autonomous systems are bounded as well."[10]

In the context of sociotechnical systems, it may be time to expand the discussion beyond the interface between actors and systems. The emergent activity of sociotechnical systems and converging technologies may indeed have, "unintended social consequences."[11] While this may expand the argument beyond the authors' original intention, collaboration between humans and machines requires us to consider social aspects.

Many recognize these issues in a wider context, and they have done so for several decades.[12] Planners, engineers, designers, and policy-makers must develop technical systems and social needs together for more cohesive outcomes through co-evolution.

While this principle is recognized widely, organizations do not often adopt it in practice. A recent study conducted by the OECD[13] found little or no debate on these important issues. The report describes several reasons[14] for the limited public discussion of sociotechnical collaboration. These reasons include the shift in ethical discourse in scholarship, our ever-wider societies, socioeconomic forces, and such considerations as privacy, equality, wealth distribution, community impact, and available resources. Other reasons include risks to human health and environmental impact. While sociotechnical systems seem to be local when we design them, they have wider effects. We must engage in a richer and deeper societal conversation – one that perhaps includes the abovementioned factors – if we are to design and create responsible sociotechnical solutions.

Behymer and Flach should frame these issues more carefully. They would support a better-contextualized discussion of sociotechnical collaboration while highlighting the terminology that makes it so hard to engage in fruitful discussion.

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Author's Response

From Designing to *Enabling* Effective Collaborations

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Introduction

First, we would like to thank the editors of *She Ji* for this opportunity to participate in a dialogue about the challenges of designing collaborations that are capable of managing complex sociotechnical problems. We also want to thank those who contributed commentaries – Derek Miller, Susu Nousala, Hugh Dubberly, and Paul Pangaro. These commentaries serve to amplify the significance of problems associated with the creation of effective collaborations, fill in gaps in our treatment of the problem, and broaden the discussion.

One obvious gap in our presentation is the lack of recognition of the long history of people who have been exploring ways to more effectively couple humans with information technologies. Certainly, our framing of the problem is greatly influenced by the opportunity to benefit from the work of such pioneers as mentioned in Dubberly and Pangaro's commentary – Engelbart, Licklider, and Negroponte. It is impossible to acknowledge all the people whose shoulders we stand on, but we would particularly like to acknowledge the contributions of Dekker,[1] Lindblom,[2] Norman,[3] March,[4] Rasmussen,[5] Simon,[6] Vicente,[7] Weick,[8] Wiener,[9] Winograd,[10] and Woods[11] in shaping our vision of sensemaking and the implications for collaborations between smart people and smart machines to solve "wicked problems."

Wicked Problems

Nousala, Dubberly, and Pangaro wondered at our use of the term wicked problems in our conceptual model of a sociotechnical system (Figure 1 in the target article). We chose the label to represent the kinds of problems that sociotechnical systems must grapple with as a way to emphasize that these are 'open systems,' and that the problems they must solve are 'complex.' The systems are open to the extent that there are external disturbances that cannot be fully specified or anticipated, and the problems are complex in the sense that there are typically large numbers of incommensurate variables – in some cases, an unspecifiable number of variables – that could potentially be relevant.

Additionally, the problems are such that there is typically no unambiguously correct solution or right answer. Thus, these problems are only solvable in the sense of *satisficing* – in other words, the solutions can only be evaluated pragmatically – are the consequences of decisions/actions deemed satisfactory with respect to the mission of the organization. The key is that there is no analytical basis for identifying any particular solution as optimal or absolutely right.

