Understanding Information Systems Complexity: A systematic Literature Review

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Abstract

Rapid changes in digital technologies and business environments have contributed to ever-rising levels of complexity of organizations' information systems (IS). Consequently, it is important to understand what IS complexity is, especially in such a way that our conceptualization of IS complexity accurately captures the characteristics of information systems. We explore how IS complexity is conceptualized in the literature. We base our analysis on three characteristics of IS: the socio-technical nature of IS, the fact that IS are transient, and the interconnectedness of IS. Through our analysis, we have identified three narratives – 'Complexity in Design', 'Complexity in Understanding', and 'Complexity in Use' – that capture the different ways that IS complexity is conceptualized. These narratives help us to explain how, depending on each conception, studies characterize IS complexity in distinct and sometimes contradictory ways; hence different ways of researching and managing IS complexity are suggested. Based on this analysis, we show that there are untapped opportunities to conceptualize and theorize the complexity of open, transient, and socio-technical information systems.

Keywords: IS Complexity, Literature review, Socio-technical systems, Complex adaptive systems.

1 Introduction

Rapid changes in digital technology and business environments have contributed to ever-rising levels of complexity of organizations' Information Systems (IS). Organizational IS landscapes have often grown into complicated patchworks of legacy systems and cutting-edge technologies, hosted both on-premise and in the cloud, and interconnected by a myriad of point-to-point interfaces. This rising complexity of IS presents managers with major challenges regarding the management of their IS landscapes (Lehman, 1980; Widjaja et al., 2012). Understanding these challenges, and how to cope with them, requires an in-depth understanding of what IS complexity really means, and how it is currently conceptualized in the IS community.

Literature that relates concepts from complexity science to IS primarily discusses complex systems as nonlinear systems, composed of many heterogeneous and partially connected components that interact with each other through a diversity of feedback loops enacted by heterogeneous agents (Canessa and Riolo, 2006; Merali, 2006; Shaw and Holland, 2010). The question is, however, to what extent current conceptions of IS complexity take into account the specific characteristics of various information systems, rather than treating them as an example of any kind of system. A more fine-grained view of IS complexity can be obtained by focusing on a number of key characteristics of IS, each of which also presents distinct challenges for IS management and, therefore, may call for very different and sometimes contradictory measures to deal with complexity. These characteristics also imply distinct and sometimes opposing views about what complexity is and what challenges managers face (Beetz and Kolbe, 2011; Widjaja et al., 2012).

We focus on three key characteristics of Information Systems to help us conceptualize IS complexity: their increasingly *socio-technical*, *transient*, and *interconnected* nature. These characteristics of IS make it important for both IS scholars and practitioners to understand the dimensions, characteristics and consequences of IS complexity. The resulting increasing complexity of IS has been found to lead to high costs, problems in Business/IT alignment, and a lack of flexibility, which negatively affect business agility and sustainable competitive advantage (Benbya and McKelvey, 2006; Hsieh and Wang, 2007; Schmidt and Buxmann, 2011; Tanriverdi et al., 2010; Van Oosterhout et al., 2006).

In order to obtain a better understanding of IS complexity, we systematically reviewed the IS literature to examine how different conceptions capture and measure the various aspects of IS complexity, and to what extent the current theoretical understanding of IS complexity is able to support organizations in understanding and managing it. Our review of 30 years of IS literature shows that the topic has been addressed through a highly diverse range of concepts, measured in very different ways, and theorized according to distinct theoretical lenses. In this paper, we organize these diverse views, concepts and measures into three narratives that were found to be predominant across the literature that we analyzed.

Through our systematic review of the IS literature, we make three contributions. First, we chart the different ways in which IS complexity has been conceptualized in the literature and structure these according to three dimensions of complexity. Second, based on the framework, we identify three main narratives that we found in the extant IS complexity literature, helping us to identify the biases and gaps in that literature. Finally, we propose avenues for further research on IS complexity based on a more integrative understanding of the issue.

2 Dimensions of IS Complexity

A classical conception of a complex system is Simon's (1962, p. 468), as a system "made up of a large number of parts that interact in a non-simple way". Nevertheless, IS have certain characteristics that call for a conception of IS complexity that goes beyond this traditional definition to capture the specific and heterogeneous characteristics of IS complexity. In this section, we portray the three main dimensions that help us characterize IS complexity. We derived these three dimensions from the literature to form a framework for understanding different aspects of IS complexity. We show how each dimension highlights particular aspects of IS complexity by providing a specific conception of what complexity means, by focusing on certain aspects of IS that are important for understanding IS complexity, and by raising some specific questions regarding the emergence and management of the phenomenon.

2.1 IS as socio-technical systems: objective and subjective complexity

Early work on IT in organizations is based on a techno-centric or technologically deterministic view of IS (Orlikowski, 1992; Zammuto et al., 2007). This view conceptualizes technology as objective: its characteristics can be measured, and its consequences can be predicted (Hanseth et al., 2006; Widjaja et al., 2012). The classical conception of complex systems referred to above (where complexity is determined by the number of elements in a system and the non-simple interactions between these elements) is in line with this: it implies that the complexity of such systems would also be *objective*, based on objectively identifiable characteristics in terms of number of elements and interactions, and implying that a system's complexity is the same for any actor engaging with the system.

