THE INFORMATION PROCESSING ASPECT OF THE DYNAMICS OF A SYSTEM AS A BASIS FOR THE DEVELOPMENT OF ITS COMPUTER-BASED INFORMATION SYSTEMS

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ABSTRACT

All dynamic systems need to process information in order to function. This means that there is an information processing aspect to the dynamics of any system (Kampfner, 1998) that in fact embodies the way in which it processes information. Complex, adaptive systems such as modern organizations include natural and artificial means of information processing as part of their dynamics. Although the natural and the artificial forms of information processing are fundamentally different, they are also highly complementary of each other. One claim of this paper is that a synergistic combination of natural and artificial computing is essential to the ability of modern organizations to successfully perform their functions and persist in the face of an uncertain environment. I also argue that considering information processing as an aspect of dynamics is essential to finding the synergistic combination of natural and artificial computing that is needed for the effective support of function and adaptability in modern organizations.

The development of computer-based information systems can be thought of as a means of integrating computer-based information processing into the dynamics of modern organizations. The abstraction-synthesis methodology of information systems development, or ASM, (Kampfner, 1987, 1997) provides a conceptual framework for this integration. In the ASM, the information needs of the functions that the computer-based information system will support are determined on the basis of the information processing aspect of its dynamics. This is followed by the design and development of the computer-based processes that will help to meet these information needs in a manner consistent with the adaptability of the system as a whole. The synergy of the combination of natural and artificial computing is possible because these two fundamentally different forms of information processing can complement each other in many useful ways.

Keywords: dynamics of systems, natural computing, artificial computing, human intelligence, biological information processing.

INTRODUCTION

In this paper I focus on the advantages that the view of information processing as an aspect of the dynamics of systems (Kampfner, 1998) provides for the design of computer-based information systems that effectively support to the functions of modern organizations. In Section 2 I explain this notion of information processing, its connection with the relationship between dynamics and computation, and the importance of understanding the relationship between information processing and the other aspects of the dynamics of which it forms a part.

The dynamics of biological systems, including its information processing aspect, has changed through the evolutionary process. An important landmark in the evolution of biological information processing is the advent of human intelligence. Section 3 discusses the significance of this monumental event which triggered the creation and improvement of artificial means of representing, storing, manipulating and communicating information, including the creation and continued development of increasingly powerful means of information processing such as digital computers and other artificial devices. Section 3 also points to the fundamental differences that exist between natural and artificial computing. These differences refer to the way in which natural and artificial systems process information, to the way in which the information processing aspect is integrated into their dynamics, and to the effect that each of these types of information processing has on the adaptability of the systems they serve.

These fundamental differences, however, also allow for their synergistic combination. After all, artificial computing has always been a means of extending the computational capabilities of natural systems. More specifically, in this respect I argue that an effective, synergistic combination of natural and artificial information processing requires for them to be compatible with each other and with the other aspects of the dynamics in which they participate, and to contribute to the adaptability of the system as a whole (Kampfner, 1987, 1997).

Section 4 discusses the basic factors that need to be considered in order to achieve a synergistic combination of natural and artificial information processing. Central to this discussion is M. Conrad's trade off principle of information processing (Conrad, 1985). This trade off principle states that the structural programmability of information processing is always traded by its adaptability and its computational efficiency. Digital computing is clearly at the programmability side of the trade off, while natural computing, including biological computing and human intelligence, is at the adaptability and computational efficiency side. The basis that the trade off principle provides for the combination of natural and artificial computing in a manner that favours adaptability can be capitalized upon with the help of a function support principle for the design of information systems. The function support principle of design calls for the compatibility of computer-based information processing with the dynamics of the systems it supports and with the adaptability of the system as a whole as a basic design goal (Kampfner, 1987, 1997).

