A BASIC PRINCIPLE FOR THE ARCHITECTURE OF COMPUTER-BASED INFORMATION PROCESSING

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ABSTRACT

In this paper we discuss the effect of computer-based information processing on the adaptability of the systems. Because of the close relationship that exists between subsystem independence and adaptability, the effect that the structure of computer-based information processing has on subsystem independence is central to our discussion. We are focusing here on complex systems that face an uncertain environment and that are controlled and operated by humans with the help of computer-based information systems. This type of systems includes organizations, complex projects, and complex processes and devices controlled by humans with the help of computers.
Three closely related, but distinct types of interdependence between the subsystems of a system can be distinguished. The first one is the interdependence between the computer-based information system and the subsystems of the main system it supports. The second type of interdependence is the one that exists among the other subsystems of the main system. The third type of interdependence is between the components, or functional subsystems, of the computer-based information system. These three types of interdependence between the subsystems of a system are clearly closely interrelated. The principle for architecture design presented here provides guidelines for the design of computer-based information systems that enhance the effectiveness and adaptability of the system they support by reducing as much as possible the effect that the various types of interdependence have on adaptability.

Keywords: architecture, computer-based information processing, adaptability, subsystem interdependence, functional subsystems.

INTRODUCTION

In this paper we discuss the effect of computer-based information processing on the adaptability of systems. Because of the close relationship that exists between subsystem independence and adaptability, the effect that the structure of computer-based information processing has on the degree of independence between the subsystems of the system it supports (referred to here also as the main system or the host system) is central to our discussion. We are focusing here on complex systems that face an uncertain environment and that are controlled and operated by people with the help of computer-based information systems. Among them we can mention organizations, complex projects, and complex processes and devices controlled by people. In all the cases of interest, the complexity of these systems and the uncertainty of the environment they face demand the use of computers to help them to effectively meet their information processing requirements. The view of information processing as an aspect of the dynamics of systems (Kampfner, 1998) is also central to our discussion. In particular, according to this view computer-based

information processing is part of the information processing aspect of the dynamics of the host system. Moreover, the architecture of computer-based information processing, that represents features of its structure, can also be considered part of the structure of the host system and, as such, it can be considered to partake in the influence that the structure of the host system has on all of its dynamic, including the information processing aspect and, more specifically, the computer-based information processing aspect. An important advantage of this view is that it provides a framework for the study of the relationship between information processing and the other aspects of the structure and dynamics in which it occurs. More specifically, it provides a framework for the study of the role that computer-based information processing plays as part of the information processing aspect of the dynamics of the host system and the effect that it has on the system's structure, behavior, properties and capabilities. Our main focus in this paper is the effect that computer-based information processing has on the adaptability of the host system.

By the adaptability of a system we mean its ability to persist despite the uncertainty of its environment (Conrad, 1983). As observed earlier (Kampfner, 1997, 2002), in order to provide effective support to the functions of the system it serves a computer-based information system must contribute to its adaptability. This makes a positive contribution to the adaptability of the host system an important goal of the design of computer-based information systems. A structural property of systems that is closely related to adaptability is subsystem independence, that is, the degree to which the subsystems of a system can act independently of each other. According to Conrad (1983) subsystem independence is good for adaptability although it also makes the more independent subsystems more difficult to coordinate. Subsystem independence is good for adaptability because it reduces the correlations between the modifiabilities of the subsystems involved (Conrad, 1983).

Viewing computer-based information processing and its architecture as integral parts of the dynamics of the host system and its structure, respectively, provides an excellent perspective from which the effect that a particular architecture of computer-based information system has on the independence of the subsystems of the host system and its adaptability can be analyzed. From this perspective, the role that computer-based information processing plays in the execution and coordination of the processes that perform the functions of the host system and the effect it has on subsystem interdependence and adaptability can indeed be effectively pursued (by the interdependence between the subsystems of a system we mean the opposite of subsystem independence; for the sake of clarity and consistency, however, we will use the term subsystem independence when we deal with its relationship to adaptability). In particular, the effect that the architecture of computer-based information processing has on structural features of the subsystems it supports such as their degree of interdependence and on features of their dynamics such as the processes and the forms of information processing involved, and the interactions between processes, including the interactions between the computer-based information system and its users. Another important advantage of this perspective is that the effect of subsystem interdependence on the correlations between the modifiabilities of the subsystems can be analyzed more effectively in the context of the dynamics in which information processing occurs.