Over time, researchers and practitioners have increasingly realized the importance of the social dimension in successfully developing, implementing, using and managing IS. Therefore, the technologically deterministic perspective has increasingly given way to an alternative perspective based on social determinism. Central to this perspective is the idea that technology is not an objective force, but a subjective social construction: the meaning and use of technologies are the product of ongoing human action and appropriation. This means that technologies are not objective, but "equivoque" (Fulk, 1993), in the sense that they can be interpreted in multiple and possibly conflicting ways. A given system may appear more or less complex depending on who is perceiving and interacting with the system (Canessa and Riolo, 2006; Merali, 2006; Nan, 2011). A conception of IS complexity that is in line with this idea is a *subjective* one, where complexity is "in the eye of the beholder" and largely dependent on the characteristics and capacities of the agent (subject) that is dealing with the system.

More recent approaches towards IS in organizations take more of a middle road here, acknowledging the roles both of social construction and of the technological artifact itself in analysing the role of technology in organizations. Hence, most modern definitions of Information Systems typically conceptualize IS as consisting of both technical system components (hardware, software, connections, etc.) and social system components (organization, users, relationships, etc.) (Alter, 2008; Bostrom and Heinen, 1977a; 1977b; Leonardi, 2013). This means that IS are essentially socio-technical systems, combining material technology as well as social aspects of organizing. This has implications for how we can conceptualize the complexity of such systems: IS complexity is determined by both *objective* (e.g. number of components, number of interfaces) and *subjective* elements such as perceptions, frames and cognitions. IS complexity is thus not merely a matter of the number of components and their interactions, but also involves users and their particular perceptions of what is complex in their use of these components (Benbya and McKelvey, 2006; Vlas and Robinson, 2015).

2.2 IS as transient systems: static and dynamic complexity

A second characteristic of IS that is relevant in conceptualizing IS complexity is their transient nature, which refers to the fact that the technologies on which IS are based, are developing at an increasingly rapid rate – yesterday's cutting edge technology is tomorrow's old fashioned legacy system. This transient nature of digital technologies significantly influences IS complexity since technologies are evolving at an increasingly rapid rate, and are constantly reinterpreted and reinvented. New and ever-changing technologies are introduced to (and decommissioned from) organizations' IS landscapes at an ever-faster pace, often being combined with the legacy systems that have different technological foundations. This makes it very challenging to predict how such systems will work and function in the future. In other words, the transient nature of IS calls for concepts that allow us to understand IS complexity as an evolving, dynamic concept, rather than only a static attribute of the way systems' components are structured.

Where the traditional approach to complexity (Simon, 1962) focuses on a *static* analysis of the number of components and their interactions at a certain point in time, a more *dynamic* view conceptualizes complexity in terms of the emergent properties and behaviours of the system over time. Emergent properties (DeLanda, 2006) refer to properties of a system that may not be easily predictable or explained from the way a system's components are configured. From this perspective, a system can be simple in terms of having only a few components and interactions, but at the same time exhibit emergent properties that cannot be easily explained and predicted. Thus, a dynamic perspective on IS complexity considers complexity to be a behavioural attribute of the system in a specific context of operation. The transient nature of IS requires us to understand IS complexity not only as the way systems are configured and designed, but also in terms of how they actually function when they are put in place and go live in day-to-day organizational practices.

2.3 IS as interconnected systems: bounded and unbounded complexity

The traditional conception of complexity tends to consider IS as closed systems, focusing on the degree of complexity within the boundaries of the system itself (Belardo and Pazer; 1985; Colazo and Fang, 2010; Deng, Fan and Geerts, 2015; Díaz et al., 2001; Hanseth et al., 2006; Kumar and Benbasat, 2004; Mannino et al., 1994). However, developments in the area of networking, service-oriented architectures, mobile technologies, and cloud computing have created modern IS landscapes consisting of a large variety of interconnected technological components that cross the traditional boundaries that used to be drawn around systems and organizations. This leads us to the third characteristic of IS that is pivotal for conceptualizing IS complexity: IS are increasingly interconnected, both within and across technological and organizational boundaries.

The interconnected nature of IS means that boundaries are blurring as organizations increasingly rely on, and are affected by, a growing range of systems and technologies in both their internal and external environments (Christiaanse and Huigen, 1997; Webb and Gallagher, 2009). This accumulation of a wide range of interconnected systems affects the complexity of an organization's IS landscape. This makes it increasingly difficult to determine the scope and boundaries of that landscape, as well as to determine how changes in that landscape are likely to affect its functioning. Hence, the interconnected nature of present-day IS requires a conception of complexity that not only considers complexity within the boundaries of a system or organization (what we call a *bounded* conception of IS complexity), but that also accounts for the interconnectedness of systems across various boundaries, i.e. a more *unbounded* conception of IS complexity.