Note that *satisficing* is generally discussed relative to human limitations, or bounded rationality. The implication is that the choice of a less than optimal solution is due to humans' internal constraints. However, we are using the term satisficing here to reflect a property of the problems. In this case, satisficing is not a compromise relative to a potentially optimal solution, but rather it indicates that it is impossible to specify an optimal solution. A solution either leads to satisfying or unsatisfying consequences, but there is no absolute basis for identifying a particular solution or set of solutions as absolutely better than another set. Further, in some cases there will be no *a priori* normative basis to predict whether a solution will be satisfying or even to judge *post hoc* whether the choices made were good ones. Healthcare provides a good example – in cases of diseases such as cancer, it will often be difficult to unambiguously judge whether a patient recovered or died because of or in spite of the treatments. Were negative side effects from treatments avoidable or not? At what point do the negative side effects outweigh any benefits of extending life? Was the ultimate outcome worth the suffering?

Derek Miller's commentary provides a clarification and amplification of our use of the term wicked problems. The problems of sociotechnical systems often involve conflicts of values. These values are often incommensurate in the sense that there is no common metric for integrating them into a unified cost-function or single figure of merit to unambiguously determine the quality of a solution. Miller suggests some examples, including how much liberty we should sacrifice in pursuit of order or security. The critical thing here is that the right balance across competing values cannot be absolutely prescribed independently from the context – including economic, social, political, and cultural considerations – and these contexts are changing, or non-stationary. A balance that is stable in one context or at one time may not be stable in another context.

We would further claim that wicked problems are far more common than is generally thought. Picking a graduate school, buying a house, choosing a mate, diagnosing and treating a cancer patient, and selecting a career path would all fit our concept of what a wicked problem is, due to the trade-off of incommensurate values they require, their non-stationary dynamics, and the size and dimensionality of their possibility sets. This should be even more obvious in the case of larger sociotechnical organizations that are dealing with problems with more global political, social, and cultural implications – managing a national healthcare system, for example.

There may be better terms for characterizing the complex challenges of sociotechnical systems. For example, Simon and Newell use the term "ill-structured problems":

> "Problems are ill-structured when they are not well-structured. In some cases, for example, the essential variables are not numerical at all, but symbolic or verbal.… Second, there are many important situations in everyday life where the objective function, the goal, is vague and non-quantitative.… Third, there are many practical problems – it would be accurate to say 'most practical problems' – for which computational algorithms simply are not available."[12]

The essential motivation behind the use of wicked problems as a term is to counter a tendency for complex natural problems to be trivialized and reduced so that they are tractable or "well structured" relative to the analytic fashions of the day. Consistent with Miller's observation that "the idea of total human fulfillment is a chimera,"[13] we would argue that the hope that sociotechnical problems are analytically tractable or solvable in any absolute sense is a chimera. The best we can hope for is a dynamic stability where the inevitable mistakes that the system makes are at least survivable – satisfactory – and perhaps that the system learns from each mistake, so that fitness generally improves with experience. This leads to a second concern of Dubberly and Pangaro.

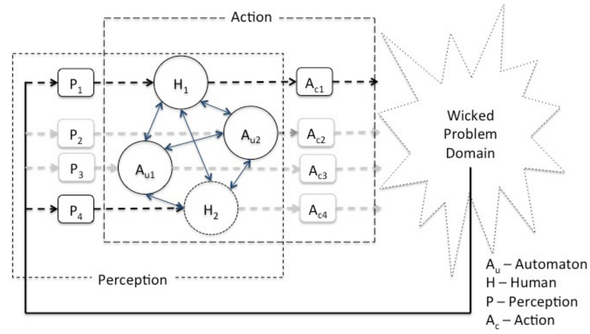

Figure R1 **This figure illustrates a self-organizing dynamic in which the perception-action loop is closed through a complex or wicked problem domain. Image © 2016 by John M. Flach and Kyle J. Behymer.**

Control versus Stability

Dubberly and Pangaro also raised a concern about the fact that there is no explicit goal in our model (Figure 1 in the target paper) noting that a goal is "a key component of any control system model."[14] The omission of any explicit goal is intentional and in fact, we think it is misleading to call this a "control system model." Although this is a circular system, where the consequences of actions feed back as information that can shape future actions, it is definitely not a simple servomechanism. There is no explicit goal, and thus there is no clear basis for computing an "error signal." As noted in the previous section, rather than a well-specified goal, performance in sociotechnical systems is often influenced by a host of diverse values that may or may not be shared by the distributed agents involved in observing the state of the world, and acting upon that world.