The focus of Section 2 is the interdependence that necessarily occurs between the subsystems of a system. Three types of interdependence between subsystems and their interrelationships are particularly important to our discussion. The first one is the interdependence that necessarily occurs between the computer-based system and the subsystems it supports. Clearly, this type of interdependence stems from the introduction of the computer-based information system. A second type of interdependence occurs between the subsystems of the host system other than the computer-based information system. The second type of interdependence exists regardless of computer-based information processing, although it may be affected by it. The third type of interdependence occurs

between the functional components (i.e. subsystems) of the computer-based information system. It can therefore be associated with the architecture of computer-based information processing. An important observation about the relationship between these three types of interdependence is that the introduction of a computer-based information system gives rise to interdependences of the first and third types, that is, between itself and the subsystems it supports and between its own functional components, respectively. In doing so, however, the computer-based information system makes the subsystems it supports less interdependent among themselves in terms of information. The important tradeoff that this relationship implies is also discussed in Section 2.

In Section 3 we discuss an important information processing-related factor of subsystem interdependence. This factor is the extent to which the subsystems of a system need to have information about other subsystems that is not essential for the performance of their respective functions in order to interact properly with them. The information that the subsystems need to have about the structure of other systems in order to interact with them is particularly important from the standpoint of the effect of interdependence on adaptability. As it is also discussed in Section 3, the analysis of this factor in a particular situation requires due consideration of the structure and dynamics of the subsystems involved. This helps to understand the relationship between computer-based information processing and other aspects of the dynamics including other forms of information processing and, ultimately, the effect that the need of information that a given subsystem has about other subsystems affects its interdependence with these other subsystems. This information processing-related factor plays a central role in the first and third types of subsystem interdependence, where computer-based information processing also plays a central role. The role of this factor on the first and third types of interdependence is also discussed in Section 3.

In Section 4 we introduce some concepts of the formal theory of adaptability (Conrad, 1983) that are essential to the analysis of the effect of subsystem interdependence on the correlations between the modifiabilities of the subsystems of a system and, consequently, on the adaptability of the system as a whole. The representation of the effect of interdependences on adaptability in terms of effective entropies is particularly useful to our analysis because it allows us to consider the effect on adaptability not only of the potential variability of a particular subsystem, but also the effects that its interdependence with each of the other subsystems, and combinations of them, have on the correlations it has with their modifiabilities. The study of the effect of the information processing-related factor on the adaptability of the host system is indeed facilitated with this formalization. The adaptability formalism allows us to analyze, for example, the correlations between modifiabilities that stem from the interdependence of the functional components of a computer-based information system (third type of interdependence) on the basis of the different kinds of information that these components must have about each other. In a similar manner, the adaptability formalism allows us to analyze the correlations between the modifiability of the computer-based information system and those of the subsystems it supports (stemming from the first type of interdependence). Also in a similar manner, although in this case considering non-computer-based forms of information processing and other aspects of the dynamics, the adaptability formalism allows us to analyze the correlations between the non computer-based subsystems of the host system (stemming from the second type of interdependence).

Section 5 is about the strategy that must be followed in order to design an architecture of computer-based information processing that allows for effective support to the functions of host system in a manner that maintains or enhances its adaptability. Because of the influence that it has on the interdependence of the subsystems of the host system the architecture of computer-based information processing needs to be designed with due

consideration of the effect that the information processing-related factor of subsystem interdependence mentioned above has on the correlations between the modifiabilities of subsystems of the host system in particular situations. The strategy for achieving this that has been outlined in the body of this paper is stated in this section as a basic principle for the architecture of computer-based information systems.

In Section 6, we conclude with some remarks on the results obtained and their implications for future research.

COMPUTER-BASED INFORMATION PROCESSING AND THE INTERDEPENDENCE OF THE SUBSYSTEMS IT SUPPORTS

Every computer-based system has an architecture consisting of architectural elements from which the system can be constructed (Rozanski and Woods, 2005). According to these authors a given architecture or architectural style expresses a fundamental structural organization scheme for software systems. Our emphasis on the effect of the architecture of computer-based information processing on the adaptability of systems responds to the fact that the structure of any system influences its dynamics and its adaptability. Just as information processing is an integral part of the dynamics in which it participates, the architecture of computer-based information processing is an integral part of the structure of the host system. As such it partakes in the influence that the structure of the host system has on its own dynamics including the information processing aspect of this dynamics. As part of the structure of the host system, the architecture of computer-based information processing influences the interdependence that exists between the subsystems of the host system, including the components (i.e. functional subsystems) of the computer-based information system. Three types of interdependence between subsystems are particularly important to our discussion. Figure 1 shows graphically these three types of interdependence. The first type of interdependence occurs between the computer-based information system and the subsystems that it supports. Because it is an integral part of the structure of the host system the architecture of computer-based information processing influences the first type of interdependence. What we refer to as the second type of interdependence involves subsystems of the host system other than the computer-based ones. As an integral part of the structure of the host system, the architecture of computer-based information processing influences the second type of interdependence as well. An important part of this influence is a reduction of the interdependence between the subsystems of the host system that occurs because a new computer-based information system provides to some of these subsystems information that they formerly received from other subsystems. This clearly reduces their interdependence. It is important to notice, however, that in doing so, the computer-based information system becomes interdependent with the subsystems it support thus creating the first type of interdependence. The third type of interdependence is between the functional components (i.e. functional subsystems) of the computer-based information system. It is also depicted in Figure 1. The architecture of computer-based information processing reflects the relationships that exist between the functional components of the computer-based information system. The interdependence between these components is therefore a property of the architecture of computer-based information processing. These three types of interdependence are particularly relevant to the study of the influence that the architecture of computer-based information processing exerts on all aspects of the dynamics of the host system and on its adaptability.

The three types of interdependence between the subsystems of a system mentioned above are closely interrelated. For example, as noted earlier, a computer-based information system reduces the interdependence that the subsystems it supports formerly had. In doing so, however, it becomes interdependent with these subsystems thus creating the first type of interdependence. In order to decrease interdependence in the system as a whole (i.e. the host system), however, the reduction of the second type of interdependence that the new

computer-based information system brings about must not be exceeded by the increase of the first and third types of interdependencies that it creates. Another way of saying this is that in order to obtain a net decrease of the interdependence between the subsystems of the host system, the architecture of computer-based information processing must be consistent with interdependences of the first and the third type that are sufficiently small. More specifically, these interdependences must be consistent with a sufficiently low correlation of the modifiabilities of the subsystems (and functional components) involved. As mentioned earlier, the architecture of computer-based information processing can be designed in a manner in which the first and third type of interdependence that it creates causes a low correlation between the modifiablities of the components of the computer-based information system and between the modifiability of the computer-based information system and the modifiabilities of the subsystems it supports. A positive contribution of computer-based information processing to the adaptability of the host system can be achieved only if the correlation between these modifiabilities does not offset the gain in adaptability that the computer-based information system obtains by reducing the second type of interdependence.

