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Towards a Complex Adaptive Systems Roadmap for Information Systems Research

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Completed Research Paper

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Abstract

Complex adaptive systems (CAS) theory conceptualises a system composed of heterogeneous agents, which interact with each other to adapt to the environment. CAS concepts have been applied in several Information Systems (IS) referent disciplines over the last decade to study complex phenomena in strategic management, social science and organisational research. The application of CAS theory in IS is more recent, wherein researchers have studied complex phenomena including agile processes, systems dynamics and IS alignment. Though CAS has gained some traction with IS researchers, general understanding of the potential of CAS, and its methodological and theoretical applications in IS research, is yet partial and fragmented. The aim of this study is to develop a roadmap for applying CAS in IS research, to analyse the key research objectives with CAS in extant IS research, and to identify methodological and theoretical approaches that researchers follow in conducting CAS-based IS research. To achieve this, we review IS papers published 2002-2014 inclusive in top IS outlets. We analyse the papers based on a supportive theoretical framework and identify eight main objectives of applying CAS, three methodological approaches, and two theoretical approaches related to CAS-based research in the IS discipline. The study reports several valuable observations, including the relative versatility of computational studies over other studies, the minimal use of CAS in design research, methodological triangulation, and theoretical triangulation in IS research. We propose several guidelines for future researchers.

Keywords: *Complex adaptive systems theory, CAS roadmap, CAS objectives, Methodological-theoretical approaches, CAS in IS.*

Introduction

Complex adaptive systems (CAS) (Holland, 1995) is a special branch of complexity science, mostly rooted in the work of the *Santa Fe Institute*, that provided a new way of thinking about systems as being comprised of agents that interact with each other, behaving according to defined rules. CAS aids in the study of how a complex system can be adaptive to its environment and how order or properties emerge from the interactions of its lower level components (Vidgen & Wang, 2006). The elements and properties of CAS can be used to model complex systems computationally and to investigate nondeterministic and dynamic behaviours of systems (Morel & Ramanujam, 1999). The computational approach provided by CAS gives researchers precision as well as control over the implemented model, and helps with understanding the myriad contingencies that are difficult to explore in field studies; are more readily considered in a virtual environment.

Advancement of the Internet and emergent technologies has given rise to myriad potential as well as complexity in information systems (IS) for businesses. The exploitation of these technologies increases organisational capabilities in terms of processes, information and expertise, which are shared across organisational and national boundaries (Merali, 2004). Many other socioeconomic and political factors also contribute to the growth in complexity. These contemporary developments have forced managers to consider the dynamism of organisations, and to better understand how capabilities, boundaries, and processes arise, adapt and change over time. This focus on organisational dynamics has engendered interest in such concepts as co-evolution of resources, self-organised decisions making, agile development etc. that are complementary with CAS theory.

Dramatic changes are taking place in the structure of business, governmental and non-profit organisations (Cohen, 1999). These changes are considered both engendering and manifesting the new networked economy (Castells, 1996). In a networked economy managers must shift focus from the strategic and managerial discourse on the organisation as a discrete unit, towards conceiving organisations as a network of firms or units, or a network of value generating systems. This is analogous to conceptualising business organisations as a kind of globally distributed system consisting of networks of internet-enabled IS, where the internet is considered both the enabler and driver of the new connected world (Merali, 2004). Thus the competitive context and structure of IS is progressively becoming more complex and less predictable, engendering doubts regarding the adequacy of traditional approaches to theorising and conceptualising IS.

CAS has over the past decade gained traction in diverse social science disciplines related to IS. Several core CAS concepts - self-organisation, emergence, and evolution – have appeared in social science and organisational studies of dynamic, non-linear phenomena (Casti, 1994; Dooley, 1997; Morel & Ramanujam, 1999). Researchers from strategic management have adopted the principles and concepts of CAS to understand the dynamic nonlinear behaviours of complex systems, like supply chain network (Choi, Dooley, & Rungtusanatham, 2001) and leadership (Schneider & Somers, 2006).

The employment of CAS theory in the IS discipline is more recent. The concepts and principles of CAS are most commonly employed in IS to study contemporary phenomena like agile software development (Vidgen & Wang, 2006, 2009), organisational knowledge processes (Habib, 2008; Merali, 2002), and complex system dynamics (Hildebrand, Hofstetter, & Herrmann, 2012). These phenomena involve unpredictable complex processes, and activities analogous with the concepts and principles of CAS. Moreover, several prominent IS journal have dedicated special issues to CAS, such as Journal of Information Technology (Merali & McKelvey, 2006) and Information Technology and People (Jacucci, Hanseth, & Lyytinen, 2006), further demonstrating the value of CAS, while encouraging its broader adoption in IS research.

Yet research employing CAS in the IS discipline remains limited and fragmented. A search of top IS outlets revealed few papers that apply CAS theory. Possible reasons are several, foremost likely being that CAS isn't well understood by many IS researchers. There seems to exist confusion with concepts central to the theory; those concepts not being intuitive nor easy to measure, in particular as they are tightly interwined (Vidgen & Wang, 2006). Further, researchers may be aware of CAS theory but are unsure of its potential. Those who attempt CAS research often face difficulties knowing where to start, what methodology to follow, etc. A common miss-conception is that the sole purpose of CAS is to model real world phenomena computationally, many perceiving computational modelling as foreign or irrelevant to IS research.

To better understand CAS theory and make it more accessible to IS researchers, there is value in better describing the alternative objectives and methodological and theoretical approaches available in CAS-based IS research. This study focuses on making CAS theory more transparent and readily accessible

to IS researchers by addressing three key questions - *What* is CAS? W*hat* are the objectives of CAS? and H*ow* CAS can be applied in IS?