3 Methods

3.1 Literature scope and selection process

For this literature study we examined journals included in the Association for Information Systems' "basket of eight" leading IS journals by searching for articles that discussed IS or IT complexity between 1983 and 2018. To include the more recent insights emerging in the IS community, we also included the proceedings of the three major AIS conferences, ICIS, AMCIS, and ECIS, over the period 2012-2018. In selecting the literature for this review, we looked for “complex” and “complexity” in the titles, abstracts, or keywords of articles published in these sources. The initial search resulted in 223 articles. We read the abstract of each paper carefully and, if this indicated that complexity was discussed in relation to IS, we read the full text. We selected the papers in which ‘complexity’ was part of the research question or the theoretical model. For conceptual papers, this implied that they considered the complexity of IS (or parts of IS, e.g. software or databases) to be one of the concepts in their conceptual model (e.g. Boisot, 2006). For empirical papers, this implied that at least one construct was related to IS complexity (e.g. Banker and Slaughter, 2000). We excluded papers that merely considered the complexity of non-IS issues – e.g. how IS can help organizations solve complex problems (e.g. Mumford, 2002). Papers were also excluded when they referred to complexity as a tentative characteristic of the study’s context, but did not discuss complexity itself (e.g. Forman et al., 2005). This resulted in 142 selected papers, as listed in Table 1.

Table 1. Selection of the literature

Journals and proceedings	**No. of studies**
European Journal of Information Systems	8
Information Systems Research	7
Information Systems Journal	8
Journal of Information Technology	10
Journal of Management Information Systems	9
Journal of Strategic Information Systems	9
Journal of the AIS	7
MIS Quarterly	15
ICIS, AMCIS and ECIS Proceedings 2012-2018	69

3.2 Systematic review and analysis of the literature

For the systematic coding of the selected papers, we developed a coding scheme to capture the major insights in these papers as they related to (1) our general understanding of the paper; (2) the way in which IS complexity is conceptualized in the paper; (3) the theorization of IS complexity, and; (4) insights regarding managing IS complexity (see Table 2).

Table 2. Coding scheme for analysis of the literature	
Review dimension	**Related questions**
General understanding of the paper	• Main research question and study objectives • Unit(s) and level(s) of analysis • Role of IS complexity in the whole study
Conceptualization of IS complexity	• Definition of IS complexity • Underlying conceptualization of complexity (e.g., structural, behavioral, subjective, environmental, combinations of some, or different) • The underlying IT artifact (complexity of "what"?) • The (specificity of) IS in conceptualizing IS complexity • Operationalization of IS complexity
Theorizing IS complexity	• Underlying theory for studying IS complexity • Causes of IS complexity and their influence mechanisms • Impacts of IS complexity and their influence mechanisms • Dynamics of IS complexity
Managing IS complexity	• Challenges, barriers, and trade-offs in dealing with IS complexity • Practices, strategies, measures, rules, principles, guidelines, and tricks for managing IS complexity

Table 2. Coding scheme used for analysis of the literature.

Based on this coding scheme, we went through four steps in our process of analysing the literature, as outlined in Table 3. Across the studies we analyzed, we found three persistent narratives based on different conceptualizations of IS complexity (see Table 4 for a summary of the narratives). Each narrative articulates a specific way of understanding IS complexity in the literature. Although the boundaries between the narratives are often blurry, they allow us to capture the heterogeneous views in the literature and thus better discuss their assumptions regarding what complexity means, how IS complexity is perceived, studied, and explained, and what specific organizational problems and solutions are discussed. To describe the findings of our literature review, we took these narratives as a starting point, comparing the narratives between the different dimensions of IS complexity and searching for emerging patterns within and across these narratives.

Table 3. Steps in the analysis of the literature	
Steps	**Actions**
Systematic coding of each paper based on the detailed coding scheme	Two initial coders reading through the entire paper and annotating the relevant parts Cross-checking and discussing with a senior scholar; ambiguities discussed and dissolved Checking with a third coder to ensure that the coding is consistent and no relevant insight is missing, resulting in coded papers with extensive extracts and illustrations
Systematic abstraction and summary of the relevant insights across the studies	Using a detailed coding scheme to summarize the insights of each paper Developing the Excel file of all papers coded based on 18 columns Comparing the insights across the papers based on the review dimensions
Mapping the insights of the literature to the complexity views and identifying emerging narratives	Mapping literature insights to different complexity dimensions (socio-technical, transient, interconnectedness) based on the studies' conceptions of IS complexity Carefully examining the insights regarding the interactions between different dimensions Inductively articulating the narratives that synthesize the insights of a set of studies that share similar conceptions of IS complexity Identifying recurring narratives within the literature to structure the reporting of literature insights and map these narratives to the studies Defining different themes that are covered in the literature within each narrative
Reflection on literature narratives and discussing the gaps and potentials for future research	Making qualitative and quantitative analyses of the narratives used in the studies Reflecting on the biases and limitations of each narrative and their associated qualitative insights Reflecting on the completeness of the narratives based on concepts such as sociomateriality, time, and openness in order to examine how the literature can advance by being more specific with regard to the characteristics of *IS* complexity

4 Findings: Three narratives of IS complexity

From our analysis of the literature, three main narratives emerged that capture the scholarly discussion on IS complexity. For each narrative, we describe how IS complexity is conceptualized, how it is theoretically framed and what practices organizations can adopt in order to manage IS complexity.