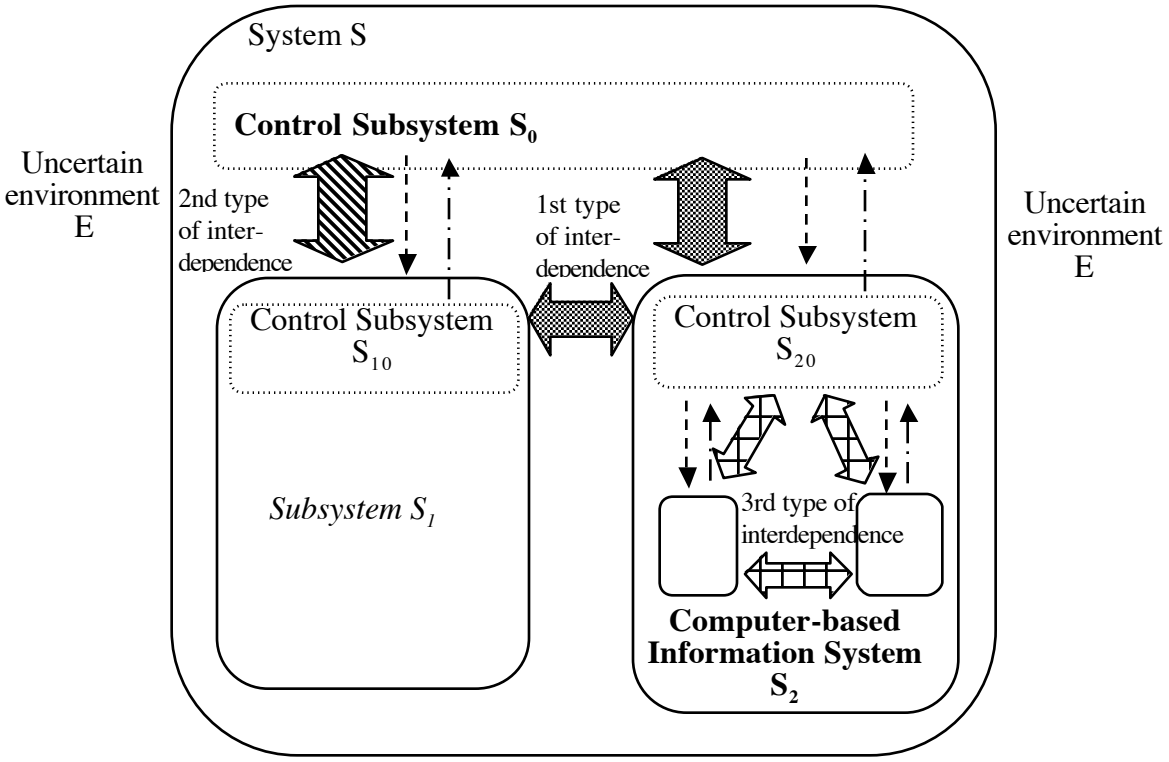

Figure 1 Hierarchy diagram of a system S with 3 subsystems: S_0, S_1, and S_2. The diagram shows the structure of system S following the OCSM modeling formalism (Kampfner, 1987). The diagram also depicts the three main types of interdependence between subsystems.

Subsystem interdependence is usually the result of the interplay of many different factors. These factors are determined to a great extent by the dynamics underlying the functions of the subsystems involved. The first type of interdependence is based on the reliance of the subsystems of the host system on the information that the computer-based information

system provides. It is therefore related to the information processing aspect of the dynamics. The interdependence between the components of the computer-based system (the third type of interdependence) is also based on the information processing aspect of the dynamics. Unlike the first type of interdependence, however, the third type of interdependence is based on computer-based information processing. The interdependence between subsystems other than the computer-based information system, that is, the second type of interdependence, is not only informational in character. It is also based on the need of these subsystems to exchange materials, equipment, energy, and economic resources. Although the dynamics underlying these subsystems is not necessarily centered on information processing it includes forms of information processing that are not computer-based, especially those based on human intelligence. The interdependence that is based in these forms of information processing is clearly reduced when a new computer-based information system is installed. As the foregoing discussion shows, different kinds of dynamics underlie each of the three forms of interdependence. The designers of the architecture of computer-based information processing must consider the kind of dynamics underlying each of these interdependences because this dynamics determines the factors that must be considered in each case for the study of the correlations between modifiabilities.

AN INFORMATION PROCESSING-RELATED FACTOR OF SUBSYSTEM INTERDEPENDENCE

The view of information processing as an aspect of the dynamics of systems allows us to consider the architecture of information processing as an integral part of the structure of the host system and the processes that the computer-based information system performs as an integral part of its dynamics. An important advantage that this view offers for the analysis of the effect of interdependence on adaptability is that it facilitates the identification of the factors that underlie the interdependence. Identifying these factors is clearly essential for the analysis and evaluation of the correlations between the modifiabilities of the interdependent subsystems in particular situations. One of these factors is particularly important from the standpoint of the effect of computer-based information processing on subsystem independence. This factor relates to the information that each of the interdependent subsystems requires about the structure and dynamics of the others in order to perform its own functions. More precisely, this factor is the extent to which the computer-based information system on the one hand, and the subsystems it supports on the other, need information about each other that is not essential for the performance of their respective functions; the need of the computer-based system and the subsystems it supports of non-essential, structural information about each other is particularly important from the standpoint of the effect of subsystem interdependence on adaptability.