Unfortunately, our choice to use the labels "controller" and "observer" in the original figure contributes to confusion about the kind of system we are describing. Thus, we have revised the figure to use the alternative labels of "perception" and "action" (Figure R1). We have also changed the labels on the components to eliminate the label "control." The original choice of terms was intended to emphasize parallels to concepts used in control theory to describe systems. However, we see control theory as a field concerned primarily with understanding stability in closed-loop systems. Thus, our view of control theory may be somewhat inconsistent with the way many social scientists understand it to be – a servomechanism. In our view, control theory considers trade-offs across many potential solutions to achieving stability, where the simple servomechanism is but one of the simpler, more primitive examples.[15]

So what kind of system do we envision in Figure R1? We see this as a self-organizing system. This is particularly reflected in the clash of values described so well by Miller in his commentary. In the dynamic of sociotechnical systems, the stable solutions are not specified *a priori* as goals and/or cost-functions. Rather, the stable solutions typically emerge as the result of contests between competing values. This is more similar to a prey-predator system than a servomechanism. That is, in the same way that stable population levels can emerge from competition in natural ecologies, stable solutions can emerge in sociotechnical systems as a result of competition among diverse values. Lindblom has described this dynamic of sociotechnical systems as "muddling through" or "incrementalism."[16] Solutions typically emerge as a result of incremental adjustments in organizations that are highly resistant to change. This resistance reflects a friction that may often be essential for stability in a complex ecology.[17]

In a self-organizing system, the stable points are not imposed from without – an explicit *a priori* goal – rather, the stable points emerge from the internal dynamics of the coupling. In the prey-predator example, the critical question from a control theoretic perspective is to understand the conditions that lead to stable populations, rather than the collapse of the ecosystem resulting in extinction. In sociotechnical systems, stability will be a function of the capabilities of the distributed organization relative to the demands of the wicked problems. This leads naturally to another of Dubberly and Pangaro's concerns.

Requisite Variety

As Dubberly and Pangaro note, there are two primary sources of variety in our model of a sociotechnical system. One source is the variety associated with the wicked problem. This determines the constraints associated with the possible outcomes that are, in essence, the problem space – like the beach in Simon's classic analogy.[18] The other source is the variety associated with the organization of agents – the ant in Simon's analogy. The key implication of Ashby's Law of Requisite Variety[19] is that complete control – the ability of the ant to go anywhere on the beach – requires that the organization has at least as much variety as the problem space. In other words, if the organization is more constrained than the problem space, there will be some states that will not be reachable. To frame this in terms of the functional components of the organization, lower variety in the organization of agents implies that either there are important discriminations with respect to the problem state that the perception component is incapable of making, or the problem requires some actions or moves that the action component cannot make. In terms of Simon's analogy, for example, constraints on the locomotion capabilities of the ant might make it impossible for it to reach some areas of the beach.

In the classical use of the term satisficing, there is at least an implication that the requisite variety of the unaided human is often less than the problem – there are internal constraints, biases or limitations – that require the human to settle for a less than optimal solution. For example, Flach has suggested that typically no single agent in an organization will satisfy the requisite variety demands for many sociotechnical problems.[20] However, Flach also suggests that it may be possible for a collection of diverse agents – including human and autonomous systems – to satisfy the demands of Ashby's law. However, there is another dimension of variety that connects to the previous ideas of wicked problems and satisficing that Dubberly and Pangaro raise. This is the potential for there to be variety within the organization above and beyond that required to meet the demands of requisite variety.