The synergistic combination of natural and artificial computing is vital to the success of complex, adaptive systems that include natural and artificial means of information processing as part of their dynamics, such as modern organizations. The complexity of the functions of modern organizations and the uncertainty of the environment that they face impose heavy demands on the information processing aspect of their dynamics. Both digital and natural computing are needed for the success of modern organizations. Digital computing is needed because of the tremendous processing speed, huge storage capacity, and great data communication capabilities that can be achieved with modern information technology. These information processing capabilities of digital computing are indeed indispensable in the domain of problems that admit algorithmic solutions. Natural computing, including human intelligence, is also indispensable in modern organizations. The specificity, computational efficiency and adaptability of natural computing, together with the creativity, intuition, ability to exercise value judgment, and general problem solving and decision-making capabilities of human intelligence are all required in order to deal with unstructured and ambiguous situations, incomplete information, and with problems for which a solution is yet to be found. The potential of a synergistic combination of these two forms of computing is clearly huge. Once it is found, however, it needs to be put to work. This requires the development and implementation of computer-based information systems that generate processes that interact in an appropriate manner with the other processes that participate in the dynamics, including those pertaining to natural computing.

The design and successful implementation of a synergistic combination of natural and artificial computing is indeed a basic goal of the development of computer-based information systems. It entails the successful integration of the computer-based processes into the dynamics they support. Section 5 describes the essentials of the integration process in terms of the implementation of the computational models used and the interfaces needed for the appropriate interaction with the computer-based processes.

This integration can be best achieved with the help of the abstraction-synthesis methodology, or ASM (Kampfner, 1987, 1997) that aims at the development of computer-based information systems that provide effective function support. The conceptual framework, modelling tools, and analysis and design techniques that the ASM provides allow for the synergistic combination of natural and artificial computing as a means of developing effective function support. Briefly, in the ASM the information needs of the functions are determined and specified on the basis of the knowledge that can be gathered about the information processing aspect of the dynamics. The requirements of a computer-based information system capable of providing effective support to these functions can then be specified on the basis of the information needs of the functions so determined. The ASM provides a synthetic approach to design in which various, alternative designs of the computer-based processes and their interfaces can be considered. Section 6 describes the essentials of the ASM and explains its adherence to the view of information processing as an aspect of the dynamics of systems.

INFORMATION PROCESSING AND THE DYNAMICS OF SYSTEMS

A strong form of the Church-Turing thesis asserts that any physical system can be simulated by a Turing machine (see for example, Conrad, 1985; Hofstadter, 1980). According to Michael Conrad (1985), this strong form of the Church-Turing thesis equates dynamics with computation in the sense that, if this thesis holds, any system can simulate (i.e. compute) at least its own dynamics, that is, its own behaviour. The view of information processing as an aspect of the dynamics of systems (Kampfner, 1998) sheds further light into this issue. According to this view, the dynamics of any system has a computational (information processing) aspect that can be thought of as the information processing capabilities that it needs in order to achieve its goals, or purpose. Another way of saying this is that the information processing aspect of the dynamics of a system represents the information processing capabilities that allow it to control and coordinate the processes that perform its functions. While the strong form of the Church-Turing thesis asserts that for any system there is an algorithm that can simulate its dynamics, the notion of information processing as an aspect of the dynamics confers to any system the computational capabilities that make its behaviour, that is, its dynamics, possible. According to this notion, the information processing aspect of the dynamics of a system is an integral, inseparable, indispensable part of this dynamics. This means that the dynamics of a system cannot take place without exerting the computational capabilities that its information processing aspect represents. The information processing aspect of the dynamics of a system is thus what allows it to compute and to realize its own behaviour (dynamics) and, as Conrad suggested, to simulate it with its own dynamics.

The algorithm for the simulation of the behaviour of a system, that according to the strong form of the Church-Turing thesis always exists, performs a computation that is equivalent to the computation that the information processing aspect of its dynamics performs. Both computations are equivalent in the sense that given the same input they produce an equivalent output, or result. It is important to realize, however, that although these two kinds of computations are equivalent in the sense mentioned above, they are performed in fundamentally different ways. The Turing machine operates on symbols that encode the inputs to this dynamics, the conditions under which it operates, and the results it produces. The information processing aspect of the dynamics of a system, on the other hand, represents the means that the dynamics uses to receive, store, transform, and communicate the information that it needs in order to achieve its purpose. As an integral part of the dynamics, information processing can be said to act on the actual values of the variables that the processes underlying this dynamics use, transform, and manipulate.