The need that the subsystems of a system have of information about each other affects negatively the adaptability of their parent system because it makes their modifiabilities more correlated. This happens because any change in a subsystem that affects the information that other subsystems need about it causes a corresponding change in those subsystems. Clearly, in this respect, the goal of architecture design is to reduce the need that the computer-based information system and the subsystems it supports have of information about each other that is not essential for the performance of their respective functions. The need of structural information about other subsystems that is not essential for a subsystem to perform its functions must be especially discouraged. For example, the information that a computer-based information system needs about the subsystems it supports is not essential for the performance of its functions if it is possible for it to perform such functions without this information. Similarly, the information that a subsystem needs about the computer-based information system that supports it is not essential for the performance of its functions if it is possible for it to interact properly with the computer-based information system and receive from it the information it needs in an appropriate manner without such

information. For example, the information that a computer-based information system may have about how the subsystems it supports obtain the information that they submit to it for processing is not essential for the performance of its functions if it can possibly perform this functions without such information. Clearly, the need of the computer-based system to have this information must be avoided as much as possible by its designers. Much of the information that a computer-based system must have about the subsystems it supports is typically included in the specification of information system requirements. The abstraction-synthesis methodology (ASM) of information systems development (Kampfner, 1987, 1997) emphasizes a specification of information system requirements that describes only the information needs of the functions (i.e. functional subsystems) to be supported as a means of avoiding the need of non-essential information.

It is particularly important to avoid as much as possible the need of the computer-based information system and the subsystems it supports of non-essential, structural information about each other. One reason for this is that changes in the structure of a system are in general more difficult to achieve than non-structural changes. A change in the procedure for the verification of the customer's credit limit in a customer order processing subsystem of an organization, for example, would require a corresponding modification of the processes that verify customer credit in the computer-based information system. Similarly, a structural change in the computer-based information system that process customer orders such as a change in the organization of its processes needed to accommodate advances in information technology would require a corresponding modification of the way in which the customer order processing subsystem of the host system performs its functions. Business process reengineering (Huff, 1992) exemplifies these situations. In order to avoid the need of non-essential, structural information, the goal of architecture design would be make the computer-based system less sensitive to changes in the subsystems it supports. In the case of the customer order processing system, for example, it could make the module of the computer-based information system that verifies the credit limit of customers as independent as possible from the other modules that process customer orders.

In the ASM the logical requirements of the information system consist of a design-independent description of the computations that need to be performed by the information system in order to perform its functions. The design independence of this specification helps to avoid the need that the computer-based information system may have of non-structural information about the subsystems it supports.

THE ARCHITECTURE OF COMPUTER-BASED INFORMATION PROCESSING AND THE ADAPTABILITY OF SYSTEMS

M. Conrad's theory of adaptability (Conrad, 1983) allows us to formalize the relationship between the adaptabilities of the subsystems of a system in a manner that permits the representation of the relationship between their modifiiabilities and facilitates the analysis of their potential correlations. We will use this formalism here for the analysis of the three types of subsystem interdependence mentioned earlier. We will first refer to some adaptability concepts and results that are essential to our analysis.

To illustrate how the independence of the functional components of computer-based system contributes positively (or, alternatively, how their interdependence contributes negatively) to the adaptability of a computer-based system and that of the host system, we consider a small simplified system of only three subsystems. We use the OCSM formalism (Kampfner, 1987, 2006) for the description of this system as a hierarchy of systems with distributed control as illustrated in Figure 1. The adaptability of such system can be expressed in terms of the independence (or interdependence) of its subsystems by the following expression:

$$V(S_0'S_1'S_2') - V(S_0'S_1'S_2'|E') + V(E'|S_0'S_1'S_2') \geq V(E') \quad (1)$$

In this expression, $V(S_0'S_1'S_2')$ represents the potential variability (or behavioral uncertainty) of the transition scheme of the computer-based system as an entropy using the information theory formalism defined by Shannon and weaver (1962). Similarly, $V(S_0'S_1'S_2'|E')$, a conditional entropy, represents the behavioral uncertainty of the system given the behavioral uncertainty of the environment; $V(E'|S_0'S_1'S_2')$ represents the potential indifference of the behavior of the system with respect to the environment; and $V(E')$ represents the behavioral uncertainty of the environment.