With the aforementioned aims, this study analyses the state of CAS-based research as reflected in the IS literature. More specifically, it analyses peer-reviewed articles 2002-2014 inclusive (the first substantive IS article on CAS appeared in 2002) published in the *AIS Senior Scholars Basket-of-Eight*[1] journals plus two major IS conferences- International Conference on Information Systems (ICIS) and European Conference on Information Systems (ECIS), these outlets being representative of high quality publications in the IS discipline. We employ a keyword search approach to identify CAS-based IS articles. We propose a conceptual framework and analyse the identified articles based on the framework. The (i) conceptual framework, (ii) literature findings for each element of the framework, and (iii) in-depth analysis of the outcomes of the literature review, together constitutes a roadmap for conducting CAS-based IS research. The aim is to offer guidance to future researchers interested in engaging with CAS theory.

The study offers several contributions to IS research. It reveals the diversity of objectives of CAS theory in IS research. The descriptive overview of the reported objectives offers IS researchers a quick and easy reference for understanding the possibilities from CAS, to aid them with specifying and shaping their own CAS-based research goals. The study also elucidates the major methodological and theoretical approaches with CAS. The systematic overview of the identified approaches offers guidance to future IS researchers, as a point of reference when seeking examples and justification for their CAS-based research approach and design. The proposed conceptual framework represents a straightforward process to apply CAS theory in IS research. It can serve as a guideline for future IS researchers to employ CAS theory. Our study also contributes to IS literature on CAS theory. To the best of our knowledge, this is the first study to undertake such a review of CAS-related IS literature.

The remainder of this paper is structured as follows: the next section contains a brief overview of CAS theory. Next, the proposed theoretical framework is presented. Then the research method used to conduct this study is described, followed by a detailed description of the objectives of CAS in IS research. Subsequently, methodological then theoretical approaches with CAS in IS are described. Latterly, a detailed discussion of the research findings is presented followed by the conclusion.

Background literature

CAS provides a new way of thinking about systems and how order emerges in systems from the interactions of its adaptive components (Vidgen & Wang, 2006). There are many accounts of CAS theory, the general view across the broader community of CAS scholars being that there is no single theory of CAS (Anderson, 1999; Vidgen & Wang, 2009). Merali (2004, p. 220) refers to CAS as, "open, non-linear dynamical systems that adapt and evolve in the process of interacting with their environments".

A majority of scholars imply that a CAS is composed of three main elements – (1) heterogeneous interconnected elements or agents, (2) interactions, and (3) the environment. The basic building blocks of CAS are agents (Dooley, 1996) that represent individuals, objects, companies, or concepts.. Each agent has its inherent attributes and an agent's behavior is constrained by a set of behavioral rules, which determine how they will interact with other agents and the environment. Interactions represent the relationships among agents or with the environment. Environment is the space in which the agents reside. Environment has its own attributes, structures and rules, and its behaviour is constrained by the environmental rules. CAS conceptualises that the agents, interactions and environment collaborately interact with each other and give rise to macroscopic properties. One of the fundamental features of CAS is nonlinearity, which means a small change in the components within the system can drastically change the behavioural patterns of the whole system, and the whole system can be very different from the sum of its parts (Anderson, 1999).

Review of the view of CAS theorists suggests several concepts and principles that are predominant, like emergence (Holland, 1995), co-evolution (Kauffman, 1993), and self-organisation (Morel & Ramanujam, 1999) that together characterise CAS. For example, Holland (1995) defined CAS through seven basic characteristics, aggregation, flows, nonlinearity, diversity, tagging, internal models, and

[1] Senior Scholars' Basket of Eight journals are- MIS Quarterly (MISQ), Information Systems Research (ISR), Journal of Management Information Systems (JMIS), European Journal of Information Systems (EJIS), Information Systems Journal (ISJ), Journal of the Association for Information Systems (JAIS), Journal of Information Technology (JIT), and Journal of Strategic Information Systems (JSIS). See further details at- https://aisnet.org/?SeniorScholarBasket

building-blocks. Moreover, Mitleton-Kelly (2003) addressed ten generic principles of CAS, like emergence, connectivity, interdependence, etc. These concepts are highly associated with each other and are mutually reinforcing (Vidgen & Wang, 2006), thus any attempt to isolate one or a subset of these concepts raises questions. The concepts and principles of systems theory and complexity science enrich the kernel of CAS theory by emphasising their interrelationships and interdependence (Mitleton-Kelly, 2003).

As a branch of complexity science, CAS has received increased attention from a diversity of scientific disciplines including thermodynamics (Prigogine, 1984), mathematics (Casti, 1994), medicine (Kauffman, 1993) etc. Due to the natural interface between CAS and a multitude of physical, biological, social, and organizational phenomena, CAS-based models have been used in diverse academic fields including management and organizational science (Nan, 2011). The concepts and principles of CAS have been used to study a growing range of contemporary IS phenomena like agile software development (Vidgen & Wang, 2009), IT supported organisational processes (Canessa & Riolo, 2006) and IT enabled organisational learning (Kane & Alavi, 2007). Several IS referent disciplines, including strategic management (Burgelman & Grove, 2007), organisation science (Frank & Fahrbach, 1999) and management science (Rivkin & Siggelkow, 2007), have also benefitted from the use of concepts and features of CAS.

Significant arguments advocating for increased employment of CAS theory in information systems management and organisational studies, include: limited success of traditional theories, non-linear changes to organisational environments that require increased appreciation of dynamic formal methods e.g. simulation, emphasis on bottom-up agent-based and rule governing behaviors and increasing appreciation of the need for holistic research (Maguire, McKelvey, Mirabeau, & Öztas, 2006).