4.1 Complexity in Design

The "Complexity in Design" narrative is based on a conceptualization of IS complexity as determined by the number of technological components and their relations as they are designed and configured in organizational IS landscapes. Overall, the Complexity in Design narrative is the most prevalent narrative we found in the literature, reflected in about half of the reviewed studies. In this narrative, complexity is considered to be intrinsic to the design and architecture of systems, and manifests itself in difficulties of managing and using technological components and relations. Concepts such as modularization, granularity, amount of interdependencies, and the level of interaction between these components are used to indicate and explain IS complexity (Aggestam and Van Laere, 2012; Banker and

Table 4. Narratives on IS Complexity

Narrative	Themes within the narrative	Complexity dimensions	Measures of IS complexity	Approaches to managing IS complexity
Complexity in Design IS complexity determined by the number of technological components and their interactions in the way that these are designed and combined in the IS (landscape).	• Number of components and interactions in the system's design. • Extent to which the system's design makes it difficult to work with. • Extent to which system design makes it more difficult to make changes to the system and leads to complex IS projects.	***Objective***: Inherent characteristics of the technology. ***Static***: Focus on how system looks at a certain point in time. ***Bounded***: Clearly defined collection of components and interactions.	• Based on number and heterogeneity of components and their interactions. • Based on how systems are configured and the interactions between components.	• Reduce the number of components and interfaces. • Apply modularization and loose coupling. • Introduce hierarchy in network structure. • Limit data linkages. • Design to specific audience and context. • Align organizational and technical design.
Complexity in Understanding IS complexity is conceptualized in terms of the perceptions and frames of different actors and groups of stakeholders and the extent to which IS are perceived as complex, difficult to understand, hard to use.	• Focus on users' perceptions and social aspects like emotions, culture, framing, and group interactions defining heterogeneous perceptions of IS complexity. • IS complexity is subjectively defined by different groups of actors' cognitive capabilities that are required to work with the system.	***Subjective***: IS complexity as a social construction in terms of perceiving, adopting and using IS. ***Static***: The perceptions and experiences are mainly studied at specific points in time. ***Bounded***: The focus is primarily on the individual systems that users directly interact with.	• Based on the way social actors construct the complexity of the system. • Based on examining the various frames, meanings and perceptions that different users have about the system.	• Include perceived ease of use, usability and task complexity as part of the acceptance criteria. • Provide training programs to reduce (perceived) task complexity. • Reuse existing (and familiar) building blocks in systems design. • Make visualizations to provide insight into how to use the system. • Invest in understanding stakeholders' interests.

Complexity in Use IS complexity is defined in terms of the behavior of the system that emerges when it is put to use.	• The complex behavior of systems is a result of the heterogeneity of their technical characteristics. • IS complexity results from users interacting with systems in unexpected ways and emerges in the interaction between systems and users.	***Objective & subjective:*** It emerges from how systems are configured, as well as in the interaction between systems and users. ***Dynamic:*** Evolves over time in interaction between various technical and social subsystems. ***Semi-bounded:*** Acknowledges that a system does not exhibit behavior in isolation, but focuses on the behavior of a well-defined system.	• Based on the explanation of the way systems behave and on understanding why such an emergent property/behavior happened. • Based on prediction of the potential range of unintended/emergent behaviors; i.e., the space of anomalies. • Based on the extent to which the anomalies can be controlled, once they have emerged.	• Use decomposable system design for rapid change and adaptation to improve IS performance. • Run simulations and tests to understand and predict the (nonlinear) properties of IS. • Use simulations to improve the adoption and use of systems. • Measure software performance to understand, monitor, predict, and improve the system’s behavior. • Improve context awareness during system development. • Focus on post-implementation phase and consider different implementation approaches depending on the expected task complexity for users.

Slaughter, 2000; Hanseth et al., 2006; Retana et al., 2012; Reggiani et al., 2010; Subramanyam et al., 2012; Travica, 2015; Um et al., 2013; Xu et al., 2014). Besides the number of technological components and interactions, the heterogeneity of the technological elements within IS is also a determinant of IS complexity. Box 1 provides an example of this narrative.

Box 1. Example of the Complexity in Design narrative
Subramanyam et al. (2012) investigate the performance outcomes of the design, development, and implementation of 92 business software components of a firm's ERP planning product. They find that the complexity is defined by the component granularity based on code volume (component's overall quantity of source code written in programming language), functionality (range of distinct business process operations), and interdependence (interrelationship of a component with a collection of other components). Coarse-grained components would require more development effort than fine-grained components, and coarse-grained components tend to increase complexity and place additional cognitive burdens on the programmers involved.

The Complexity in Design narrative has a technologically deterministic orientation, as it conceptualizes the core of IS complexity as intrinsic to the way the technology is designed. This also means that the narrative leans towards an objective conceptualization of complexity – complexity is an inherent characteristic of the technology that can be determined based on the number of components and interactions between these components (Banker and Slaughter, 2000), and the configuration of subsystems (Cui et al., 2012). The Complexity in Design narrative also rests on a primarily static conceptualization of complexity: studies within this narrative frame complexity in terms of the way technological components and their relations are configured (Dörbecker et al., 2015; Gill, 2013; Lee et al., 2015; Retana et al., 2012; Schneider et al., 2014; Schuetz et al., 2013; Schuetz et al., 2013B; Thalmann et al., 2012; Um et al., 2013; Widjaja et al., 2012). Finally, this narrative takes a primarily bounded perspective of IS complexity. In order to be able to evaluate the complexity of technological design, it is necessary to determine the boundaries of that system: what aspects are part of the collection of components and interactions that we are considering at a certain point in time? (Banker and Slaughter, 2000; Colazo and Fang, 2010; Reggiani, et al., 2010; Rossi and Brinkkemper, 1996).

