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Introduction to the Special Issue

Using Complexity Science to effect a paradigm shift in Information Systems for the 21st century

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Thomas Kuhn (1962) is famous for his descriptions of science as consisting of long periods of 'normal puzzle solving' separated by brief periods of 'paradigm shift'. Computers have been around for half a century, with Information Systems (IS) in firms existing for several decades. Increasingly, we see various observers complaining about normal puzzle solving in IS (Ciborra, 1994; Orlikowski and Iacono, 2001) at a time when people increasingly spend time in virtual worlds – business people work more and more in virtual teams (VTs), while there are now special programs to rescue teenagers from total emersion in virtual worlds.

In the tradition of exploratory learning, this *Special Issue* is intended to act as a catalyst to stimulate discussion and debate among those who see the need for a paradigm shift in the IS community. To this end, we 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. The motivation for this S*pecial Issue* comes from our observation that the IS and the information technology (IT) landscape is characterized by network dominance and increasing complexity, coupled with the possibility that this heralds a paradigm shift for IS research and practice. For those who are championing the paradigm shift, we think complexity science applications to IS, such as those presented in this *Special Issue*, offer hope.

The network motif is a recursive one. First, the potency of discrete advances in hardware and software capabilities to generate significant change in business and society is realized through the mobilization of network effects. Second, technological advances escalate the potency of network effects by continually enhancing the connectivity and bandwidth of networks. Third, the growth of IT-enabled socio-economic networks is accompanied by globalization and an increase in the number and heterogeneity of players who can affect the dynamics of networks. Recent work elucidating the relationship between network topologies and network dynamics illustrates that the low cost of connectivity supported by the internet means that emergent new network order is cheap. 'Almost free' network changes can bring about transformational changes in the state of the world. (Barabási, 2002; Newman *et al*., 2006). The net effect of this is a perception that individuals and organizations have to deal with a world that is increasingly dynamical, complex and uncertain, and that their actions may have unintended consequences that impact on other parts of the world.

This is reflected in the management literature where there has been a discernible shift from focusing solely on the firm as a unit of organization to focusing on networks of firms, from considerations of industry-specific value systems to considerations of networks of value systems, and from the concept of discrete industry structures to the concept of ecologies. The fact that the terms 'network economy' and 'network society' (Castells, 1996) have become integrated into the management lexicon highlights the extent to which networking developments in the IS domain are implicated in the development of the wider management arena. In particular, this shows up in the literature on competitive dynamics where the network economy is characterized by competition in high-velocity environments, speed of technological change and uncertainty (Eisenhardt, 1990, Li and Atuahene-Gima, 2002). Organizations, needing to shape and redefine their own competitive arena (Hayton, 2005), are confronted with the need to continually innovate (Tushman and O'Reilly, 1996; Autio *et al*., 2000, Hayton 2005). This brings with it the challenges of working towards radical and incremental innovation, (Nambisan, 2002) while dealing with resource constraints (Barney, 1991; McDougall *et al*. 1994; Stevenson, 1999) to achieve an efficacious balance of risk and return. The quest for coherent integration of social, economic, and IT networks has resulted in the convergence of strategy, OD and IS research on issues of information and informating, connectivity, coordination, competition, collaboration, learning and transformation at multiple levels of analysis in the networked world. These developments highlight the importance of trans-disciplinary research, and the strong position of IS research in this context.

Complexity science is viewed as a source of concepts for enabling the trans-disciplinary exploration of complex organization in the network economy and network society, and for explaining the dynamics of networked systems at different levels of description ranging from the micro- to the macro-level. It offers a powerful set of methods for explaining non-linear, emergent behaviour in complex systems.[1] In the IS literature, there have recently been two special issues dedicated to applications of complexity theory,[2,3] both extolling the value of adopting the complex systems perspective in IS research and practice, but despondent at the slow rate of adoption of complexity concepts in the IS domain.

We recognize three basic Schools of complexity science:

European: Prigogine (Nicolis and Prigogine, 1989) and others (e.g., Haken, 1977; Cramer, 1993; Mainzer, 1994) focus on adaptive tension and the first critical value of the imposed energy in physical systems that sets off phase transitions. Prigogine is famous for his emergent 'dissipative structures'. Haken and Mainzer zero-in 'order parameters' that drive new order creation in one way or another at the phase transition. This school is math intensive.

