The Need of Compatibility of Information Processing with the Control Structure of the Organization

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Abstract

In order to be effective an information system must be compatible with the structure and dynamics of the organizational functions it supports and with the adaptability of the organization. An important aspect of the structure of organizations is their control structure, that is, the way in which their control functions relate to each other and to the organizational functions they control. The potential impact of the information system on the adaptability of the organization is particularly important since it affects the ability of the organization to cope with the uncertainty of its environment. This paper addresses the need for an information system to be compatible with the structure and dynamics of the organization it supports and with its adaptability. Because of the effect that the control structure of an organization has on its adaptability, modeling organizations as distributed control structures is particularly useful in our case.

Keywords: compatibility; information processing; control structure of organizations

Introduction

Any dynamic system needs to process information in order to achieve its goals or purpose. The need of information processing arises from the need of these systems to control and coordinate their functions. Biological systems, for example, coordinate a variety of functions of different types and at different levels in order to achieve their purpose. The amazing variety of functions performed by even the simplest of biological systems clearly calls for a corresponding variety of ways of processing information. It is in fact remarkable that despite their enormous variety each of the functions of biological systems is supported in a highly effective manner. Biological systems process information in a manner that is highly compatible with their structure, dynamics and adaptability. One of the most important manifestations of the dynamics of a system is the performance of its functions. The compatibility of biological information processing with the structure, dynamics, and adaptability of biological systems can thus be seen as concomitant to its ability to provide effective

support to their functions. The same idea can be applied to information processing in organizations. In fact, we consider the achievement of the compatibility of information processing with the structure, dynamics, and adaptability of the organization as a guiding principle for the design of computer-based information systems capable of providing effective support to its functions (Kampfner, 1997, 2002).

In biological systems, information processing is natural and has evolved with the functions it supports. Its effectiveness has been tuned by the evolutionary process to the specific needs of biological functions. In organizations, however, biologically-based information processing, represented mostly by human intelligence, is combined with a growing use of computer-based information processing. Computer-based information systems are the product of human design and planning. The effectiveness of a computer-based information system therefore depends on the ability of its designers to make it compatible with the functions it supports and with the adaptability of the organization. An important difference between biological information processing and computer-based information processing in organizations clearly becomes apparent here: while in biological systems information processing provides effective function support in a natural manner, the designers of information systems in organizations must create the necessary compatibility of computer-based information processing with the organizational functions it supports.

Obviously, this cannot be accomplished without duly taking into account the structure and dynamics of the organization with which the information system must be compatible. The structure of the organization is particularly important in this respect. The reason is that the structure of a system necessarily influences its dynamics and its adaptability. Since information processing can be considered an aspect, indeed an integral part, of the dynamics of systems (Kampfner, 1998), the way information is processed in an organization and the way in which it flows through its functions is necessarily influenced by its structure. The structure of an organization also affects its adaptability. