Systemic Complexity and Sociomateriality—A Research Agenda

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Abstract

This study proposes an agenda—Systemic Complexity—that returns the information systems (IS) field back to its original foundations in systems thinking by focusing on the elements of complexity in systems. It extends previous studies of complexity in IS by (1) emphasizing the material agency of the information technology (IT) artifact and its symmetry with human agency, (2) leveraging existing research traditions in IS using principles of complexity such as nonlinearity and self-organization, and (3) opening the IS field to better understand emergent behaviors of complex systems. The study also argues how these concepts are commensurable with sociomaterial research approaches allowing IS to progress into new directions of research using mutually reinforcing methods in both complexity science and sociomateriality.

Keywords
Complexity science, sociomateriality, IS theory, IS Paradigm

Introduction

This study proposes an agenda for research that captures elements that are already natural to IS but has arguably eluded the focus of information systems (IS) researchers. This agenda, labeled Systemic Complexity, is a call to return to the foundations of the field in the name of systems. We are already very familiar with the notion of "systemic failure" or the need for a "systemic change," but research in such areas are historically not major concerns in IS, at least in comparison to other more "traditional" agendas such as adoption, trust, and IT strategy. Such a state of affairs is ironic given that system-related concerns such as catastrophic failures in software-intensive systems, systemic failures in financial markets and information security have always been major societal concerns. Research in different disciplines have only begun discovering how inherently complex systems can be. Different disciplines approach the general subject in different ways and there is a lot of cross-disciplinary activity studying the complexity of financial systems, biological systems, epidemiological systems, and electrical grid systems, to name a few. This paper proposes to include IS in these cross-disciplinary efforts by defining a focus area that is not yet addressed by other disciplines. The common thread that runs through these systems is the element of information that each of them creates, holds, transports and transforms. For a field that has its title covering both of these terms, "information" and "systems," the IS field is naturally positioned to study these phenomena of systemic complexity, which focuses on information and complexity in systems from the perspective of the material in both the technical and human sciences.

Literature Review of Complexity in IS

Complexity as a research area is making inroads within the IS community, but its impact has been minimal (Jacucci et al. 2006). Merali (2004), one of the earliest introductions of complexity to IS, describes basic concepts from the science of complexity, tools that can be used to study complexity and proposes some foundational ontological and epistemological bases for effectively engaging complexity in IS. Our closest neighbor, the management discipline has a much longer history in this area of research. Led by scholars like Bill McKelvey (1997; 1999), Philip Anderson (1999) and others, the management discipline has studied various organization-related complexity issues such as the complex nature of
organizations, organizational dynamics and organizational designs in complex environments (Dooley and Van de Ven 1999). The latest findings and collections of these works can be found in the SAGE Handbook of Complexity and Management (Allen et al. 2011). Similar concerns are studied by IS researchers published in the Communications of the ACM (Desai 2005). In one study, the healthcare system is viewed as a complex adaptive system that, if understood as such, can be designed to become a spontaneously adaptive and resilient platform capable of reducing errors, waste and delays, improving quality of life, and addressing medical catastrophes such as epidemics (Tan et al. 2005). An earlier article by IS researchers in the same journal (Xia and Lee 2004) proposes dimensions and measures for the complexity in IS development projects.

Two IS journals, the Journal of Information Technology, and Information Technology & People published special issues on the topic of complexity. Information Technology & People’s special issue on "Complexity and IT design and evolution" is aimed at encouraging IS researchers to take complexity more seriously (Jacucci et al. 2006). Nearly all of the articles in that special issue discussed various complex processes in IS. In one article (Benbya and McKelvey 2006a), the IS development process is analyzed as a complex adaptive system, which, if its increasing complexity is not managed appropriately, will result in the failure of the system. The article then applies complexity theory as a frame of reference to propose seven "principles of adaptive success" to better manage the co-evolutionary process of IS development. Another article (Kim and Kaplan 2006) continues the themes of complexity and co-evolution and applies them to the process of implementing large enterprise-wide systems and finds that goal-seeking behaviors of actors in the implementation enacts the complexity within the implementation process as their behaviors co-evolve. A third article (Chae and Lanzara 2006) examines why the change process involved with such large enterprise-wide systems is complex and links the complexity to institutional theory to propose several intervention strategies.