American: The Santa Fe Institute focuses on how new order arises in biological and social systems (Anderson *et al*., 1988; Pines, 1988; Cowan *et al*., 1994; Arthur *et al*., 1997). They focus more on the second critical value at the so-called 'edge of chaos' where new order emerges. Here, new order emerges when heterogeneous agents – such as biomolecules, organisms, people or social systems – are motivated by a drive for improved fitness or learning to initiate connections with other agents. This is all it takes. A key method, computational modelling, begins with Kauffman's work on 'spontaneous order creation' (1969, 1993), resulting from heterogeneous agents and connectivity (see also Merali as well as Canessa and Riolo, this issue).

Econophysics: Here the focus is on how the order creation actually unfolds once the forces of emergent order creation by self-organizing agents are set in motion (Zipf, 1949; West and Deering, 1995; Newman, 2005). Key parts of this third aspect are *fractal structures*, *power laws* and *scale-free theory*. An obvious example of a fractal structure is a cauliflower – its adaptive design is the same from the one large whole cauliflower down to its hundreds of tiny, almost invisible, florets. If plotted, this size-by-frequency ratio forms a Pareto distribution. A power law is a representation of the Pareto distribution in a double-log graph.[4] Andriani and McKelvey (2005) report 80 kinds of power laws, including 40 pertaining to organizations and other social phenomena. Power laws frequently signify underlying fractal structures. Why do fractal structures happen? Andriani and McKelvey (2006) discuss some 15 kinds of scale-free theories explaining why some adaptive phenomena use the same causal dynamic at multiple levels. This is opposite to the practice of using different disciplines in organizations from bottom to top: individuals/psychology, groups/social psychology, networks/sociology, organizations/organization theory, industries/IO economics and population ecology and so on.

The purpose of this *Special Issue* is to explore the utility of complexity science and its concepts in advancing the development of paradigms for IS research in the networked world, and to explore the potential contribution of complexity science to the development of ontological and epistemological constructs deployed to articulate the nature and role of information, IS and IT in the networked world. Our intention in this issue is not to present complexity science as a ready-made paradigm for IS research and practice, but to provoke a debate in the IS community about the adequacy of current approaches in dealing with the dynamics of the emergent networked world, using complexity science as the launch pad for what we hope will be a voyage of exploration in the best of learning traditions.

To this end, we have included papers that showcase the utilization of complexity science concepts to explore problems in the networked world ranging from the micro- to the macro-level, covering issues of IS strategy development, design and utilization. The papers cover the strategic alignment of IS and the cultural and institutional challenges that the new information and communication technologies (ICTs) pose for both state and corporate bureaucracies confronted with the complexities of an increasingly distributed social order.

Our seven articles stretch across the broadest landscape yet seen in the recent use of complexity science to further understand and respond to IS difficulties in organizations. They extend from Weberian bureaucracy and Boisot's Information-Space (*I-Space*) to the use of scale-free theories from econophysics; they reach from epistemology and axiology to a discussion of the advantages of *agent-based* computational modelling; they range from business processes to virtual teams (VTs); and they range from introductory to state-of-the-art complexity concepts. Complexity science is put to use as a post-normal puzzle-solving set of concepts and dynamics aimed at reinvigorating the entire IS fitness landscape. We have ordered the articles as much as possible so that their applications of complexity science build progressively.

Yasmin Merali focuses on the emergence of the IS domain as a central feature of the management research landscape in a networked world. She shows that the emergence of the network economy and network society necessitates a paradigm shift in the IS discipline, and that complexity science offers the apposite concepts and tools for effecting such a shift. To avoid confusing fundamental complexity science concepts with the more colloquial uses of complexity terminology, she provides an introduction to concepts from complexity science for scholars in the IS field who are unacquainted with complexity science. Yasmin then proceeds to explore the utility of these concepts for developing IS theory and practice for the emergent networked world. She starts with an overview of the networked world, highlighting the features that have led to the current interest in complexity science across the management field. Then she defines the information and systems characteristics of the dynamical networked world. The dynamics of emergence are predicated on micro-diversity, and fine-grained representations are essentially descriptive models of the detailed complexity of the world and its dynamics. However, to *understand* the dynamics of emergence, we need to access representations at different levels of granularity and abstraction simultaneously. Computational modelling allows us to discover how macro-level properties and behaviours of systems emerge from micro-level diversity and dynamics. Modelling emerges as the principal research tool for complex systems. Yasmin concludes by discussing the contribution, the complexity science can make to the development of ontological and epistemological frameworks and computational modelling methods for IS in the networked world.