Towards a Roadmap for Applying CAS in IS Research

In the previous section, we briefly described CAS theory and its applications in organization and management studies. In this section, we propose a roadmap (Figure 1) to guide future IS researchers who have interest in exploring the merits of CAS theory in IS research, but who have limited prior exposure to CAS and are uncertain of where to start and of what methodological and theoretical approach to follow. The roadmap consists of: a) a conceptual framework, b) literature findings for each element of the framework, and c) further analysis of the literature findings. While the proposed framework may be of most value to novice CAS researchers, its coverage of theory and methodology types may serve as a useful reference for more experienced CAS researchers.

The framework represents four simple steps that researchers can follow to apply CAS theory in IS research. In brief, a researcher first needs to do groundwork in understanding the foundations of CAS theory from the literature. Next they should clarify their rationale for choosing CAS theory. Lastly, is the choice of theoretical foundation then methodological approach to employ CAS theory.

Figure 1 depicts the framework, containing four rectangles representing the 4 steps connected by arrows. The large rectangle containing the three steps together indicates the core research project and the single outer rectangle is the basic CAS literature review to conduct the research. The steps can be iterative in manner.For the purpose of simplification, we represent a very straightforward approach in the framework. The steps in the framework are described below-

Understand the CAS basics: Before applying CAS theory in research, the researcher needs to understand the background and foundations of the theory from the literature. As CAS is a branch of complexity science, the generic literature on CAS is mostly related to complexity theory based scientific research outside the IS discipline, which is vast. Several IS referent disciplines like social science, organisational and management studies, engage in CAS research and provide excellent summaries on CAS (e.g. Anderson, 1999; Mitleton-Kelly, 2003). Recently, several senior IS scholars (Allen & Varga, 2006; Merali & McKelvey, 2006) have provided useful introductory literature on CAS in IS.

Justify and explain the objectives: Researchers needs to justify and explain the objectives of undertaking CAS-based research. There are several others, in some sense competing theories within complexity science, including chaos and dissipative structure that have many points of resonance with CAS theory. It is thus important to understand and justify the reasons for using CAS theory in the research. Moreover, CAS theory can be used for several purposes like conceptualisations, modeling, theory building etc. (see section Objectives of CAS). Researchers should discuss their specific research objectives before proceeding to the next step. For example, one can employ CAS for conceptualising the process of agile software development. They may want to develop a computational model for better

understanding the process. Here, two research objectives are implied- conceptualisation and computational modeling. Researcher should explain their objectives briefly.

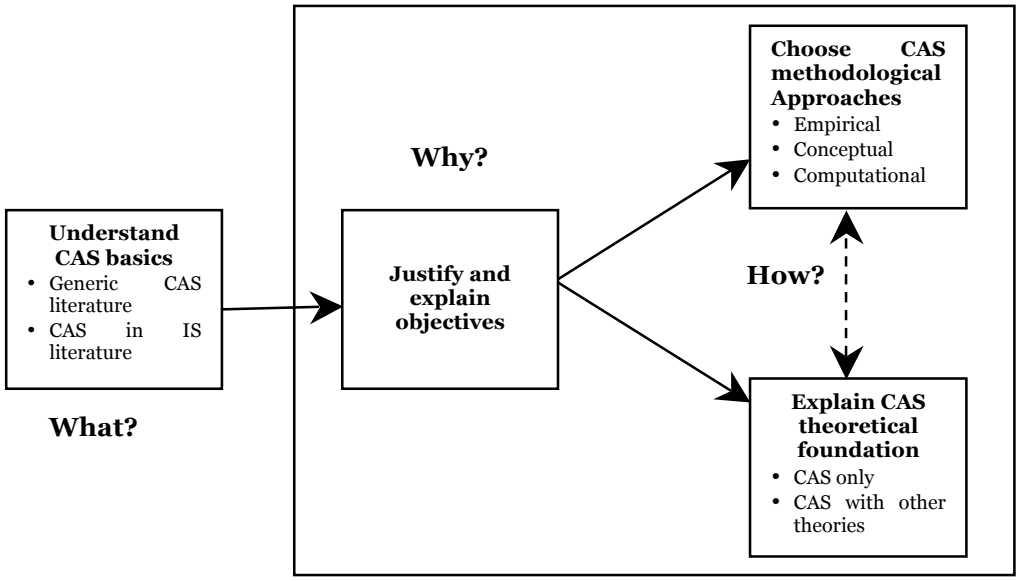

Figure 1: Conceptual framework for applying CAS theory in IS research

Identify and define theoretical foundations: Researchers should define the proper theoretical foundations for conducting the research. Some research may demand more than one theory to better explore the phenomena. Based on their research objectives, researchers should decide and explain why they have chosen only CAS theory or CAS combined with other theory. For example, should the researcher seek to explore the role of employee relationships in agile software development, they might choose CAS to better explain the complex processes of agile development. They may or may not choose another theory e.g. actor-network theory to explain the relationships among employees.

Choose methodological approaches: CAS provides three major methodological approaches, empirical, non-empirical or conceptual, and computational. Researchers can choose one or a combination of these for research. Both empirical and conceptual approaches can be used in isolation or combined, while the computational approach is seldom used independently, as prior to developing and simulating a computational model in simulation platform, the researcher needs to define a conceptual model representing the relationships among the variables and factors from the data. General practices for the three approaches are, first, with the empirical approach, the researcher undertakes a case or multiple case study to gather and analyse empirical evidence using CAS theory for deeper understandings. With the conceptual approach, the researcher analyses a particular complex phenomenon using one or more CAS concepts to generate new insights. And, with the computational approach, the researcher develops a conceptual model from empirical or non-empirical data, uses it to build computational model, and simulates it in a virtual environment for testing and developing new concepts. Thus researchers can follow both single and multi-method approaches to undertaking their research.