The Journal of Information Technology's special issue on "Using complexity science to effect a paradigm shift in information systems for the 21st century" aims to initiate a debate in the IS community concerning the adequacy of current approaches in dealing with the emergent networked world (Merali and McKelvey 2006). The first article in the special issue uses the emergence of IS, and the networked economy and society, as a central feature in the management domain to introduce complexity science concepts. The article also describes tools available for studying socially embedded systems in IS, in particular, agent-based modeling, which is elaborated using the example of computer-mediated communications in a another article (Canessa and Riolo 2006). The next article (Allen and Varga 2006) views complexity in organizations as a science of evolution in organizational forms, structures, emergent capabilities and features resulting from the interaction of autonomous individuals, which in turn produces mutual responses, hence the term co-evolution. These changes, which take place over time, will impact internally and externally the organization's ontology, epistemology and ultimately its axiology, as the individuals in that organization socially construct them. The authors suggest that it is the IT system surrounding the agents that help construct this reality and become the agents’ IS. Hence, the IS associated with the human agents becomes a critical factor in the coevolution of the complexity surrounding the organization. The notion of coevolution is applied to business process management in one article (Vidgen and Wang 2006), and in another is applied to align IS components to the rest of the organization (Benbya and McKelvey 2006b). Two other articles discuss applying the complexity lens to study organizational forms, bureaucracy (Boisot 2006) and virtual teams (Curieu 2006).

These works provide valuable contributions toward making complexity a new paradigm of research in IS. However, the vast majority of these studies views complexity as a paradigm for the organizational sciences, with IS as a contributing or perhaps enabling element, rather than developing a paradigm of research for IS itself. The implicit assumption in introducing complexity to IS is to "explore the contribution that complexity science can make to fostering such a shift in the IS discipline and its re-positioning in the management field" (Merali and McKelvey 2006, p. 211). A lot can be accomplished by this goal. But a lot more is possible if the research agenda is undertaken alongside and not within the organizational paradigm.
A Brief Review and Distinguishing Elements of Systemic Complexity in IS

Although complexity science qualifies as a new research paradigm in the Kuhnian sense, it is not a unified theory. It is an emerging set of concepts and methods that surfaced as a result of accommodating nondeterministic and non-probabilistic behaviors of natural phenomena that was later adapted for social phenomena (Merali 2004). A useful way of distinguishing complexity science from traditional lay conception of complexity is by contrasting the classical IS approach of top-down design, modularization and control with bottom-up emergence of dynamic change. The former is predicated on clear definitions of sub-system boundaries and causal relationships, persistent organization of elements and a regulation of processes supported by feedback loops that help the system achieve a steady state of equilibrium. Such systems are complicated (e.g. the internal combustion engine), but not necessarily complex (e.g. the meteorological environment). Complexity defines certain systems that have no central controls, no persistent organization of elements, changing sub-system boundaries, and no clear causal path or feedback loops, which makes predicting the outcomes of these systems difficult (Merali 2004; Merali and McKelvey 2006). The saying that "the whole is greater than the sum of its parts" depicts one characteristic of such a system. Not all systems are complex and the focus of this study is on those that are.

Because this paradigm is still emerging, an agreed-upon definition for complexity is still in progress. Lloyd (2001) provides nearly 40 different measures of complexity, each with its own basis and related definition. Nevertheless, most experts can agree that the following characteristics qualify a system as being complex (Mitchell 2009).

1. The system is made up of simple components or agents
2. These agents interact in non-linear ways, in other words, "the whole is greater than the sum of its parts"
3. No central control
4. The system as a whole demonstrates emergent behavior. This emergent behavior may take the form of hierarchical organizations, information processing at the level of the system, complex dynamics of the system, evolution and learning.

Many of these elements are discussed in some detail in Merali (2004) and in many articles in the aforementioned special issues. Other elements are not explained since they do not pertain to the management field directly. What distinguishes this study is the weight given to each of these properties in studying systems. Whereas the management field’s approach is circumscribed by organizational concerns, this study proposes not to limit those concerns and to focus on the nature of complexity in the system in whatever forms that system takes. For example, an individual interacting with his or her social media can be treated as a agent, and the collection of these agents may not make up a formal organization in the classic management sense since there is no central control. Nevertheless, their behaviors have major impacts on society as evidenced by the recent Arab Spring phenomenon.