The technologically deterministic character of this narrative is clearly reflected in the proposed solutions and approaches to managing or reducing complexity, which focus on design approaches aimed not only at improving the design of the technology itself, but also at aligning technology, organization, and users. We find approaches to reducing the number of technical components and interfaces and to following architectural principles in order to understand the impact of the technical design on IS complexity. Examples of such approaches include applying modularization and loose coupling in system architecture (Benbya and McKelvey, 2006; Hanseth et al., 2006; Mannino et al., 1994; Mikusz, 2015; Orman, 1991; Shaw and Holland, 2010), reducing the number of heterogeneous components within a system (Dörbecker et al., 2015; Schuetz et al., 2013; Widjaja et al., 2012), introducing hierarchy into network structure (Reggiani et al., 2010), quantifying and mapping the components (Schuetz et al., 2013; Widjaja et al., 2012), and limiting data linkages (Fuerstenau and Glaschke, 2015; Subramanyam et al., 2012). Other approaches focus on tailoring technological design to specific audiences and contexts (Deng and Poole, 2010; Geissler et al., 2001; Gosain, 2004; Merali et al., 2012; Nan, 2011), and aligning organizational design with (changes in) technological design (Bygstad et al., 2015; Vessey and Ward, 2013).

Studies focus on the design of change and implementation projects in line with technological design, and suggest solutions in terms of gaining insight into the role and position of stakeholders during decision-making and implementations (Cameron et al., 2015; Natu and Kennedy, 2012; Sharma and Yetton, 2007), improving oversight by listing and comparing different IS projects and the impacted technical components within organizations (Kottemann and Konsynski, 1983; Piccinini et al., 2014), and learning from past experiences (Allen and Varga, 2006; Chua et al., 2012; Weidong and Lee, 2005) to address the complexity of IS projects in the future.

4.2 Complexity in Understanding

The second narrative that emerged from our review conceptualizes complexity in terms of the perceptions of different stakeholders: the extent to which IS are perceived as difficult to understand (Farbey et al., 1999; Kung et al., 2013; Li et al., 2011; Lycett and Paul, 1999; Picoto et al., 2012; Troshani and Goldberg, 2012; Webb and Gallagher, 2009). In this narrative, IS complexity is mainly based on the people who interact with an IS are an integral part of the system and their perceptions and experiences are the main criteria for defining what is “complex”. As Lycett and Paul (1999) state: “The system is defined by the observer and is not something that is necessarily objectively given” (p. 128). Different stakeholder groups have different technological frames (Orlikowski and Gash, 1994), leading to different levels of perceived difficulty of IS (Picoto et al., 2012; Li et al., 2011). Therefore, instead of assuming that there is one specific level of complexity for a given system, studies that follow this narrative recognize that given the heterogeneity of actors, the same system can be perceived as more or less complex (Benbya and McKelvey, 2006; Troshani and Goldberg, 2012). This applies to specific systems and technologies (Deng and Poole, 2010; Hsieh and Wang, 2007; Maier et al., 2012) as well as to individual IS projects (Farbey et al., 1999; Schefe and Timbrell, 2013).

Contrary to the Complexity in Design narrative, this narrative is based on social determinism since it conceptualizes IS complexity as a social construction, as the product of ongoing human action and appropriation. Consequently this narrative is based on a subjective notion of complexity, conceptualizing complexity not as being inherent to the technology and its design, but as inherent to the agents interacting with the technology – their cognitions, perceptions, emotions, etc. IS complexity is conceptualized as being constructed by users in their perceptions and experiences (for instance, regarding ease of use) (Krancher and Dibbern, 2012; Li et al., 2008; Mennecke et al., 2000). As a result this narrative draws attention to what it is that influences these perceptions and experiences, and to how these mutually influence each other (Lycett and Paul, 1999; Troshani and Goldberg, 2012; Webb and Gallagher, 2009).

The Complexity in Understanding narrative also builds on a primarily static conceptualization of IS complexity. Although studies do pay attention to the dynamics influencing perceptions and experiences, and to the mutual influence between the two, these perceptions and experiences are mainly studied for a particular system at a specific points in time. Finally, this narrative conceptualizes IS complexity in a primarily bounded way, as the focus is primarily on the individual systems that are introduced to users and with which these users interact. Box 2 presents an example of this narrative.

Box 2. Example of the Complexity in Understanding narrative

Li et al. (2011) take the view that specific causes of IS complexity lie in the fact that new information technologies such as instant messaging provide interruptions between tasks and provide additional information, both of which are likely to increase perceived task complexity as this is dependent on information processing capacity. They suggest "that understanding process satisfaction provides pragmatic insights into whether employees will accept IM technology in a voluntary setting and, perhaps more importantly, help management decide whether and how to deploy IM successfully in the workplace to increase employee satisfaction".

In line with the social and subjective character of IS complexity, the literature that follows this narrative suggests that managing IS complexity primarily entails paying attention to the perceived ease of use, usability, and task complexity of systems as part of the acceptance criteria. This should reduce the perceived complexity of IS and consequently ensure higher rates of IS adoption (Bacic and Henry, 2012; Cui et al., 2012; Lambeck et al., 2014; Mennecke et al., 2000; Weidong and Lee, 2005). These studies often find a mismatch between the required and the available knowledge of heterogeneous actors, and consequently call on designers and developers to improve stakeholder interaction when introducing new systems (Sharma and Yetton, 2007; Webb and Gallagher, 2009). Concrete measures to address IS complexity that can be derived from studies in this narrative are: providing training programs to reduce (perceived) task complexity (Sharma and Yetton, 2007); reusing existing (and familiar) building blocks in systems design (Lycett and Paul, 1999); making visualizations to provide insight into how to use systems (Bacic and Henry, 2012; Lambeck et al., 2014), and; investing in understanding stakeholders' interests (Kung et al., 2013; Lambeck et al., 2014).

The social emphasis of the Complexity in Understanding narrative means that this narrative considers the users of systems to be a central element for understanding and managing IS complexity, focusing on subjective elements such as perceptions and frames. Since these subjective elements are more difficult to measure, the narrative does not provide many concrete measures or metrics of IS complexity. Because the object of complexity consists mainly of specific IS applications (rather than an organizational IS landscape), this narrative focuses mostly on specific technologies like websites, mobile devices, and e-health applications (Deng and Poole, 2010; Li et al., 2011; Nadkarni and Gupta, 2007; Picoto et al., 2012; Troshani and Goldberg, 2012). The social determinism inherent to this narrative leaves little room to unpack the underlying technological characteristics of the systems that influence the tasks and knowledge implied or required by a particular system. In fact, the studies in this narrative tend to "black box" technology itself.

4.3 Complexity in Use

The third narrative, Complexity in Use, defines IS complexity in terms of the behaviour of a system when it is put to use. Here, complexity is conceptualized as resulting from the fact that IS behave in unpredictable ways because they are transient, dynamic, and interconnected (Gosain, 2007; Hassan, 2014; Jarke et al., 2011; Perrow, 1961). Studies that reflect this narrative build on the idea that systems have emergent properties since "complexity defines certain systems that have no central controls, no persistent organization of elements, changing subsystem boundaries, and no clear causal path or feedback loops, which makes predicting the outcomes of these systems difficult" (Hassan, 2014, p.3). Box 3 provides an example of this narrative.

Box 3. Example of the Complexity in Use narrative

Jarke et al. (2011) recognize that the complexity of systems fundamentally arises from the existence of multiple uncertain futures that relate to software systems, and that the behavior of the overall systems is surprising and hard to predict. In addition, the evolving nature of information systems, which consists of human, social, political, economic, technological, and organizational factors, contributes to its complexity when IS are actively used in organizations. One way of coping with the complexity in use is to design systems based on simpler principles of self-organizing sub-systems that enable rapid change by allowing constant and natural reorganization of these sub-systems.

In terms of managing IS complexity, the Complexity in Use narrative points towards different techniques for understanding and predicting the emergent behaviour of systems in use. For instance, some studies describe how applying different types of simulations can help to obtain a better understanding of how a system might behave under different circumstances (Allen and Varga, 2006; Burns et al., 2012; Díaz et al., 2001; Hassan, 2014; Roberts et al., 2004). In addition, various studies connect with the Complexity in Design narrative as they emphasize how particular architectural designs may allow for anticipating and rapidly adapting to IS performance in use. For instance, introducing decomposable system design (Jarke et al., 2011), improving context awareness during system development (Mikusz, 2015), testing software to understand performance (Geissler et al., 2001), and measuring software performance to understand, monitor, control, predict, and improve the system's behavior (Díaz et al., 2001) are examples of practices for managing complexity.

Other studies suggest that organizations can manage IS complexity by focusing on understanding the interactions between various subsystems, the relationship between user knowledge and system usage (Gray, 2000), the effects of training programs (Webby and O'Connor, 1994), and the use of simulations to improve the adoption and use of systems (Gray, 2000). This draws managerial attention towards the post-implementation phase, and towards considering different approaches depending on the expected task complexity for system users (Ghobabi and Campbell, 2012; Hsieh and Wang, 2007; Najjar and Bui, 2012; Read et al., 2012; Sharma and Yetton, 2007). Studies in this narrative suggest explicating the logic of systems usage (to users) and increasing the understanding and usage of the system (Bowen et al., 2009; Cervera et al., 2015; Gray, 2000; Nan, 2011).

5 Discussion

In this section, we critically reflect on the reviewed literature by asking to what extent the IS complexity narratives account for the specific characteristics of information systems. We map the narratives along the three dimensions that characterize IS complexity: objective–subjective, static–dynamic, and bounded–unbounded. By so doing, we show that the increasingly transient and interconnected nature of IS is reflected in the literature only to a very limited degree. We therefore suggest ways in which future studies can build on more integrative conceptions to advance our current conceptualizations of IS complexity.