Following is related an example of how the framework actually works. Nan (2011) conceptualises IT use as a bottom–up process, and to examine the macroscopic properties of the IT use process, she extends the elements of CAS and develops a conceptual framework. Agent based modeling is later introduced to extend the conceptual framework into a computational model and simulate the model for their theory building exercise. Retrospectively applying our framework to Nan's research, we identify the preliminary objectives of their research were conceptualisation, conceptual framework, simulation and theory building. The theoretical foundation is CAS theory only that is employed to explore and explain the bottom-up nature of IT use process. Simulation method is used to develop the computational model and run it in a virtual environment; hence the methodology employed here is computational. Further details and examples from IS research for each step of the roadmap can be found in the findings of the literature review section reported next.

Research Design

With the objective of instantiating the study framework, we canvassed the IS literature. In preparing the study sample, we surveyed peer-reviewed articles published 2002-2014 inclusive. We surveyed articles published in the *AIS Senior Scholars' Basket of Eight* Journals endorsed by the Association for Information Systems (AIS) as high quality IS journals, as well as two prominent IS conferences- International Conference on Information Systems (ICIS) and European Conference on Information Systems (ECIS). We commenced our search with the basket of eight journals, later extending to the mentioned AIS conferences.

In order to identify articles that use CAS as a core theory, a keyword search was conducted (Levy & Ellis, 2006), i.e. the use of a specific word or phrase[2]. The search was performed searching for the phrase "Complex Adaptive System*"[3] in the title, abstract and full text sections of the databases. The *Proquest* database returned 33 articles for seven of the basket of eight journals, with 44 articles found from *Science Direct* database for JSIS. Additionally, ICIS and ECIS returned 30 and 26 conference papers respectively. Thus, the initial search yielded 133 articles in total, of which on further reading, only 27 used CAS or at least one concept of CAS to theorize phenomena. These 27 papers (see Appendix A) formed the core sample for further analysis. We employed a formal coding scheme and maintained an excel database to record all relevant information, including- keywords, CAS concepts used in IS research and related contributions, and methodological and theoretical approaches followed in CAS-IS research from the pool of papers. To identify the objectives, theoretical and methodology approaches of CAS-IS research, we analysed the surveyed articles employing the conceptual framework described in the previous section. We explain outcomes of the analysis in subsequent sections; the outcomes contain findings for each element of the framework.

The Objectives of CAS in IS Research

To identify the major objectives with CAS theory in IS research, we preliminarily analysed the introduction section of the papers, later exploring their full text. The preliminary analysis identified two major goals of CAS in IS. Subsequent analysis of the full text identified six more objectives. The analysis also discerned a range of distinctive characteristics among the objectives. We categorised the objectives according to their characteristics, yielding three groupings. The first group contains two objectives, which are more specifically the key goals of applying CAS theory in IS; we named this group *goals*. The second group consists of three objectives, which are more specifically the types of theory generated from applying CAS in IS research; we labeled this group as *theory types*. The remaining three objectives we grouped as *stages* (see following).

Objectives as Goals

Our analysis suggests two key goals of CAS theory in IS research: (i) to develop novel theory and (ii) to test existing theory through simulation.

Theory Building

The elements and concepts of CAS are used for developing new theories in IS research. Nan (2011) develops a theoretical framework drawing on the concepts and the analytical tools of CAS. A CAS model of IT use that encodes a bottom-up IT use process into three interrelated elements- agents, interactions and environment. Agent based modeling (ABM) is performed for computationally representing and examining the CAS model of IT use. The CAS model is operationalised and the analytical tool ABM is demonstrated through a theory-building exercise, translating an interpretive case study of IT use to a specific version of the CAS model. This theory building study represents the bottom-up nature of IT use process, further demonstrating that collective level patterns of outcomes are logical and often unpredictable as a consequence of individual level behaviors.

[2] Please note that 'keyword' refers here to the search string, not to the keywords property of the documents that we searched (as stated, we searched in the title, abstract and full text properties of the documents).

[3] The asterisk symbol '*' used in the Boolean keywords of the search string combination allows for the inclusion of derivatives in the search criteria.

Theory Testing

CAS is a popular way of experimenting with theories. The key elements of CAS - agents, interactions and environment, allow researchers to capture interactions among the basic entities of actions and relationships, and between these entities and an environment in a virtual platform, and analyse their patterns of behaviors under certain conditions. CAS theory serves as a better approach to encode real life processes or activities into the computational model and enable analysis of the properties, complex mechanisms, and dynamics in a virtual environment. As it is hard to represent every aspect of real life phenomenon in a virtual environment, researchers specify a set of assumptions that connect the theoretical logic of real life and test them in the simulation. For example, Hahn and Lee (2010) argue that knowledge overlaps between business and IS, play an important role in the Information Systems Development (ISD) process. Using an NK fitness simulation, they seek to investigate how knowledge overlaps influence IS performance under various levels of interdependencies, distributions of interdependencies, and levels of inter-unit trust. The results of the simulation are analysed to developing deep theoretical insights. The findings yield a set of testable propositions, which are further tested in the simulation environment.

Objectives as Theory Types

Our analysis suggests that applying CAS theory in IS yields three types of theory- exploratory, explanatory, and design theory, which are also objectives of CAS in IS research.