The difficulty of wicked problems may lie in part with the fact that there is greater variety in the organization than in the problem. One obvious source of this variety, suggested in Miller's commentary, would be differences in the values among the various agents in an organization. For example, even if a solution is satisfactory because the organization remains viable, there may often not be consensus across the agents about whether any particular solution is satisfying. In solving sociotechnical problems, no matter the quality of a solution, there will almost always be people within the organization who are unsatisfied and who will second-guess decisions and actions taken.

Figure R2 illustrates some of the potential relations between variety associated with a wicked problem (solid circle) and variety associated with the organization (dashed circle). The first relation (A) illustrates a bounded rationality in which the variety of the problem exceeds the variety of the organization. In this case, full or optimal control is not possible. However, it still may be possible for the system to achieve a stable equilibrium or to satisfice. In other words, the system may not be able to go everywhere, but it may be able to avoid catastrophe most of the time – for example, through the use of smart heuristics. The second relation (B) illustrates a situation where the organization has more variety than the wicked problem. In this case, full control is possible. On the positive side, the excess variety may allow increased flexibility and redundancy, increasing system stability. On the negative side, the excess variety may be only so much "noise," possibly making it difficult for the system to discover or settle on even a satisfying solution.

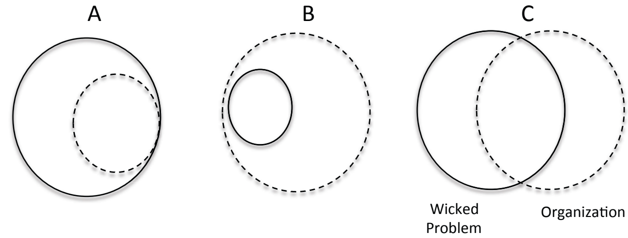

Figure R2 This figure illustrates three possible relations between the variety associated with a wicked problem (solid circles) and the variety associated with an organization of agents (dashed circles). Image © 2016 by John M. Flach and Kyle J. Behymer.

The third relation in Figure R2 (C) illustrates what is probably the most common situation – a partial overlap between the variety associated with the problem and the variety associated with the organization. In this context, it is easier to frame the discussion in terms of constraints, or factors that limit variety. Thus, the constraints associated with the organization are not fully aligned with the constraints of the wicked problem. This implies that the rationality of the organization will be bounded relative to the problem and that there may be internal noise that increases the difficulty of identifying satisfying strategies for achieving stability. The critical point is that in shaping an organization to deal with wicked problems, one must often consider both 1) how to scale-up the limited variety of individual agents to satisfy the requisite demands of the wicked problem, and 2) how to filter out the noise, or extract the signal from the noise that reflects a diversity of opinions within the organization. This leads naturally to the last of Dubberly and Pangaro's concerns.

The Quality of Communications

Dubberly and Pangaro note that our model "does not say much about the nature of communication between the actors, except that it should be 'rich' and 'effective.'"[21] Then they pose the million-dollar question: "How do we achieve it?" In the target paper, we finessed this by providing examples of systems where we feel that the communications were effective (Chef Watson) and ineffective (Clippy). We did this partly because we don't think there is a single, simple prescription for quality communications. The design challenge will always be to align the constraints (variety) internal to the organization with the constraints (variety) of the wicked problems to be solved. As suggested in the previous section, this will involve aligning the internal constraints with the problem constraints, which may require 1) diversifying the organization to scale up the internal variety to meet the demands of Ashby's Law, and 2) tuning the internal constraints to pull out the signal from the noise.