In other words, this study extends all of these previous efforts and proposes a direction that does not limit the study of complexity in IS to organizational concerns only. At the same time it provides additional perspectives that enriches the study of complexity in systems. This study agrees with Paul Cilliers’ (1998) definition of complexity in systems as not just being complicated (e.g. having a large number of components) but are at least characterized by all the properties of complexity mentioned above. More importantly, each of those properties is handled in the proposed research agenda in ways that makes IS more relevant and significant as it addresses complex phenomena.

Simple Agents

The first distinguishing feature of this study’s proposal for systemic complexity is the focus on the agents within the system regardless of whether they are human or material agents. In the management paradigm with its focus on human agency, the information technology (IT) artifact will tend to be treated as a black box (Orlikowski and Iacono 2001). Systemic complexity treats each material agent as a significant factor in the ultimate behavior and decision making of the whole system. The IT artifact can itself be described
as being complicated and acting locally based on inputs it receives, or it can be analyzed as a subsystem within the hierarchy of organization of the whole system. Depending on the level of detail or closeness in analyzing the system, the research will be able to place a greater focus on the IT artifact, which is acting as autonomous agents within the system.

**Non-Linear Interactions**

This property of complex systems opens a whole new world of opportunity for the IS field because it leverages the enabling capabilities of IT that are already well researched in IS. Complexity science adds depth to the study of IT’s enabling capabilities by providing tools to analyze non-linear interactions and relationships between various IT artifacts and between the human agent and the IT artifact. Other areas in IS that will benefit from a study of non-linear interactions is the study of business process management. Vidgen and Wang (2006) explores this opportunity in the context of services-oriented architectures (SOA) and applies a genetic-based algorithm to better manage inventory.

**No Central Control**

As Merali (2004) suggests, the top-down, centrally controlled approach is becoming increasingly rare in today’s systems. The management field with its inherent paradigm of control and coordination may not be the best source of inspiration for understanding systems that have no central controls. As more information moves to lower levels, and agents are provided more autonomy at work, complexity sciences offers more insights into how systems behave in different circumstances. Using systemic complexity as a research agenda, the IS field can undertake the study degrees of self-organization, how it persists and how to create conditions for it to take place. Much of this self-organization takes place as a result of local information provided to agents. What is required here is a different approach towards understanding how information is provided to and distributed among agents within the system. Since information processing is the unifying framework for understanding self-organization (Mitchell 2009), the IS field is perfectly positioned to undertake this new direction.

**Emergent Behavior**

Perhaps the most interesting outcome of applying this research agenda is the understanding of emergent behavior in systems. As mentioned in the introduction, these are the most prominent phenomena that many experts have failed to predict. Very few economists predicted the many financial crashes that took place in history. Even fewer experts predicted the dot-com crash. These emergent phenomena occur as a result of the hierarchical organization of the system’s components, the act of going over a tipping point as information flowing in the system reaches a certain threshold, featured as the overall complex dynamics of the system. Although we are familiar with the concepts of "systemic failure" or "system catastrophes" the IS field itself has done little to study its causes, its dynamics and how to mitigate its unintended circumstances especially once they are detected.

In summary, our proposed research agenda of systemic complexity extends the existing approach already undertaken by the management field. This approach aligns itself nicely with other cross-disciplinary approaches similar to the efforts by the Santa Fe Institute and other centers of complexity science around the world. It leverages the concepts offered by complexity science that most benefit and is relevant to the IS field and returns the IS field back to its roots in systems thinking.

**Commensurability with Sociomateriality**

Many of the concepts discussed above commensurate well with the sociomaterial approach that is also gaining ground in the IS field (Orlikowski and Scott 2008; Scott and Orlikowski 2013). In addition to the philosophy, approach and methods offered in complexity sciences, sociomateriality offers a complementary philosophy and useful methods and tools for researching systemic complexity in IS. Much of this commensurability comes from the network-centric paradigm that is closely shared by both complexity science and sociomateriality.
**Simple Agents and Performativity**