The information processing aspect of the dynamics of a system represents the particular way in which it processes information. This aspect of the dynamics represents what can be thought of as the information processing capabilities that are manifested through the execution of the physical processes in which it is embodied. It acts on the values of the variables that the physical processes that participate in it actually use, transform, and manipulate. The way in which systems actually process information varies with the type of dynamics they have, which itself varies with the type of system and its level in the systems hierarchy. There is clearly a staggering number of ways to process information. Our view of information processing, however, tells us that we can determine the way in which any particular system processes information if we identify the information processing aspect of its dynamics, that is, the way in which the processes that constitute its dynamics process information. This may be a very complex and challenging endeavour, especially when the dynamics of the system under study is highly complex. Once this is done, however, the relationship between information processing and the other aspects of the dynamics can be established in a way that can be expressed in terms akin to the processes that participate in this dynamics. Understanding this relationship is central to the study of a variety of issues and problems such as the effectiveness with which information processing supports the rest of the dynamics of a system, the effect that the way in which a system processes information has on its adaptability, the properties and capabilities of information processing in specific systems or types of systems, and many others. Expressing this relationship in terms akin to the processes that constitute the dynamics of a system clearly provides a solid, robust basis for the study of these issues and problems. We will discuss the importance of this relationship and refer to some of these issues and problems and to the systems, and types of systems, for which they are especially relevant. Figure 1 shows schematically the information processing aspect of the dynamics of a system.

NATURAL AND ARTIFICIAL INFORMATION PROCESSING

The information processing aspect of the dynamics of natural systems has evolved with these systems and, more specifically, with the dynamics of which it forms a part. An important landmark in this evolutionary process is undoubtedly the advent of human intelligence. Explaining the beginnings of human intelligence is clearly beyond the scope of this paper, but the fact is that through its existence human intelligence can be credited with the creation and development of increasingly powerful artificial means of processing information. The process of creating artificial means of processing information started with the creation and use of very primitive symbols for recording and communicating information and continued with the development and use of ever more advanced languages, devices, and systems for recording, storing, transforming, and communicating information. This process manifests the ability of human intelligence to augment its own computational capabilities in a way in which all of us, individually and as a society, participate. The development of increasingly powerful artificial means of information processing spans the development and use of human intelligence since its advent to the present and beyond. And it continues nowadays at an increasingly rapid pace. The success of this endeavour, however, depends not only on the quality, variety, flexibility, and computational capabilities of the tools and methods of information processing that we develop to this effect, but also on the ability of the designers of computer-based information systems to extend with them the computational capabilities of human intelligence and other natural forms of information processing in an effective manner.

As suggested earlier, the creation of artificial means of information processing can be considered an integral part of the development of human intelligence. It can be thought of as evolving gradually as a means to respond to the needs of information processing and communication brought about by the development of new knowledge and the increased sophistication and specialization of human activities. At some point during this process the advances in computer and information science and technology made possible the development of increasingly powerful means of storing, organizing, retrieving, and displaying larger and larger amounts of information, as well as the means of transmitting information at greater speeds and over increasingly larger distances. These advances, together with the growing information needs of individuals and organizations to which they have responded, have contributed to the acceleration of the pace at which artificial means of information processing are developed and used. The increasingly powerful capabilities of artificial information processing make it potentially more capable of extending the computational capabilities of human intelligence and other forms of natural computing. The realization of this potential, however, requires the appropriate integration of a synergistic combination of natural and artificial information processing into the dynamics of the system it serves.