Peter Allen and Liz Varga explain the coevolution of IS and the processes that underpin the construction and development of IT from a complex systems perspective. Their analysis highlights the process of emergence in IS. Evolution operates at the microscopic level; in organizations, this is the individual or agent, and each agent has an idiosyncratic view of the organization, using to some extent personal constructs in dealing with the reality of organizational life. The agents also have their own view as to how they know what they know, that is, an epistemology. Peter and Liz argue that agents' epistemology is their IS, which is seen as more than the IT system they use. The IS of each agent coevolves, by interaction with other agents, based on the agent's view of reality; it adds to the agent's view of reality, it refines it and it enables learning. The interaction of all agents constitutes the organization. Even more importantly, each agent is motivated by different values and interests. This is their axiology. If the motivations of many agents in an organization are similar, we may speak of a shared culture. It is the axiology of an agent that motivates them to learn and develop their IS. This agent-based axiological framework is essential to understanding the evolution of organizations. It is the interaction of agents that build consensus as to the shared reality of the organization, and this in turn affects each agent's ability and motivation to evolve the organization's IS further. In addition, they propose that it is time that IT systems included modelling capabilities, based on multi-agent representations of the organization and its context, to explore and support strategic thinking and decision making.

Max Boisot starts with the question: How did bureaucracies evolve? Bureaucracies in the Weberian mould, whether of the state or corporate type, are rational-legal structures organized to deliver order, stability and predictability. He attributes these changes to post-medieval developments in ICTs. Then he asks: Could the new ICTs that have appeared over the past 20 years have a similar impact on 21st century organizations? And, what kind of challenge does this pose 21st century organizations? To address these questions, Max first presents a conceptual framework, the *I-Space*, which allows us to explore the relationship between how knowledge is structured and how it flows within and between populations of agents. His paper then examines what cultural and institutional challenges the new ICTs pose for both state and corporate bureaucracies, confronted as they are with the complexities of an increasingly distributed social order. Would such a development necessarily presage a further extension of either state or corporate bureaucracy? If not, what might it presage? Ever since Coase's seminal 1937 paper, the options, whether applied at the level of the firm or at the level of the state, have tended to be framed exclusively as either bureaucratic hierarchies or competitive markets. Are such institutional forms our only options? Might the clan-like networks that characterize China's social and economic evolution, for example, point to possible alternatives? To answer these questions, we must first briefly consider how knowledge is structured and shared within and between organizations and how this might affect the way that such organizations get institutionalized. We can then explore the effect that ICTs might have on this process.

Petru Curşeu observes that research on VTs has proliferated in the last few decades. However, he argues, few clear and consistent theoretical attempts to integrate the literature on VTs in a systemic way have emerged. His article uses the complex adaptive systems (CAS) perspective to integrate the literature on emergent states in VTs. According to this framework, VT effectiveness depends on the interaction between three levels of dynamics: local, global and contextual. Team cognition, trust, cohesion and conflict are described as states that emerge from the interactions among the VT members. Furthermore, as parts of global dynamics, they impact on VT effectiveness, and at the same time, they are influenced by the outcomes of the VT. Petru also shows how insights from this bi-directional causality as well as other benefits of using the CAS framework work to improve our understanding of VT dynamics. Finally, his article also provides an overview of artificial simulation models as well as simulation results concerning the emergence of the four states described in the CAS framework. He also discusses several ways to improve the accuracy of the simulation models using empirical data collected in real VTs.

Richard Vidgen and Xiaofeng Wang note that new technologies, notably service-oriented architectures and Web services, are enabling what they call the third wave of business process management (BPM). Other observers claim that BPM is informed by complexity theory and that business processes can evolve and adapt to changing business circumstances. BPM adherents suggest that the business/IT divide will be obliterated through a process-centric approach to systems development. Richard and Xiaofeng first explore the evolution of BPM and its associated technologies. Then they turn to complexity theory for new ideas about how distributed multi-agent processes, emergence, chaos and self-organization will further inform the scientific application of third-wave process management over the coming decade. They use coevolutionary theory to understand the business/IT relationship. Specifically, Richard and Xiaofeng apply Stuart Kauffman's NKC model to a business process ecosystem to bring out the implications of coevolution for the theory and practice of BPM and for the relationship between business and IT. They argue that a wider view of the business process ecosystem is needed to take account of the social perspective as well as the human/non-human dimension.

