Defining the Criteria for Supporting Pervasiveness in Complex Adaptive Systems

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Abstract. This paper, will explore potential contributions from the study of complexity theory to the area of pervasiveness of information systems. It offers insights for enriching traditional approaches of information system design that could lead to better framework for supporting pervasiveness in complex environment. Complex environment makes new problems for pervasiveness because it is hard for users to be aware of change. So to be aware of change is what this paper tries to introduce as a new criterion. First it describes complexity theory as a metaphorical devise which gives new insights of the environment. Second a short review of implication of these concepts to complex systems modeling especially on ways to define requirements that should be provided by infrastructure, which tend to be initially incomplete. Then it suggest how complexity theory can provide the guidelines and concepts needed to be aware of change and defines new research directions for the future that uses these guidelines for building an infrastructure of pervasive adaptive systems.

Keywords: Pervasive adaptive system, complexity theory, system design.

1 Introduction

This paper, offers insights for enriching traditional approaches of information system design that could lead to better framework for supporting pervasiveness in complex environments. It describes important issues in system and identifies concepts from complexity theory which can be applied to information systems to support pervasiveness and user awareness of change. It is organized as follows: it starts with describing the trends in systems and their correspondence to pervasive adaptive systems. This is followed by an overview of ways of applying complexity theory in computing systems and then introducing concepts driven from complexity science which can be used in information systems. The last section describes future work to define the kind of concepts needed to support pervasiveness and user awareness in complex adaptive environments.

Regarding some challenges, moving from desktop computers to designing pervasive adaptive systems, the research scope of system architecture has to become more interdisciplinary. The issues which designers usually face are due to increases in computing speed, decreasing computing cost and changes in technological, task, and organizational environments where more user-centric pervasive systems are either

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produced or deployed. They need to know how to build an infrastructure to support people remain aware in complex environment. They also need to attend more to the dynamic composition of the system and environment.

According to the literature, it seems that information system scholars are ready to take a paradigm shift for moving toward better theoretical and methodological platform suited for pervasiveness, user awareness of change in information system design and developments. To achieve this goal, complexity theory can be outlined and influence information system professionals in order to meet these goals. So the questions regarding the application of complexity theory to pervasive adaptive systems are: what is the impact of complexity theory on designing infrastructures? How it would be possible to bring complexity theory concepts in to the complex system architectures? How to ensure that they can be modelled? How to research information systems as complex adaptive systems, in the concept of user-centric pervasiveness and system adaptability?

2 Complexity Theory

A complex system is comprised of large number of different systems which obey some rules that connect them interactively with other parts. The systems can cause the system as a whole to display emergent patterns at the global level. The emergence cannot be predicted from properties of each part. There are two groups of complex systems. One is the complex system which consists of parts which are not complex and are called agents. These agents manage by unchanging rules. The other group of complex systems consist of other complex systems capable of learning and simply means that they are governed by rules that they are involved[12].

Bill McKelvey[1] claims that complexity theory is relatively a new way of thinking about the systems of interacting agents such as companies. Such systems are not centrally controlled, they rest on the idea that order emerge through the interactions of companies and agents[1]. So the complexity theory seeks to explain the processes of interaction leading to emergent structure rather than the effects of enteric forces of objects. In complexity science we study systems as a whole without the simplifications, and observing the interactions between the elements more than the elements itself[4]. A complex system is not categorized a new class of systems. Complex systems are comprised of group of interacting entities which emerge through these interactions and the behavior of the system is not predefined. Different scholars have defined different characteristics for complex systems. For example Lucas[5] defined fourteen characteristics for complex systems. These characteristics are: autonomous agents, nonstandard, co evolution, self modification, downward causation, self reproduction, undefined values, fitness, non uniform, nonlinear, emergence, attractors, phase changes and unpredictability[5]. He categorized these characteristics to three groups, such as autonomous agents, undefined values and non linearity. Another definition is that, complex system consist of a large number of self organizing agents that interact in a dynamic and nun-linear fashion that share a path dependent history. Some information systems can be considered as complex systems, which contain large number of independent systems and agents which interact locally and randomly to produce a goal oriented behaviour[13][1]. It is manifested by the continuous changes in complex environments due to changing organizational goals driven by the external competitive environment [2]. So because of its adaptability to change, complexity theory can be a good foundation for systems design architecture and infrastructures. There are many concepts in complexity theory like: self organisations, learning, knowledge, co-evolution, adaptation, emergent, responding to change, chaos and lack of central control that can be translated to the information system architecture and infrastructure context.

3 Complex Adaptive System Theory

The meaning of complex adaptive information system comes from such systems in the nature. These systems are composed of huge number of components that interact locally to produce global behavior. The random and local interactions of components lead to the emergence and goal oriented behavior of the whole system. And the adaptation means the ability to accommodate influences from changing environments without disintegrating[13]. These systems have no central control and cannot be equilibrium. Kovacs[13], defines complex information system as a large number of memes, micro-strategies and users. All of these parts interact with each other locally without global control. The bits of information that can be stored and be processed are called memes. Information system is composed of micro-strategies which take memes from outside and, processes, stores and retrieve them later. The complex adaptive information system cannot be built, it needs to grow and evolve. And have highly decentralized interactions with its components. By understanding information system architecture and infrastructural design as a complex activity, it would be possible for designers to improve their innovative solutions. Complexity theory is a promising framework that accounts for the dynamic evolution of information system and the complex interactions among industry actors. By conceptualizing information systems as chaotic systems, a number of design implications can be developed. Long term forecasting is almost impossible for chaotic systems, and dramatic change can occur unexpectedly.