5.1 Beyond the objective-subjective dichotomy

The narratives take different positions regarding the objective-subjective dimension of IS complexity. The Complexity in Design narrative leans towards the objective side of this dimension, since it focuses on the number of components and interactions that are inscribed into the (often technological) design of the systems. The subjective side, on the other hand, is central to the Complexity in Understanding narrative since this narrative highlights how IS complexity depends on the subjects that interact with the system. The Complexity in Use narrative covers both the objective and subjective sides, and thus seems to acknowledge the socio-technical nature of IS more explicitly than other narratives. With the emergence of studies in the latter two narratives, the IS literature is moving away from the classic view of complex systems that often assumes that complexity is inherent in the objective configuration of systems' components and the way these are interconnected in the system's architecture. More recent studies that use the Complexity in Use narrative particularly embrace the integrated socio-technical nature of IS in their conceptualization of complexity.

Something that can be explored still further is specifying in more detail the different ways in which the subjective and objective aspects of IS complexity may interact. In particular, there may be situations in which acting on objective complexity is in contradiction with the practices that accommodate subjective complexity. In practical terms, there is a trend towards the modularization of various technological components to reduce objective complexity when the resulting components are more loosely coupled with each other and interact through standard interfaces (Dörbecker and Böhmann, 2015; Dörbecker et al., 2015; Mikusz, 2015; Shaw and Holland, 2010; Subramanyam et al., 2012). However, a more componentized architecture can be more difficult to understand than the previous meshwork of various technologies, because previously each user was able to make sense of the particular technological components with which they were familiar. Obviously one perspective is not by definition better or worse than the other, but it would be valuable to combine these perspectives in order to more fully understand the consequences of componentization for IS complexity, as well as why the effects of such architectural changes are often so ambiguous and difficult to predict.

5.2 Beyond the static view

Regarding the static–dynamic dimension there is a general emphasis on a conceptualization of IS Complexity as a static phenomenon. Both the Complexity in Design and Complexity in Understanding narratives focus on a static conceptualization of IS complexity. The Complexity in Use narrative recognizes the dynamic aspects of IS complexity regarding how systems behave unexpectedly when they are put into use. We see that the in-depth exploration of the dynamic aspects of IS complexity is still at an early stage; there is limited exploration of how nonlinear and emergent behaviour contributes to IS complexity and how it can be managed to reduce IS complexity.

The emerging literature that conceptualizes IS in terms of Complex Adaptive Systems (CAS) (Benbya and McKelvey, 2006; Burns et al., 2012; Canessa and Riolo, 2006; Curseu, 2006; Hanseth and Lyytinen, 2010; Merali, 2006; Nan, 2011; Onik, Fielt and Gable, 2017; Read et al., 2012; Tanriverdi, 2010; Vessey and Ward, 2013) is promising here, as it focuses our attention on dynamic aspects such as emergence, non-linearity, and coevolution within dynamically interacting networks of components

(Holland, 2006). Again, the componentization of IS architectures (as in Service Oriented Architectures) can serve as an example of how a more dynamic conceptualization of IS complexity can help in the practice of managing IS complexity: while rationalizing the number and variety of systems can be a valid approach from a static point of view, a more dynamic conceptualization of complexity can show how complexity may increase when (part of the) functionalities of systems are moved to some of the remaining components in the landscape, possibly making these more unpredictable in their behaviour as a result of these new additional functionalities.

5.3 Beyond the bounded bias

The literature tends to focus on a bounded conceptualization of IS complexity. The narratives we found in the literature predominantly assume that systems have identifiable boundaries that set the systems apart from their environment. The Complexity in Design and Complexity in Understanding narratives explain the IS complexity of a particular system, but generally do not consider components (either technical or organizational) outside the boundaries of that system. The Complexity in Use narrative, although recognizing how the interactions between various subsystems (either technological or social) give rise to complex behaviours of IS, still focuses on the assumption that systems have more or less identifiable boundaries.

Some studies have taken initial steps to recognize IS as open systems that have interactions with their environment (Allen and Varga, 2006; Jarke et al., 2011; Lycett and Paul, 1999; Nan, 2011). However, they still assume that we can identify the boundaries around these systems. Nevertheless, the more interconnected nature of modern IS goes hand in hand with the trend towards open, collaborative modes of IS governance that confront organizations with situations in which the boundaries of the systems are difficult (if not impossible) to define ex-ante.

Again, we see promise in the emerging literature based on CAS, as it explicitly builds on a conceptualization of "systems" as being composed of large numbers of components that interact and adapt, undergoing constant change – both autonomously and in interaction with their environment (Holland, 1995; 2006). In practice it is helpful to embrace an unbounded conceptualization of IS complexity, especially when organizations cannot draw a boundary around the technological components and organizational practices and stakeholders that interact with each other. For instance, various 'standardization' approaches that aim to impose a universal standard upon technologies and systems integration assume that the boundary of the systems is defined (Fuerstenau and Glaschke, 2015; Lee et al., 2015). Yet a more unbounded conceptualization considers the emerging interactions between various components or subsystems and thus can accommodate more flexible approaches towards managing multiple technological developments such as, for example, different SaaS and Cloud solutions that come onto the market (Kung et al., 2015).