The effect of the interdependence of the components of a system on adaptability can be seen if we express any of the above mentioned components of adaptability in terms of the behavioral uncertainties of its subsystems as a sum of their effective entropies (Conrad, 1983). Let us consider $V(S_0'S_1'S_2')$ to illustrate the use of effective entropies, as shown in Equation (2).

$$V(S_0'S_1'S_2') = V_e(S_0') + V_e(S_1') + V_e(S_2') \quad (2)$$

where $V_e(S_0')$ represents the effective entropy of S_0', the transition scheme of subsystem S_0., and similarly for $V_e(S_1')$, and $V_e(S_2')$.

The advantage of this representation is that we can expand the effective entropies in a form that allows us to consider the effect of subsystem interdependence on the correlation of the modifiabilities of the subsystems of a system, hence on its adaptability.

To illustrate this, consider the expansion of the effective entropy represented by the term $V_e(S_0')$ of Eq. (2). This expansion is shown in Eq. (3).

$$V_e(S_0') = 1/3[V(S_0') + 1/2V(S_0'|S_1') + 1/2V(S_1'|S_2') + V(S_0'|S_1'S_2')] \quad (3)$$

In Eq. (3) the leading term $V(S_0')$ that represents the modifiability of the transition scheme of subsystem S_0 should be sufficiently large. The conditioned modifiability terms, also called independence terms, $V(S_0'|S_1')$ and $V(S_0'|S_1'S_2')$ on the other hand, express the extent to which the modifiabilities of the three subsystems S_0', S_1', and S_2' will be correlated. It is important to observe here that the observable modifiabilities of the different subsystems will be correlated to the extent to which the maximum uncertainty is not achieved for a given component of adaptability. For example, the modifiabilities of S_0', S_1', and S_2' will be correlated to the extent to which the maximum uncertainty of $V(S_0')$ is not achieved.

The magnitude of the effect that the degree of interdependence of the subsystems of a system has on its adaptability clearly depends on the potential behavioral variability of each of these subsystems and the correlations between their modifiabilities as implied by the conditioned modifiability terms.

A BASIC PRINCIPLE FOR THE ARCHITECTURE OF COMPUTER-BASED INFORMATION PROCESSING

The architecture of the computer-based information system defines the relationship between its functional components and, consequently, has a strong influence on the interdependence between these components (third type of subsystem interdependence) and on its interdependence with the subsystems it supports (first type of interdependence). Also,

although in a more indirect manner, the architecture of computer-based information processing influences the interdependence between the non-computer-based subsystems of the host system (second type of interdependence). As an integral part of the structure of the host system the architecture of computer-based information processing contributes to shape all the aspects of its dynamics including the computer-based information processing aspect of this dynamics. What we want to point out here is that, because of its influence in the three types of interdependence, the architecture is critical to the ability of computer-based information processing to provide effective support to the functions of the host system and to contribute to its adaptability. But how can architecture design contribute to achieve the more general, overarching goal of providing effective function support while preserving or enhancing the adaptability of the host system? The answer is that the architecture of computer-based information processing must make the effective support of function possible in a manner that is consistent with the achievement of the necessary adaptability.

From the standpoint of achieving the necessary adaptability, the architecture of computer-based information processing must reduce the third type of interdependence in a manner consistent with a sufficiently low correlation between the modifiabilities of the computer-based system components. It must also reduce the interdependence between the computer-based information system and the subsystems it supports in a manner consistent with a sufficiently low correlation between their modifiabilities. Finally, it must also be consistent with a low correlation between the modifiabilities of the subsystems of the host system other than the computer-based system.
By sufficiently low correlations between modifiabilities we mean here that the loss of adaptability that they entail must not exceed the gains that in terms of adaptability the reduction of the second type of interdependence brought about by the introduction of computer-based information processing. In other words, achieving these sufficiently low correlations between the modifiabilities of the subsystems of the host system, including those involving the computer-based information system and its functional components is a basic, underlying goal of architecture design.