A distinguishing feature of systemic complexity when viewed from the lens of sociomateriality is the performative nature of material agents or what Barad (2007) calls "agential realism." The natural and social sciences assume that the world is composed of things presumed to exist before its discovery, and that such things can be represented in some way that is independent of the thing in and of itself. This is the core of representationalism, which underpins most of the sciences. A performative understanding of science assumes that knowing does not just come from standing at a distance and representing but rather from a direct material engagement with the world. Representation is necessary but is not the end of science and the study of IS phenomena should include the performative image of the powers and capabilities situated in computers. In fact, the performative paradigm is very natural to humans because we often describe how certain inanimate things are "doing" something as in the "bomb destroyed the city" or the "computer messed my day." Research, especially classical IS research, does not view agency in this way and has focused primarily on human agency. Doing so does not mean that material agency is treated the same way as human agency. They are different because whereas sense making of practice requires referencing the scientist's goals and plans, there is no requirement with regard to nonhuman agency or machines. So human intentionality has no counterpart in the material realm. Although they may be unknown and unpredictable they can be investigated and complexity's agent-based modeling is one such way of doing so. Either way, the notion of performativity is consistent with complexity science because both views the world as not being filled with facts and observations but with agency.

**Non-Linear Network Interactions**

As Barabási (2002; 2012) explains, networks lie at the heart of complex systems, because behind each complex system is an intricate network that defines the non-linear interactions between the system components. Therefore an understanding of complex systems is dependent on a deep understanding of the networks behind them. Epidemiologists study the complex system of disease transmission through networks of people. Sociologists study complex structures of social networks while economics study the behavior of economic and complex financial networks. All of these networks exhibit properties that are non-linear such as small-worldness, being scaled free and resilient (Mitchell 2009). Sociomateriality is based on a relational network ontology in which the phenomena are made up of "intra-acting" agencies. A related network-centric approach, Actor Network Theory (ANT) (Callon 1986; Latour 1987) is closely related to sociomateriality where "an object is an effect of an array of relations" (Law 2000, p. 1), in which humans and technologies are interdependent and symmetrically relevant (Orlikowski and Scott 2008).

**Control, Self-Organization, Reconfigurations and the Mangle**

Actor network theorists (Law 2009) write about the semiotic relationality of the system, where elements define and shape each other. This notion is similar to the concept of coevolution in complexity theory (Benbya and McKelvey 2006b) and the concepts of reconfiguration (Barad 2007) and the mangle (Pickering 1995) in sociomaterality. In reconfigurations, the idea is that heterogeneous components of the system intra-act to enact an object in reality from specific reconfigurations, which Barad calls the "agential cut." Pickering (1995) refers to the "mangle" as human and material agencies which are reciprocally intertwined in "a dialectic of resistance and accommodation" (p. 22) that temporally emerges on the plan of practice. These are all forms of self-organization that are enacted and sustained, not from central control but by the collaboration and intra-action of the system components.

**Agency and Emergence**

Only a fully performative understanding of science and material agency will enable an understanding of emergence (Pickering 1995). Following Foucault's (1972) analysis of the "surface of emergence," Pickering (1995) describes emergence of objects as the result of the relation between different material and human agencies. Hence, disciplines such as criminology emerge from institutions and societies, the material context of the prisons, the authority of the penal code and the intervention of the medical fields (Foucault 1977). Scientific practice is the act of capturing the material agency of machines used in experiments as results emerge. Emergence features prominently in Barad's (2007) description of the agential cut in which entities do not exist independently but emerge as a result of their intra-action. In sociomaterality,
causality is reimagined and since causal relations are thought to be the source of emergence, sociomaterial causality redefines what emergence entails. Traditional causality is about relationships between distinct sequential events whereas sociomaterial causality is about enacting a causal structure from specific intra-actions or reconfigurations. Not only are these relations non-linear but they are mangled where time, space and matter are iteratively produced and performed. As a result there are no singular causes and no individual agents of change and emergence.