Exploratory Theory

Most CAS studies that use empirical data are exploratory in nature. These studies typically first entail one or multiple case studies to collect data about the phenomenon and then apply the CAS lens to explore theoretical insights from the data. Vidgen and Wang (2006) argue that the theoretical foundation of agile software development (ASD) has not been articulated systematically, and propose a conceptual framework to study agile software development based on CAS. They follow an interpretive approach for collecting empirical data through a case study of an ASD team. They identify several agile practices from the CAS perspective as a result of analysis. Moreover, CAS studies that include simulation are also exploratory in nature, as a real-life phenomenon is encoded in the computational model; and by running the model in simulation it can be clearly depicted how a process unfolds and evolves over time; something much more difficult to understand through verbal communication or observation.

Explanatory Theory

The concepts and principles of CAS are suitable for explaining complex phenomena and thus IS researchers have been using it for analysing sophisticated organisational processes like, agile software development (ASD) and IS alignment or service platforms. For example, Wang and Vidgen (2007) argue that the agile processes are marked by some chaotic processes and are placed in opposition to waterfall approaches. They use the edge of chaos concept from CAS to analyse the role of structure and planning in software development (SD) processes. They gather data on project structure and planning of SD processes of two teams from a major IT company, who often use both agile and waterfall approach and compare them from a CAS perspective. The analysis shows structure and planning is essential to agile processes and takes different forms from the waterfall model.

Design Theory

CAS theory is also used for deriving design principles more precisely, as design theory in IS research. Only a single such paper was found from our analysis. Hanseth and Lyytinen (2010) argue that contemporary IT systems involve complexity that extends beyond what can be addressed by traditional design approaches. They seek to develop a design theory based on CAS theory that tackles information infrastructures' dynamic complexity. By exploring the design histories of infrastructures and reviewing the principles of CAS theory, the design theory is derived and illustrated by analysing Internet exegesis.

Objectives as Stages

Applying CAS theory in IS research involves two main stages; (i) conceptualisation and (ii) modeling of the phenomena of interest. Some studies involve only stage 1 conceptualisation. Studies that entail stage 2 modeling of the phenomena must be preceded by stage 1. A third stage (which demands prior

completion of the 1st two stages) may follow, which entails computationally representing the phenomena from the conceptual model in a simulation of the virtual environment; we broadly name this stage *simulation*. Very few of the studies engage in this stage of the research. These three stages represent three CAS objectives.

Conceptualisation

One of the most prominent purposes of CAS theory is conceptualising a phenomenon from a CAS perspective and explaining it with CAS theoretical concepts, sometimes using the key elements of CAS. The analysis shows that most of the IS studies use CAS or CAS concepts to conceptualise phenomenon and theoretically explain them. For example- Vidgen and Wang (2006) conceptualise agile software development as CAS and propose a theoretical framework. The framework is used as a sensitizing device for collecting data and analysis in an interpretive case study. As a result of their analysis, several agile practices are identified, and reflected on, from the theoretical perspective of CAS.

CAS Framework or Modeling

Our analysis of the papers suggests that the CAS concepts and key elements are used for conceptual or theoretical framework or modeling of complex business processes like IT use (Habib, 2008; Nan, 2011) or computer information systems (Canessa & Riolo, 2006). For example, Curşeu (2006) uses the CAS perspective to integrate the literature on emergent states in virtual teams (VT). She uses the concept of emergence to develop a CAS framework and provide a new theoretical understanding for some of the phenomena of VTs' dynamics that were previously studied in isolation. By combining the insights from CAS framework with the empirical data, the study seeks to provide a basis for matching emergence in VT with the virtual simulations.

Simulation

As an analytical theory, CAS provides a way of encoding and presenting real life complex processes through a computational model, then in virtual simulation. The tenets of CAS theory, agents, interactions and environment, have been applied in IS research to understand the underlying complexities of different contexts, computer information systems (Canessa & Riolo, 2006), virtual teams (Curşeu, 2006), viral marketing dynamics (Hildebrand, et al., 2012) etc. Researchers have employed different computational modeling or simulation techniques in IS research, like, Agent based modeling (ABM) (Bonabeau, 2002), NK modeling (Kauffman, 1993) and MySQL simulation. The theoretical propositions of real life processes are outlined under certain assumptions and conditions in the model. The model is executed to explore a wide range of possible contingencies that are difficult to assess in a laboratory setting or through field studies (Nan, 2011).

The Methodological Approaches of CAS in IS Research

In the previous section, we presented different purposes or objectives of CAS theory in IS research (stages, types and goals). This section presents the methodological approaches researchers follow to conduct CAS-based IS research. In order to identify the methodological approaches, we analysed the research method or methodology section of the papers. Following Chen and Hirschheim (2004), we classified the papers into two broad methodological classes, empirical and non-empirical. In addition, we added another category termed computational; those papers that use computational method to model real world phenomena.

Empirical

The empirical papers contain observations and data (primary or secondary data) that provide strong evidence for testing theories. Typically, one or multiple case studies are conducted to gather empirical data about the phenomenon. CAS is used to provide an in depth theoretical description of the phenomena. The description contains detailed explanation of the phenomena; what it is, how, why, when and where. For example, Vidgen and Wang (2006) propose a theoretical framework of agile software development using CAS. An interpretive case study is conducted to gather data on a software development process. The framework is used as a sensitizing device for data collection and analysis. Several agile practices are identified and reflected on from the theoretical perspective of CAS as a result of analysis.

Non-empirical or Conceptual

The non-empirical papers develop new concepts and theories; we refer these as conceptual papers. CAS theory is used to conceptualize a phenomenon, explore it and then provide an in depth explanation of it. One or more CAS concepts are used to investigate and provide theoretical statements on the phenomena. The outcome of the analysis generates new insights, concepts and theories. For example, Tanriverdi, Rai, and Venkatraman (2010) employ CAS to theorize about IS strategic alignment. They suggest organisations consider three quests of IS strategy- strategic alignment to co-evolution, integration to reconfiguration and sustained competitive advantage to renewal; in the competitive performance landscapes of products and services, which are highly dynamic and co-evolve in nature.