Focusing on the information processing-based factor of subsystem interdependence mentioned above further helps the designers of the computer-based information system to find concrete ways of achieving the necessary reductions of the interdependence between subsystems and of the correlations between their modifiabilities. The correlations between modifiabilities associated with the first type of subsystem interdependence can be reduced discouraging the need that the computer-based system and the subsystems it supports have of information about each other that is not essential for the performance of their respective functions. The need to have structural information about each other must of course be discouraged even more strongly. This factor of subsystem interdependence helps also to find concrete ways of handling the third type of subsystem interdependence in a manner that favors adaptability. In this respect the goal of architecture design becomes to discourage the need between the functional components of the computer-based information system of having information about each other that is not essential in order for each of them to perform their respective functions. The following basic principle provides the necessary guidance for the achievement of this design goal for the architecture of computer-based information processing: *The architecture of computer-based information processing must reduce the interdependence between the components of the computer-based information system in a manner that increases the adaptability of the host system. This can be done by reducing as much as possible the information that the computer-based information system and the subsystems it supports need to have about each other that is not essential for them to perform their respective functions. The need of structural information about each other must be especially avoided.*

A Basic Principle for the Architecture

The adaptability of computer-based information processing is an important, although usually not very explicit, concern of computer scientists, software engineers, and information system designers. A common underlying goal of many important developments and strategies of information technology, software engineering and information systems design is to develop software that is easy to maintain, flexible, reusable, and consistent with the interoperability and the scalability of the systems it supports. A series of developments leading to these results includes the development of structured design and module independence as a means of improving the maintainability of software, the development of structured data types and the properties of encapsulation, information hiding and class inheritance that led to object-oriented systems and the resulting reusability and extensibility of software. To this we can add the development of java and platform independent systems, the development of client/server architectures, different types of middle ware and distributed systems, service oriented architectures, the .Net framework and Web services. As a particular arrangement of the components of a computer-based information system together with the relationships between these elements that it implies, the architecture of computer-based information processing can be associated with the effect that the structure it represents has on the adaptability of the host system and on its own adaptability. The basic principle for the architecture of computer-based information processing introduced here offers a framework in which the effectiveness of computer-based information processing and the adaptability of the systems they support can be effectively pursued.

CONCLUSIONS

As an integral part of the structure of the system it supports, the architecture of computer-based information processing influences the structure and the dynamics of the system it supports, the host system, including structure and dynamics of computer-based information processing. In doing so, however, it influences the interdependence of the subsystems of the host system and consequently, the adaptability of the host system. The basic principle for the architecture of computer-based information processing stated above provides a framework for architecture design that allows us to harness three different types of subsystem interdependence in a manner that allows for the effective support of the functions of the host system in a manner that maintains or enhances its adaptability.

An important factor of subsystem interdependence is the information that the computer-based information system and the systems it supports need to have in order to perform their respective functions. The basic principle for the architecture of computer-based information processing introduced here aims at reducing as much as possible the need that the computer-based information system and the subsystems it supports have of information about each other in order to perform their functions. The architecture of computer-based information processing must discourage the need of structural information about each other in an even stronger manner.

Future research is needed to identify specific factors of interdependence in specific kinds of systems and relate these factors to particular architectural styles and perspectives of software systems and to particular frameworks and approaches to information systems development.

REFERENCES

Conrad, M. (1983). *Adaptability*, Plenum Press, New York.

Huff, S. L. (1992). "Re-engineering the Business," *Business Quarterly*.

Kampfner, R. (1987). A hierarchical model of organizational control for the analysis of information systems requirements, *Inf. Syst.* 3(3): 243-254.

Kampfner, R. (1997). Function Support as an Information Systems Development Paradigm, *World Futures,* Vol. 50: 689-702.

Kampfner, R. (1998). Dynamics and Information Processing in Adaptive Systems, BioSystems, Vol. 46: 153-162.
Kampfner, R. (2002). Digital and Biological Computing in Organizations, *BioSystems*, Vol 64: 179-188.
Kampfner, R. (2006). Adaptability and the integration of computer-based information processing into the dynamics of organizations, *BioSystems*, Vol. 85: 30-36.
Rozanski, N. and E. Woods (2005). *Software Systems Architecture*, Addison-Wesley, New York.
Shannon, C. E., and W. Weaver (1962). *The Mathematical Theory of Communication*, University of Illinois Press, Urbana.