Research Agenda

The combination of complexity science and sociomateriality as systemic complexity invites a wide range of possible topics for research, from "algorithmic complexity" commonly studied in computer science and the natural sciences, to "deterministic complexity" (Manson 2001, pp. 406-409), which involves the study of chaos theory and its mathematical cousins. The kind of complexity studies that are most relevant to IS will most likely be located within the study of "aggregate complexity" (Manson 2001), which considers systems of linked components. In systemic complexity, this category of complexity studies is modified to fit the principles of sociomateriality. This research agenda invites the IS field to engage directly with the most significant problems facing humanity, focusing in the niche where information and material systems are already making a difference, but are not being addressed satisfactorily by other disciplines. Typically the environments in which these complex processes are operating are rich with material agents that are producing information that impact the system in unexpected and emerging ways. A small sampling of topics for research in systemic complexity is proposed below:

Globalized economics and financial markets

Financial and economic markets are becoming not only complicated, but also increasingly complex (Rosser 1999). Its complexity can be traced in part as a result of the ever-growing global computer network that operates the millions of transactions taking place at any moment in time. The traditional economic notion of equilibrium is challenged by complexity sciences and studies are being done to better appreciate this new paradigm of continuous change (Arthur 2013). Typically economic and financial studies of computers involve using the computer to simulate or model the economy, not viewing computers as a material agent in the evolution of the socio-technical environment IS studies in this stream of research asks how computer networks might exacerbate or control the sometimes catastrophic changes with a view of lessening economic problems.

Urbanization, food security and epidemiology

As the population of the world continues to urbanize, food security and epidemiological issues become increasingly critical (Chen 2007). Urbanization has direct impacts on food security and increases the likelihood of outbreaks of diseases. All these processes are complex processes that can be managed by understanding how information is consumed and applied in different forms. For example, by creating information networks among agriculturists, food shortages can be alleviated (Niederman et al. 2012). Similarly, uncovering complex networks and interactions among urban population, IS scholars working with epidemiologists can reduce the likelihood of contamination and spread of disease.

Sustainability

As discussed above, a new research paradigm in complexity science affords the IS field with the ability to investigate phenomena with no central controls, no persistent organization of elements, changing sub-system boundaries, and no clear causal path or feedback loops, all of which describe the global ecology and related conservation efforts (Merali and McKelvey 2006). The IS field will be able to draw from a trans-disciplinary framework for sustainability research that recognizes the environment as a critical stakeholder rather than a collection of resources to be managed and exploited (Hovorka and Corbett 2012).
**Security and privacy**

Technical solutions alone are not effective against security and privacy threats. Most other disciplines deal with security and privacy issues from either a technical or social perspective whereas what is required is a holistic solution that views all agents operating within the socio-technical system. Even complexity science by itself will be limited to studying network dynamics, fault tolerance, and large-scale modeling and simulation of security and privacy. The systemic complexity approach includes both human and material agents symmetrically and by not assuming any central control and the existence of only known threats, it will be in a better position to address previously undetectable threats.

**Architectural and human development**

Although computers have had significant impact on human development, treating them as mere tools limit their potential for enriching and improving the quality of life. As noted architect Christopher Alexander (1999) emphasized, software, because of its ubiquity, has a critical role in redesigning the billions of buildings in the world to make them more “whole” and friendly to human life. This challenge of bridging the world of computer science and the world of art and architecture is a natural fit for the research agenda of systemic complexity.

**Systemic failures**

Despite the software industry's 60-year history, software continues to demonstrate systemic failures, sometimes catastrophically. Project management research has shown that sociomaterial approaches offer fruitful insights into the complex sequencing of factors contributing to the failure (Mähring et al. 2004). This new approach is needed to overcome the limitations of viewing software and systems development from narrow disciplinary perspectives.

**Conclusion**

This paper proposes a research agenda as an extension of the works already undertaken under the umbrella of complexity with a new direction—to return back to the origins and foundations of the IS field in name of systems and seriously engage in the science of complexity by leveraging our field's familiarity in both systems thinking and information. We accrue several benefits by doing so: (1) we do not limit ourselves to organizational concerns as is done by the organizational sciences. As a result we are free to apply the principles of complexity that are not necessarily commensurable with management traditions; (2) systemic complexity allows the IS field to focus on all forms of agency, especially material agents (IT artifacts) that have always been our major concern and disciplinary focus; (3) it leverages the IS field’s research tradition in studying the enabling capabilities of various IT artifacts; (4) it takes the IS field into new paradigms of understanding information processing in today's increasingly complex environments, and (5) it guides the field towards relevant IS phenomena that are also societal concerns therefore enhancing the value of IS research. These benefits can be realized by reinforcing this research agenda with the help of sociomaterial approaches that we've shown are consistent with complexity science and provide many additional research benefits.

**References**