5.4 Towards an integrative understanding of IS complexity

Based on our review of the existing literature, it becomes clear that IS complexity is a multidimensional concept and that the different dimensions interrelate. It is not only each of the three characterizing dimensions but also their interactions that define IS complexity. In fact, we can see these dimensions as conceptually orthogonal axes that together create a "space of possibilities" for various types of information systems, and therefore for various ways of conceptualizing their complexity. As we discussed in the previous sections, the literature so far seems to be skewed towards certain corners of this space. In particular, Complexity-in-Design focuses on the objective–static–bounded corner; Complexity-in-Understanding inhabits mainly the subjective–static–bounded corner, and Complexity-in-Use focuses on the subjective/objective–dynamic–semi–bounded corners. However, there are various other corners that have been understudied in the literature, despite the fact that they are becoming more and more crucial for organizations.

In general, the literature on IS complexity has a tendency to focus on the static and bounded conceptualizations over the dynamic and unbounded ones. In light of the increasingly transient and interconnected nature of IS, this presents a relevant challenge to the field: in addition to the narratives that we found, the IS field should dedicate more attention to conceptualizing and studying the dynamic and unbounded aspects of complexity (Vlas and Robinson, 2015). This is not to say that current (and valuable) conceptualizations of complexity should be abandoned; it is specifically in the integration across various narratives that a better understanding of IS complexity can be created. These other potential narratives can be developed and used for further understanding of IS complexity. In this section, we discuss some of these opportunities for future research.

In order to obtain a fuller understanding of IS complexity, it is valuable to integrate the insights from the different narratives that we identified in the literature (as well as those that should be further developed) and create a more integrative vision of IS complexity. This is not to say that every conceptualization of IS complexity should include the extreme end of all the dimensions: we suggest considering the specific organizational context in which IS complexity must be managed, and taking a situational approach to applying the relevant aspects of the different dimensions. In fact, each specific context within an organization may require a specific combination of different dimensions of IS complexity.

As a potential theoretical lens, we would like to highlight the possible contribution of Complex Adaptive Systems (CAS) to understanding the dynamic and unbounded aspects of IS complexity. In fact, the principles underlying CAS can also provide a starting point for a more integrative perspective on IS complexity. As Merali (2006, p. 224) argues, "the CAS framework provides a unifying frame to articulate the technological and the social across multiple levels of organization", as it encompasses different levels of complexity – from the societal to the technological. A CAS is conceptualized as consisting of an interacting network of loosely coupled components (or "agents"), where the behaviour of the system as a whole emerges from the interactions between these components. This behaviour is non-linear (changes in the system cannot be predicted from changes in the components) and is characterized by coevolution (each component influences and is in turn influenced by all other related components in the environment).

This approach integrates the objective and the subjective dimensions as it is built on the premise that system components and their interactions are the foundation of complexity (in essence, an objective view of complexity) and that these can be defined and classified at a certain point in time (Allen and Varga, 2006). In fact, one particular stream of CAS-based research is aimed at representing complex systems through mathematical and computational models (Nan, 2011; Onik, Fielt and Gable, 2017). At the same time, the interaction between components is central – which implies an interaction between both technical and social subsystems (Merali, 2006; Vessey and Ward, 2013), and explicitly addresses the subjective aspect of complexity. Merali (2006), for instance, describes how IS can be conceptualized as "cyber-socio entities", incorporating societal, group, individual, informational, and technological perspectives on complexity. Next, CAS posits that systems are inherently dynamic in that (co-)evolution of components or subsystems is central, and that complex behavior emerges in the interaction between components (Benbya and McKelvey, 2006; Merali, 2006). At the same time, this does not exclude the possibility of observing these components and their interactions at a certain point in time in order to obtain a static "picture" of the system at that point in time (Allen and Varga, 2006). In addition, CAS highlights that systems are inherently unbounded in the sense that it is the adaptation and interaction of components that is central, and the constant change they undergo, both autonomously and in interaction with their environment. In fact, Merali (2006, p. 224) identifies a shift in focus from one "on discrete bounded systems to focusing on networks" as a central tenet of her CAS-based perspective on IS. On the other hand, identifying these components at times requires a bounded view of complexity, defining (and redefining) boundaries, as it is the change both within and between these components – and their environment – that gives rise to the emergent behavior of the system. This is in line with the central premise of complexity science that "there is a system boundary" and that "we can define and classify the content of the system" within that boundary (Allen and Varga, 2006, p. 231).

As Onik et al. (2017) argue, the use of the CAS perspective has been rather limited and fragmented until now. As mentioned above, we did find some applications of this perspective within the second sub-narrative in the Complexity in Use narrative, but not in a very systematic or consistent way. Special issues of the Journal of Information Technology (Merali and McKelvey, 2006) and Information Technology and People (Jacucci et al., 2006) were dedicated to explorations of its use in the IS field, and CAS has been used in IS research, for instance on business-IT alignment (Vessey and Ward, 2013), agile software development (Vidgen and Wang, 2009), IS development (Allen and Varga, 2006), and IT use processes (Nan, 2011). Seeing the potential it provides for a more integrative view of IS complexity, we conclude that more use of the principles of Complex Adaptive Systems in research into complexity in relation to IS seems a fruitful avenue towards achieving a deeper and more complete understanding of the phenomenon. By conceptualizing more dynamic and unbounded IS complexity, we may be able to envision new and potentially more effective ways of dealing with IS legacy.

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