Enrique Canessa and Rick Riolo state right off that organizations that make use of computer information systems are prototypical CAS. They show how a key complexity science method, *agent-based modelling* (ABM), can be used to study the impact of two different modes of use of computer-mediated communication (CMC) on organizational culture (OC) and performance. The ABM includes stylized representations of (1) agents communicating with other agents to complete tasks; (2) an OC consisting of the distribution of agent traits, changing as agents communicate; (3) the effect of OC on communication effectiveness (CE) and (4) the effect of CE on task completion times, that is, performance. If CMC is used in a broad mode, that is, to contact and collaborate with many new agents, the development of a strong OC is slowed, leading to decreased CE and poorer performance early on. If CMC is used in a local mode, repeatedly contacting the same agents, a strong OC develops rapidly, leading to increased CE and high performance early on. However, if CMC is used in a broad mode over longer time periods, a strong OC can develop over a wider set of agents, leading to an OC that is stronger than an OC which develops with local CMC use. Thus the broad use of CMC results in overall CE and performance that is higher than is generated by local use of CMC. Enrique and Rick end their article with an excellent discussion of how the dynamics generated by an ABM can lead to a deeper understanding of the behaviour of a CAS, thereby allowing researchers to better design empirical longitudinal studies.

Hind Benbya and Bill McKelvey focus on IS misalignment – a significant problem in a changing world. Despite years of attention, IS misalignment remains a critical and chronic unsolved problem in today's complex and turbulent world. They argue that the coevolutionary and emergent nature of alignment has rarely been taken into consideration in IS research and that this is the fundamental reason behind *why IS alignment is so difficult*. Hind and Bill present a view of IS alignment in organizations that draws and builds on complexity theory and especially its focus on coevolution-based self-organized emergent behaviour and structure. This, they suggest, provides important insights for dealing with the emergent nature of IS alignment. Their view considers business/IS alignment as a series of adjustments at three levels of analysis: individual, operational and strategic and suggests several enabling conditions – principles of adaptation and scale-free dynamics – aimed at speeding up the adaptive coevolutionary dynamics among the three levels. Instead of focusing upon simple cause–effect deterministic logic, Hind and Bill suggest a chain of causal dynamics: first, organizational effectiveness is a function of IS alignment; second, IS alignment is a function of coevolutionary dynamics spreading across three levels: individual users, business and IS subcomponents, and top-level business strategy; third, adaptation via coevolution is a function of several first principles of efficacious adaptation; fourth, the first principles are best achieved via scale-free dynamics; and fifth, IS alignment leadership begins when managers set scale-free dynamics in action.

Collectively, these papers provide a 'taster' or sampler for those who are new to complexity science. They show how concepts from complexity theory can be used to explore and yield insights into issues central to the IS domain. It is important to note that we do not see complexity science as *replacing* all the earlier methodological developments in IS: for each of the issues tackled in this *Special Issue*, there exists, in the IS literature, a rich and insightful research base derived from the application of a range of more conventional IS methodological approaches. We *do*, however, maintain that the language, tools and methods of complexity science compel us to make explicit the limitations of traditional approaches in IS, particularly with regard to the dynamics of emergence and the attribution of causality in complex systems.

The compelling argument for complexity science is that it provides a wide and powerful lens to define and move around the multi-dimensional 'problem' and 'solution' spaces in a dynamic way, at multiple levels of abstraction. In the IS domain, we have a legacy of approaches rooted in heterogeneous philosophical schools, and complexity science offers a number of philosophical openings for connecting with these schools (Merali, 2004). The mission of this *Special Issue* is to stimulate a review of the ontological and epistemological bases for the concepts and methods that the IS community subscribes to, and to explore avenues for future developments.

Finally, for IS scholars ready to take the paradigm-shift plunge, we offer complexity science as an apt means for moving toward a more dynamical theoretical and methodological platform better suited for studying IS dynamics at the dawn of the 21st century. Collectively, the authors of the assembled articles provide a meaty introduction to complexity principles along their way toward studies of more idiosyncratic aspects of IS, business and organizational domains.

Notes

1 See Anderson (1999) and Maguire *et al.* (2006) for a review of the utilization of complexity concepts in organizational theory literature, and Merali (2004) for a review of complexity concepts and their relevance for IS.

2 *Communications of the ACM*, 2005, 48(5): Special Issue on Adaptive Complex Enterprises.

3 *Information Technology and People*, 2006, 19(1): Special Issue on Complexity in IS Research.

4 Power laws are also defined by their fixed exponent. They often take the form of rank/size expressions such as $F \sim N^{-\beta}$, where F is frequency, N is rank (the variable) and β the exponent, is constant. In exponential functions the exponent is the variable and N is constant.

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