We can restate the fundamental difference between natural computing, and artificial computing as exemplified by the Turing machine paradigm of computation, by saying that natural information processing is implicit in the dynamics of the systems it supports, but artificial computing is not and that for that reason it relies on computational models that describe relevant parts of such a dynamics. Clearly, natural computing does not rely on computational models of the systems it supports because it is embodied in their dynamics. In other words, natural computing does not need the guidance of computational models because it acts directly on the dynamics it supports. This restatement of the fundamental difference between natural computing and artificial computing highlights an important feature of artificial information processing: its reliance on computational models that describe relevant parts of the dynamics it supports. This makes the adequacy of the computational models that artificial information processing uses critical to its ability to extend the computational capabilities of human intelligence and other forms of natural computing in an effective manner. The adequacy of the computational models it uses, however, is not sufficient for the effectiveness of artificial computing in extending the computational capabilities of natural computing. The synergistic combination of natural and artificial computing is also needed for the effective support of function. In the next section we refer to basic principles and criteria that can guide us in the development of computer-based systems that achieve this goal.

PRINCIPLES AND CRITERIA FOR THE SYNERGISTIC COMBINATION OF NATURAL AND ARTIFICIAL COMPUTING

A function support principle for the development of computer-based information systems calls for the compatibility of the computer-based processes with the dynamics underlying the functions they support and with the adaptability of the whole system as a basic goal for the design of information systems (Kampfner, 1987, 1997). By the compatibility of the computer-based processes with the dynamics underlying the functions they support we mean their ability to provide the other processes that participate in the dynamics with the information they need, in the form they need it, and at the time they need it. According to the function support principle, this compatibility is essential for the effective support of function because it allows the functions being supported to achieve their goals. The function support principle also calls for the contribution of the computer-based information system to the adaptability of the whole system. Conrad's trade off principle is most relevant here, because according to it the programmability of digital computing makes it less adaptable and less computationally efficient than natural computing and vice versa. This means that in addition to ensuring the compatibility of the computer-based information processes with the dynamics that is needed for the effective support of function it must also be ensured that their design favours the adaptability of the system as a whole. In order to achieve this goal, the computer-based information system must be sufficiently modifiable but in a manner that contributes to the modifiability of the system as a whole, that is, to its adaptability.

The compatibility of the computer-based processes with the other processes that participate in the dynamics cannot be achieved without the design and construction of the appropriate interfaces between the computer-based processes and the processes with which they interact. The nature of these interfaces and the role they play in the integration of the computer-based processes into the dynamics they support are explained below. From the standpoint of adaptability, a computer-based information system that favours the right degree of subsystem independence is critically important (Kampfner, 2006). In this respect, various types of subsystems independence (or interdependence) and an approach to architecture design that aims at reducing the interdependence between subsystems in a convenient manner (Kampfner, 2008), and a top-down approach to design that focuses on architecture design as a means of achieving subsystem independence (Kampfner, 2009) have been considered. The idea that some of the information processing knowledge that a computer-based information system needs can be transferred to it only when it needs to be used has also been explored as a means of reducing the interdependence between the computer-based information system and the system it supports (Kampfner, 2010). This of course needs to be done in a manner consistent with the function support principle. I can also mention that the view of information processing as an aspect of dynamics helps us to handle the variability of information processing that exists due to the lack of structure of the processes that participate in the dynamics and the uncertainty of the changes that occur in these processes. Central to our approach to handling the variability of information processing is finding a combination of digital computing, human intelligence, and other forms of information processing as a basis for the design of a computer-based information system that effectively supports the functions of the system and contributes to its adaptability (Kampfner, 2011).

THE INTEGRATION OF COMPUTER-BASED INFORMATION PROCESSING INTO THE DYNAMICS IT SUPPORTS

The integration of artificial information processing into the dynamics of a system makes it part of the information processing aspect of its dynamics. The success of this integration, however, requires computational models that correctly describe relevant parts of the dynamics that they model, and that are implemented in a manner that makes the processes that they produce compatible with this dynamics.