Computational

These studies employ computational models to represent the phenomena under study, and using empirical or non-empirical data (Davis, Eisenhardt, & Bingham, 2007), test models to develop new concepts and theories. The computational studies may use empirical data, yet we categorise them as computational because the ultimate objective of these studies is to build and simulate computational models based on empirical evidences. For example, Nan (2011) uses secondary empirical data to explore bottom-up emergence of IT use in organisations. She develops a computational model to represent the IT use process, operationalises the model using empirical data and emulates it in a virtual platform for studying the properties and mechanisms of bottom-up IT use processes.

The Theoretical Approaches of CAS in IS Research

In the preceding section, we discussed different methodological approaches that researchers follow in CAS-IS research. In this section, we present the theoretical approaches of applying CAS in IS research. For the theoretical approaches, it was necessary to consider the full text of the surveyed papers. As a result of analysis, we identified two major theoretical approaches- only CAS theory and CAS with other theories.

CAS Theory Only

This class of research engages only the basic principles of CAS theory to conceptualise complex phenomena and for analysis to develop in-depth understanding. Tanriverdi, et al. (2010) (mentioned earlier) conceptualise business systems as CAS in order to theorise about IS strategic alignment. In other study, Allen and Varga (2006) explain the construction and development of IT systems from the co-evolutionary perspective of CAS. They conceptualise organisations as CAS and individuals as agents to develop understandings of the evolution of IS from the interactions of agents and other constructs, like IT systems in organisations.

CAS with Other Theories

In this class of research, various supporting theories are used with CAS to achieve in-depth understanding and to explore complexities of the phenomena. For example- Benbya and McKelvey (2006) present a view of IS alignment in organisations drawing on the co-evolution concept of CAS theory, especially focusing on co-evolution based self-organized behaviour, which provides important insights on the emergent nature of IS alignment. This view considers business/ IS alignment as a series of adjustments at three levels of analysis- individual, operational and strategic. Drawing on scale free dynamics theory and principles of adaptation, they suggest several enabling conditions to speed up the adaptive co-evolutionary dynamics among the three levels.

Discussion

In the previous sections, we presented our proposed CAS roadmap in the form of a theoretical framework and the findings from the CAS literature in IS field for each element of the framework. We hope our framework as well as the outcomes of the literature review offer useful guidance on the conduct of CAS-based IS research. This section highlights some of the insights generated as a result of our analysis of the 27 CAS-IS papers. First, we briefly discuss the relationships of the objectives, with the different methodological and theoretical settings, followed by some insights generated from the relationships, observations on the versatility of computational CAS studies, and suggest several agendas for future research. We then discuss the lack of design research in IS using CAS, and

methodological triangulation between case study and simulation method, followed by a discourse on theoretical triangulation between CAS and other theories.

Table 1 represents the relationships of the objectives of CAS theory in IS with the different methodological and theoretical approaches identified in this study. The rows represent the objectives of the CAS theory in IS research (stages, types and goals). The columns represent the methodological (*empirical, conceptual* and *computational*) and theoretical (*CAS theory only* and *CAS with other theories*) approaches identified from the surveyed papers. Included in each cell are studies that address that nexus of objectives and approaches. Note that a single study may have multiple objectives and multiple approaches, thus may be represented in more than one cell.

	Methodological Approach	**Empirical**		**Conceptual**		**Computational**	
	Theoretical Approach	**CAS Theory Only**	**CAS with other theories**	**CAS Theory Only**	**CAS with other theories**	**CAS Theory Only**	**CAS with other theories**
	Objectives of CAS						
Goals	**Theory building**	(Vidgen & Wang, 2006); (Wang & Vidgen, 2007); (Vidgen & Wang, 2009); (Wang & Conboy, 2009); (Kautz, 2012); (Förderer, et al., 2014); (Nan & Lu, 2014)	(Lanham & McDaniel Jr, 2008)	(Hanseth & Lyytinen, 2010); (Tanriverdi, et al., 2010); (Vessey & Ward, 2013)	(Benbya & McKelvey, 2006)	(Canessa & Riolo, 2006); (Curşeu, 2006); (Nan, 2011); (Basole, 2009); (Hahn & Lee, 2010); (Hildebrand, et al., 2012)	
	Theory testing					(Canessa & Riolo, 2006); (Curşeu, 2006); (Nan, 2011); (Basole, 2009); (Hahn & Lee, 2010); (Hildebrand, et al., 2012)	
Theory Types	**Exploratory**		(Merali, 2002); (Kim & Kaplan, 2006); (Habib, 2008); (Lanham & McDaniel Jr, 2008)	(Hanseth & Lyytinen, 2010)		(Canessa & Riolo, 2006); (Curşeu, 2006); (Nan, 2011); (Basole, 2009); (Hahn & Lee, 2010); (Hildebrand, et al., 2012)	
	Explanatory	(Vidgen & Wang, 2006); (Wang & Vidgen, 2007); (Vidgen & Wang, 2009); (Wang & Conboy, 2009); (Kautz, 2012); (Khanna & Venters, 2013); (Förderer, et al., 2014); (Nan & Lu, 2014)		(Allen & Varga, 2006); (Merali, 2006); (Tanriverdi, et al., 2010); (Chae & Olson, 2011); (Grover, 2012); (Merali, et al., 2012); (Vessey & Ward, 2013)	(Benbya & McKelvey, 2006);	(Canessa & Riolo, 2006); (Curşeu, 2006); (Nan, 2011); (Basole, 2009); (Hahn & Lee, 2010); (Hildebrand, et al., 2012)	
	Design			(Hanseth & Lyytinen, 2010)			
Stages	**Conceptualisation**	(Vidgen & Wang, 2006); (Wang & Vidgen, 2007); (Vidgen & Wang, 2009); (Wang & Conboy, 2009); (Kautz, 2012); (Khanna & Venters, 2013); (Förderer, et al., 2014); (Nan & Lu, 2014)	(Merali, 2002); (Kim & Kaplan, 2006);(Habib, 2008);(Lanham & McDaniel Jr, 2008)	(Allen & Varga, 2006);(Merali, 2006); (Hanseth & Lyytinen, 2010); (Tanriverdi, et al., 2010); (Chae & Olson, 2011); (Grover, 2012); (Merali, et al., 2012); (Vessey & Ward, 2013)	(Benbya & McKelvey, 2006)	(Canessa & Riolo, 2006); (Curşeu, 2006); (Nan, 2011); (Basole, 2009); (Hahn & Lee, 2010); (Hildebrand, et al., 2012)	
	CAS Framework or modeling	(Vidgen & Wang, 2006); (Wang & Vidgen, 2007); (Vidgen & Wang, 2009); (Wang & Conboy, 2009); (Kautz, 2012); (Khanna & Venters, 2013); (Förderer, et al., 2014); (Nan & Lu, 2014)	(Merali, 2002); (Habib, 2008)		(Benbya & McKelvey, 2006)	(Canessa & Riolo, 2006); (Curşeu, 2006); (Nan, 2011); (Basole, 2009); (Hahn & Lee, 2010); (Hildebrand, et al., 2012)	
	Simulation					(Canessa & Riolo, 2006); (Curşeu, 2006); (Nan, 2011); (Basole, 2009); (Hahn & Lee, 2010); (Hildebrand, et al., 2012)	

