverages boundary-spanning networks to establish communication channels, trust and reputation. **(iv)** Dynamically steers the dynamics as it rapidly unfolds in an unpredictable manner.

Brown et al. (2010) aim to "stimulate our imagination" about how we approach wicked problems. Russell (2010: 56–58) kicks off the volume with a set of "guiding principles" based on thorough philosophical considerations about epistemological, ontological and ethical issues. Of central importance is a view of complexity (overwhelmingness in our terminology) as responsible for: (i) *partiality* – our inability to know everything about the systems; (ii) *plurality* – of perspectives and ways of knowing; (iii) *provisionality* – partiality and plurality causes fallibility, and so knowledge must remain provisional and open to change. Normative prescriptions are formulated on this basis, e.g.: a "social process of critical deliberation"; explicitness about underlying values, assumptions and interests; considerations should extend as far as necessary; legitimization of knowledge and action. In summary, the principles focus strongly on action in the face of intrinsic and multi-faceted uncertainty, and the prescriptions emphasize dynamics, integration and alignment.

Transition Management (Loorbach & Rotmans, 2006; Loorbach, 2010) is in many ways representative for how change is envisioned in the sustainability transitions community (e.g. Markard, Raven, & Truffer, 2012): a transition (as opposed to lock-in) is a period where *agency counts*, so where it will go can be affected if we manage the transition wisely: if we dynamically navigate and construct a feasible pathway to where we want to go. The Transition Management Cycle (Loorbach, 2010: 173) summarizes the idea behind the approach as four steps: **(i)** Problem structuring, envisioning and establishment of the transition arena; **(ii)** Developing coalitions, images and transition agendas; **(iii)** Mobilizing actors and executing projects and experiments; **(iv)** Evaluating, monitoring and learning.

The "pathways approach" (Leach et al., 2010) also has a transition focus and a signature feature is that it ties normative value- and power-related aspects tightly to the instrumental aspects of navigating and constructing transition pathways: it is not just a matter of integrating hard *capabilities* (models, expertise etc.) but also of involving those that are affected as parts of the system. Three of the four main hurdles to better approaches to sustainability that they list – dynamics, incomplete knowledge and multiple framings – have direct bearing on the here-described causal structure of wickedness (Leach et al., 2010: 3–5).

Adaptive Governance (Olsson et al., 2006) deals with transition pathways from a different intellectual trajectory (e.g. *resilience,* Folke et al., 2010 and *panarchy,* Gunderson & Holling, 2002), focusing on socio-ecological rather than socio-technical systems. The overall view of transitions is, however, highly congruent to that of the former two examples: a lock-in, a window of opportunity, and a swift and tumultuous transition phase. The latter is characterized by uncertainty and must be managed to lead to a beneficial state ("adaptive governance", ensuring *resilience* of ecosystems threatened by collapse.) Preparing for navigating the transition involves development around three key factors: *building knowledge*, *networking* and *leadership*. The role of the leader is similar to that described above by Nickerson and Sanders (2013).

Turnheim et al. (2015) point to the richness, yet lack of integration, among approaches for analyzing and governing transition pathways, reviewing the current literature on this topic. Embodying different methodologies and perspectives, they argue that these may be used as mutually complementary components in more versatile synthetic approaches. What is proposed is an iterative process of *alignment* and *bridging* to bring the components into conversation as they operate across the historically unfolding innovation process to be governed and assessed. This recalls our biological examples of symbiotic origins of high-level complicated systems (Section 3.1.1) which (perhaps notably) ended up in wholly transformed components, entirely subservient to the emergent synthetic functions (although it began that way, we do not think of eukaryotic cells as "combinations between bacteria").

Other approaches share the same basic picture of innovation and wicked problems, but are more planning-oriented, aiming to build *foundations* for change. One prominent such example is backcasting (see Quist and Vergragt, 2006 for a review). For example, Holmberg and Robért (2000) addresses the question of "how can ecology and economy be merged together into one strategy that makes sense in the short term as well as in the long term, and from a business perspective as well as for the common good?" (Holmberg and Robért, 2000:292). Backcasting is organized around *target pictures* as tools of alignment and integration (of actors, tools, etc.), and collective problem formulation-and-solving. Target pictures, and ways of getting there, are reflexively refined to a point where they can generate agreement and serve as a basis for future aligned and integrated action. Backcasting is argued (see also Dreborg, 1996:817) to embody and formalize the principles according to which we solve problems in everyday life: everyday problems are see as miniature versions of larger and more long-term society-level problems Holmberg and Robért (2000: 296).

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