Artificial information processing systems based on digital computing execute computer programs that implement the computational models. The inputs to these computer programs are symbols that encode values of the variables that participate in the dynamics they model. Similarly, the outputs of these computer programs are symbols that encode the results of the execution of the computational models. However, in order for the computer-based processes that implement the computational models to become an integral part of the dynamics they support, they must be executed as part of the information processing aspect of this dynamics. In other words, these computer-based processes must interact in an appropriate manner with the other processes that participate in this dynamics.

The need to use symbols that encode the inputs and outputs of computer-based processes highlights an important characteristic of digital computing and other forms of artificial computing, namely, that in order to participate properly in the dynamics it supports, any artificial information processing device or system requires interfaces that properly encode the input values that it acts on and decode the results that it produces. Designing, building, testing, and implementing the computer programs that implement the computational models and the appropriate interfaces is clearly essential to the development of computer-based information systems and other types of artificial information processing systems.

In the case of complex, adaptive systems such as modern organizations, the integration of artificial information processing into their dynamics requires also that any negative effect of artificial information processing on their adaptability be reduced as much as possible. More precisely, the goal is to enhance the adaptability of the system or, at the very least, to make sure that any loss of adaptability that may occur doesn't outweigh the benefits of artificial information processing. Making sure that the benefits of artificial information processing are not outweighed by a loss of adaptability is particularly important in the case of computer-based information systems in modern organizations. The reason is that in these systems the processes that the computer-based information systems generate become part of a very complex dynamics that is subject to unpredictable changes. What we need is computer-based information systems that capitalize on the advantages of modern information technology in a manner consistent with the adaptability of the organization they serve.

COMBINING NATURAL AND ARTIFICIAL INFORMATION PROCESSING FOR THE EFFECTIVE SUPPORT OF FUNCTION AND ADAPTABILITY

The ability of computer-based information systems to effectively extend the computational capabilities of human intelligence and other forms of natural computing cannot be achieved without the necessary synergy. This synergy must therefore be an essential goal for the development of computer-based information systems. The abstraction-synthesis methodology of information systems development, or ASM, (Kampfner, 1987, 1997, 2002) provides a means of achieving this goal on the basis of the information processing aspect of the dynamics of the systems to be supported. The ASM considers four basic steps for the development of computer-based information systems that provide effective function support and contribute to adaptability.

The first step determines and specifies the information needs of the functions to be supported. The information processing aspect of the dynamics underlying these functions is identified first. This amounts to finding out the information that the functions need, and the way in which their underlying dynamics receives, stores, transforms and communicates information. The ASM provides two basic tools for the analysis and specification of the information needs of specific functions of a system. One of these tools is the organizational control systems modelling formalism, or OCSM (Kampfner, 1987, 1997, 2002). This formalism provides a means of describing the structure of the system being supported in terms of the functions it performs and the relationships between them. The other tool is the informational interaction diagrams that describe the flows of information that must occur between functions in order for them to achieve their goals. These diagrams are developed on the basis of the description of the structure of the system (that the OCSM provides in terms of the functions it performs and the way they relate to each other). It is important to notice that the structure of a system and the nature and characteristics of the functions both determine the way in which the information must flow inside and between the processes that underlie these functions.

The OCSM description of the structure of a system, the informational interaction diagrams developed on the basis o this description, and all the necessary details about the way in which the functions to be supported use and exchange information constitute the specification of the information needs of these functions. This specification in fact describes an important part of the information processing aspect of the dynamics underlying the functions to be supported. As such, it provides an excellent basis for the analysis of the relationship of the information processing aspect with the other aspects of the dynamics. Understanding this relationship is clearly vital for the design, construction, and implementation of a computer-based information system that effectively supports these functions. Especially important in this respect is the value of the knowledge that the designers of the information system have about the relationship between information processing and the other aspects of the dynamics. This knowledge is clearly essential for the design and implementation of the interfaces needed for the integration of the computer-based processes into the dynamics they support.