Table 1: The objectives of CAS theory in different methodological and theoretical settings

Empty cells indicate combinations not encountered in the study sample, and perhaps opportunities. A large number of studies in a column suggests the methodological/theoretical combination (e.g. Computational Modeling with CAS theory) is versatile, lending to multiple stages, theory types and/or theory building or testing. Alternatively, it may simply suggest this combination has been better exploited. Few studies in a column (e.g. Computational Modeling with CAS and other theory) suggest a lack, an opportunity, or hurdles worthy of caution. The greyed six cells indicate combinations that are not possible. For instance, theory cannot be tested conceptually and simulation is only possible in computational studies.

A large number of studies in a row suggests the row (e.g. conceptualisation) objective is readily addressed through multiple, alternative methodological/theoretical combinations. A relatively empty row (e.g. Design) indicates either inattention to, or difficulties with addressing that objective with many of the combinations.

The table helps to understand the specific objectives of a paper in different methodological- theoretical settings. For example- from the table we realise that the *empirical* studies which adopt *CAS theory only* are used for conceptualisation (e.g. Vidgen & Wang, 2006). Note that, a single paper can use both empirical and computational approaches at the same time, but the ultimate aim is to develop a computational model from the empirical evidence. Thus, we classify these as computational studies. For example- Nan (2011) uses empirical (secondary) case data to build the computational model, thus this study is categorized as a computational study.

The relational table also reveals some insights that may be of value to future IS researchers; a better understanding the potential of CAS in IS research. From the table we observe that computational CAS studies appear relatively more versatile than the other study types (empirical, conceptual), with computational studies employed in attention to all but 1 of the 8 objectives. The reason seems clear, as a real world complex phenomenon can be conceptualised theoretically (*1. conceptualisation*), modelled (*2. conceptual model*), explained (*3. explanatory*) computationally represented, run (*4.simulation*), and tested in simulation with specific assumptions (*5. theory testing*), and the results of the simulation are analysed (*6. theory building*) for in-depth understandings about the phenomena (*7. explanatory*) (e.g. Nan, 2011). The analysis also reports that the other theories are not used with CAS in computational IS studies. Though other theories may align well with CAS theory they may not be easily represented in the simulation model. This is possibly the reason that other theories are not used in computational CAS studies.

This study reports that a limited number of design research studies have been conducted in IS discipline using CAS theory. We identified only a single study that used CAS to derive design principles, a.k.a. design theory. This may suggest an opportunity to further apply CAS theory in design science research.

The literature presents a brief overview of the methodological approaches used in CAS theory based IS research. Our analysis identified methodological triangulation (Denzin, 1978), that refers to the use of multiple methods. Of the empirical research methods employed in CAS theory based IS research, case study is dominant (14 out of the 27) and simulation second most prominent (7 out of 27). The analysis also reports the absence of survey method in CAS-based IS research (27 papers). We identify triangulation between case study and simulation method in 2 papers, though they together provide the most versatile means of investigating and understanding complex phenomenon (Nan, 2011). There are several overriding purposes of the methodological triangulation. The preliminary purpose is to eliminate or reduce biases and ensure the validity of the study (Jonsen & Jehn, 2009). Another purpose is to ensure the richness and in-depth understandings of the study. Using the case data in the simulation model and analysing it by running the model enriches the understanding of the researchers and also ensures that the simulation result satisfies the theoretical logics of the case findings, and thus establishes the validity as well.