4 Conceptual Foundation

We utilize the concepts which arise from complexity theory in user-centric and pervasive information system architecture. These concepts can give a metaphorical device for users to be aware of change. They can be described as follows:

- **Chaos:** A system which is deterministic, but it is hard to be predicted technically is called a chaotic system. The behavior of a chaotic system in future times depends on its sensibility to initial conditions. It means that you cannot define patterns to model its behavior. Models of chaotic system describe the dynamics of a few variables which reveals some special characteristics[7].
- **Self-organizing:** Self-organizing is the ability of a complex system to generate new behavior and structure is called. Self-organizing makes the information system as an open system with continuous flow of energy and

resources pass through it. In a self-organized process, the components reorient and restructure their relationships with other components[7]. This action introduces the relationship packages. Designing modules and defining the interaction between them are important issues in information system design concepts.

- **Learning:** Complexity theory is the key to understand how knowledge naturally unfolds in living systems. This process offers a solid foundation on which we can build tools and techniques for use in the real world. It illustrate the nature and role of cognition in living systems, and shows: (i) how knowledge take place in human organizations and (ii) how learning happens in organization[6]. Learning is very important in organizations and allows evolution to higher forms and behaviors. This requires a lot of shared information in form which is easily accessible to everyone.
- **Agent:** A living part of a complex system is called an agent. Agents interact and affect each other, and can have high degree of creativity which cannot be precisely predicted. The perspectives which arise from this concepts are:

- Representation of agents communicating with other agents to complete the task.
- The distribution of agents in the organizations and changing as agents communicate.
- The ability of the agent to make decisions in response to the environment and to the action of other entities.
- The active agent rules, the reason why agents follow some rules and not others and When do agents' rules change
- The kinds of emergent social phenomena arise from interacting and learning agents
- The role which do contextual energy differentials (adaptive tension) play in motivating agent behaviors
- Managing agents and get them to produce more economically viable teams, new product developments, entrepreneurial ventures, and generally, more effective socioeconomic and/or organizational (complex adaptive) systems

Evolution and Co-evolution: Co-evolution is a multi-level phenomena within an organization as well as between organizations. It involves interactions between different species and adaptive moves by the members of one species will deform the fitness landscape of the other species with which it is co-evolving [11]. There are two kinds of evolutions: i) the gradual development of a system, (ii) the development over generation. This means that adaptation can happen during the development of a system or while components of system develop [13]. Merali and McKelvey[8] look at strategic alignment as a co evolutionary process and tried to identify the need for dynamic approach to strategy development between information system and business. They considered various levels involved in strategic alignment. These approaches are individual, operational and strategic.

Thompson[10] classified different types of co evolutionary relationships. He also tried to identify the primary forms of selection influencing each type. Future information system research applying a co evolutionary framework can be enhanced with incorporation of theories from the social sciences and deep consideration of the nature of the interactions.

- **Adaptation:** New users with different ideas and functionality, bring new requirements that the designed system cannot accommodate. These new ideas change the perspective of the organization regarding the requirements of the information system [1]. In order to manage the complexity, organizations have started to learn the benefit of being adaptive in their behavior. For instance Sheffi and Rice[9] tried to represent adaptive firm behavior in a cellular telephone supply network. They modified designs of the handsets where possible and secured worldwide manufacturing capacity from Philips to ensure a steady supply of the specific product. Meanwhile the direct interaction between top management of Nokia and Philips further enhanced the ability of Nokia to adapt in the future[9].
- **Emergent:** Emergence describe that the macroscopic properties of a system arise from microscopic properties. These microscopic properties are interactions, relationships, structures and behaviors[7]. So defining emergence as an overall system that comes out of the interaction of many participants behavior cannot be predicted from the knowledge of what each component of the system does in isolation.
- **Non-standard:** Complex systems are non-standard as well. They contain structures in space and time. Their part freedoms will allow varying associations or movement, permitting clumping and changes over time. Thus initially homogenous systems will develop self-organizing structures dynamically; order – and thereby value – increases over time rather than decreasing as expected in conventional thought[3].
- **Downward causation:** This means that the existence and properties of the parts themselves are affected by the emergent properties - or higher level systemic features – of the whole, which form constraints or boundary conditions on the freedom of the constituents[3][2].

5 Summary and Future Work

This paper has explored current ideas in the field of complexity theory focusing in particular on information systems. It tries to explore potential contributions from the study of complexity theory to the area of pervasiveness of information systems. It offers insights for enriching traditional approaches of information system design that could lead to better framework for supporting pervasiveness in complex environment. Complex environment makes new problems for pervasiveness because it is hard for users to be aware of change. So to be aware of change is what this paper tries to introduce as a new criterion. It is considered as a source of concepts for user-centric and pervasive information systems in complex environments. Complexity theory offers a powerful set of methods for explaining non-linear, emergent behavior in complex environments. It offers us concepts and tools for building multi-level representations of different environments. It helps us to make sense the dynamics and emergence behavior of the complex environments and offer insights regarding building effective infrastructure for pervasive adaptive systems and increase user awareness of environments.

The literature indicates that there is much work to be done to deepen the theoretical framework and to re-conceptualize adaptive system architecture. In order to deepen our understanding of sources of complexity in information system, we need to come up with a concrete definition of complexity theory. Current definitions vary according to the research fields, so future work could be: defining complex system characteristics in the field of information system infrastructure, drawing more concepts from complexity theory, developing practical implication for user-centric pervasive complex adaptive system.

We need to be more emphasis on providing the infrastructure that allows systems to evolve in a self-organizing manner. So regarding to this concept, working on the following concepts should be taken in to considerations:

- Developing a better definition of complexity and how it can be operationalized and be considered in architectural and infrastructure aspects.
- Ways to specify the user-centric concepts in IS and integrate them into functional specifications.
- The kinds of infrastructure needed and how to include them in specifications.

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