One reason that it is difficult to specify *a priori* rules or standards for quality communications is that communication and language both appear to be dynamic, self-organizing processes. For example, Rączaszek-Leonardi writes:

> "Language is thus claimed to be embodied, situated and distributed, and thus linguistic structures, instead of being independent 'vessels of meaning', are seen as immersed in a variety of dynamical events that give rise to them and are, in turn, controlled by them … communication, instead of being meaning transfer between individuals is rather seen as creating something-in-common, or *communion*, that is, formation of temporal, adaptive wholes, in which individuals coordinate in functional synergies."[22]

With respect to the role of effective communications and collaboration, there is a kind of chicken and egg problem that is always associated with circular dynamics. Each is both simultaneously being shaped by and shaping the other. Effective communication is simultaneously a pre-requisite for, and a product of, effective coordination. Thus, as designers, it may not be possible to predetermine the quality of communications. However, there may be ways that designers can influence or constrain communications in potentially productive ways. One way that designers can do this is to align the internal constraints with the problem constraints through the construction of representations. This is the central focus of Ecological Interface Design – construct graphical interfaces that represent the deep structure of problems in a way that is compatible with users' capabilities – for example, by designing interfaces that represent the aircraft dynamics in a way that is compatible (with a pilot's skills, rules, and knowledge).[23] Such representations are typically constructed using spatial analogs or metaphors. The incorporation of the mouse and the desktop metaphor that transformed the computer from a scientific instrument to an all-purpose personal information system is a classical example of how design can improve the quality of communications between humans and computers. Shneiderman's concept for direct manipulation interfaces is another example of how representations can facilitate coordination between humans and computers to manage complex problems.[24]

Another potentially powerful way to tune the internal constraints of an organization to better match the deep structure of the problem domain is through narratives or stories that reflect the insights of experts in dealing with critical events. Klein, Snowden, and others have found that narratives provide a useful vehicle for both mining expertise and for training.[25] We hypothesize that the reason that analogs, metaphors, and narratives facilitate communications is that they translate constraints of the problem into terms that are more familiar with the agents, making the signals – the problem constraints – more salient relative to the background noise.

Another important consideration in the design of organizations to facilitate communications is the formalization of lines of communication and authority. For example, a major source of discussion in both economic and military systems is the relative benefits and costs of centralization, or hierarchy, relative to more distributed organizations, or networks.[26] The key again seems to be discovering the appropriate balance between internal constraints and the demands of particular problem domains. For example, we can image situations where conversations should be inclusive and collaborative, taking full advantage of the diversity among a network of collaborating agents, as did the puzzle-solving exercises used in the MIT study on group intelligence.[27] However, we can also image situations where the addition of more hierarchical constraints will reduce the internal variety – potential noise – in ways that will facilitate achieving stability. For example, Sage and Cuppan describe a federalist style of organization that can be very effective in helping various agencies – like police departments, fire departments, and hospitals – to coordinate activities in response to regional disasters/emergencies.[28] Thus, our guess is that various organizational forms – hierarchies, heterarchies, networks, federalism – will have different strengths and weaknesses relative to meeting the requisite variety demands for achieving stability in different contexts. There is no single one-size-fits-all solution.

Conclusion

Again, we thank the editors of *She Ji* and the authors of the commentaries for enriching the discussion of design thinking relative to improving the quality of collaborations. As a result of the feedback from the commentaries, we would like to reframe the discussion from "Designing for Effective Collaboration" to "Enabling Effective Collaboration." This is to emphasize the self-organization dynamic of sociotechnical systems. Thus, we are skeptical that it is possible for designers to fully determine the quality of communications or collaborations through *a priori* design decisions. Rather we think that the quality of both will be an emergent property of the system dynamic. However, we think that focusing design thinking on the sociotechnical dynamic – communication and collaboration – rather than exclusively on the technological artifacts – autonomous systems – is critical to enabling quality collaborations to emerge. As Dubberly and Pangaro note, this is not a new or novel insight. Clearly, this was a critical insight that led to the development of personal computers and later developments such as smart phones. Yet, despite this history, this is a lesson that we have to keep reminding ourselves of in order not to become seduced by the growing powers of information technologies and the illusion that with enough computational power it will be possible to completely tame the wickedness that is inherent in a complex world.

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