Further research can be undertaken based on our analysis of the literature review. Research might focus further on the computational studies engaging multiple theories. Using only CAS theory it may not be possible for researchers to gain all data required for developing the conceptual framework, hence the computational model. For example, if the researchers seek to find out how the determinants interact with each other and affect the IT use process in the Nan (2011) study on the IT use process, they might use adaptive structuration theory (AST) (DeSanctis & Poole, 1994) to collect relevant concepts and processes from the literature. The use of AST makes it easier to identify the existing concepts and processes of IT use. Thus AST and CAS jointly leverage the analytic capability to understand IT use process. Research therefore needs to be conducted using multiple theories to better understand complex phenomena.

CAS as a dynamic theory provides a way of recognizing competitive dynamics, interdependencies in the network of firms, properties of competitive landscapes and contextual interactions that span multiple levels (Tanriverdi, et al., 2010). The concepts of CAS thus can be employed as a dynamic means for exploring complex IS phenomena, like co-evolution of organisational resources, strategic decision-making, and IS transformation etc.

Conclusions

The purpose of this paper is to develop a roadmap for conducting CAS-based IS research. The aim is to develop a conceptual framework that depicts simpler ways of applying CAS theory in IS research. The framework also helps us to conduct a systematic overview of the CAS-based IS studies and to identify researchers' objectives in applying CAS for exploring complexity in different IS research topics and their relevance with the methods and theories. Our source of insight is the survey and analysis of relevant papers on CAS in the IS literature (27 papers in total) from the top IS outlets over the period 2002-2014. Eight objectives of applying CAS in IS studies, three methodological and two theoretical approaches are identified from the analysis. The framework and insights of the analysis can serve as guidelines for future researchers interested in employing the concepts of CAS in differing IS research topics.

The study has several limitations. The theoretical framework proposed is neither complete nor ideal, rather it serves as a supportive tool to analyse the CAS related literature in IS. Further, we have considered the CAS-IS articles only from the basket-of-eight IS journals and two prominent AIS conferences for this research. There has been a long history of the employment of CAS theory in other IS referent disciplines, like strategic management and organisational studies, but we do not include them in this study. Future research will include those studies in order to develop a more thorough understanding of the objectives and approaches of CAS in IS research. Further, we have used only a single key phrase "complex adaptive system*" to search for the articles in the databases. We found some of the papers outside IS disciplines use different terms, like complex system or adaptive systems to address CAS. We will expand the number of the search terms in future research, so that we can identify all the articles relevant to our interest. To conclude, this study presents a partial phase of an exploratory study. Future research will focus more on the application phases and the outcomes generated from the research venture.

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Appendix A

Author	Title	Author	Title
(Merali, 2002)	The Role of Boundaries in Knowledge Processes	(Wang & Conboy, 2009)	Understanding Agility in Software Development through a Complex Adaptive Systems Perspective
(Allen & Varga, 2006)	A Co-evolutionary Complex Systems Perspective on Information Systems	(Hahn & Lee, 2010)	Knowledge Overlap, Task Interdependence, and Trust in IS Development
(Benbya & McKelvey, 2006)	Using Coevolutionary and Complexity Theories to Improve IS Alignment: A Multi-level Approach	(Hanseth & Lyytinen, 2010)	Design Theory for Dynamic Complexity in Information Infrastructures: the Case of Building Internet
(Canessa & Riolo, 2006)	An Agent-Based Model of the Impact of Computer-Mediated Communication on Organizational Culture and Performance: An Example of the Application of Complex Systems Analysis Tools to the Study of CIS	(Tanriverdi, et al., 2010)	Reframing the Dominant Quests of Information Systems Strategy Research for Complex Adaptive Business Systems
(Curşeu, 2006)	Emergent States in Virtual Teams: A Complex Adaptive Systems Perspective	(Nan, 2011)	Capturing Bottom-Up Information Technology Use Processes: a Complex Adaptive Systems Model
(Kim & Kaplan, 2006)	The Co-evolutionary Dynamics of IS Engagement	(Grover, 2012)	The Information Systems Field: Making a Case for Maturity and Contribution
(Merali, 2006)	Complexity and Information Systems: the Emergent Domain	(Hildebrand, et al., 2012)	Modeling Viral Marketing Dynamics in Social Networks–Findings from Computational Experiments with Agent-Based Simulation Models
(Vidgen & Wang, 2006)	Organizing for Agility: a Complex Adaptive Systems Perspective on Agile Software Development Process	(Kautz, 2012)	Beyond Simple Classifications: Contemporary Information Systems Development Projects as Complex Adaptive Systems
(Wang & Vidgen, 2007)	Order and Chaos in Software Development: A Comparison of Two Software Development Teams in a Major IT Company	(Merali, et al., 2012)	Information Systems Strategy: Past, Present, Future?
(Habib, 2008)	The Dynamics of Knowledge Creation within Innovation Process from Case Studies to Agent Based Modelling	(Khanna & Venters, 2013)	The Role of Intermediaries in Designing Information Infrastructures in Strategic Niches: The Case of a Sustainable Mobility Infrastructure Experiment in Berlin
(Lanham & McDaniel Jr, 2008)	An Exploration of Heterogeneity in Electronic Medical Record Use: Information Technology Use as Emergent and Driven by Values and Expertise	(Vessey & Ward, 2013)	The Dynamics of Sustainable IS Alignment: The Case for IS Adaptivity
(Basole, 2009)	Visualization of Interfirm Relations in a Converging Mobile Ecosystem	(Förderer, Kude, Schütz, & Heinzl, 2014)	Control versus Generativity: A Complex Adaptive Systems Perspective on Platforms
(Vidgen & Wang, 2009)	Coevolving Systems and the Organization of Agile Software Development	(Nan & Lu, 2014)	Harnessing the Power of Self-Organization in an Online Community During Organizational Crisis
(Chae & Olson, 2011)	IT-Enabled Services as Complex Adaptive Service Systems: A Co-Evolutionary View of Service Innovation		