The second basic step of the ASM deals with the determination of the requirements of a computer-based information system that brings the necessary synergy. Once the information needs of a system (i.e. an organization) have been identified in the context of the processes that constitute its dynamics, the requirements of the computer-based information system can be successfully determined and specified. The ASM considers three types of information system requirements. These are the logical, performance, and user interface requirements. These three types of requirements are briefly described next.

> The logical (also called computational) requirements, describe the transformations of the information representations that the computer-based information system can in principle perform. These computational requirements, identified in the information needs analysis process, are part of the information processing aspect of the dynamics to be supported.
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> The performance requirements are performance targets that need to be achieved with these computations in order for the functions that the computer-based information system supports to achieve their goals. These requirements describe the amounts of information to be processed, the response times required of each of these computations, the times at which these computations must be executed,

and the requirements for the transmission and communication of information.

The user interface requirements describe the way in which the computer-based information system must interact with its users, that is, with the other processes that perform the functions that the information system supports, including functions external to the system that provide inputs to the computer-based information system, or receive outputs from it. Some of these interactions are mediated by people. Some of them, however, are interfaces between computer-based processes and other processes that participate in the dynamics, but without human intervention. It is important to recall in this respect that artificial computing always requires suitable interfaces in order to become an integral part of the dynamics it supports.

An important feature of the information system requirements in the ASM is that the logical requirements are specified in a completely design-independent manner, and the performance and user interface requirements are expressed in a manner as design-independent as possible. The design-independent character of the specification of requirements in the ASM allows the designers to consider virtually any conceivable design alternative.

The third basic step of the ASM is the design of a computer-based information system that satisfies these three types of requirements. The ASM adopts a synthetic approach to the design of information systems. The design-independent nature of the specification of information systems requirements greatly facilitates the synthetic approach to design which in the ASM is a process of synthesis, evaluation, and selection of design alternatives. The synthesis of each design alternative is followed by the evaluation of its ability to satisfy all the requirements of the information system. Several alternative designs can be synthesized and evaluated as necessary and convenient. If more than one of these designs satisfies the information system requirements, one that meets suitable design objectives is selected for implementation.

The fourth basic step of the ASM is the implementation of a design alternative that meets all the requirements of the information system. The significance of the implementation step of the ASM is that it must accomplish the goal of integrating the processes that the computer-based information system generates into the dynamics underlying the functions it supports in an appropriate manner. This means that the processes must be compatible with this dynamics and must contribute to the adaptability of the system as a whole. In this respect, the correct implementation of the appropriate interfaces between the computer-based processes and the processes with which they interact are as important as the correctness of the processes that they interconnect with the rest of the dynamics. The correctness and compatibility of the processes, the suitability of their interfaces, and their contribution to the adaptability of the system are all critically important to the effective integration of the computer-based processes into the dynamics of the system being supported.

CONCLUSIONS

This paper discusses the notion of information processing as an aspect of the dynamics of systems and illustrates its value as a framework for the study of the information processing capabilities that the dynamics of a system possesses. An important advantage of this view is that it allows us to describe the information processing capabilities of the dynamics of a system in terms akin to the processes that constitute this dynamics. It also helps us to understand the way in which information processing relates to the other aspects of the dynamics. We focused on complex, adaptive systems such as modern organizations, which include both natural and artificial information processing capabilities as part of their dynamics.

The abstraction-synthesis methodology of information systems development (ASM) allows the designers to determine the information needs of the functions to be supported by a computer-based information system on the basis of the information processing aspect of their underlying dynamics. The ASM also allows for the design and implementation of the computer-based processes and their interfaces that are needed in order to fulfil these information needs. The ASM provides a framework for the integration of the computer-based processes and their interfaces into the dynamics they support. As the discussion illustrates, the view of information processing as an aspect of the dynamics of systems greatly facilitates the achievement of the synergistic combination of natural and artificial computing that is needed for the effective support of function and adaptability.

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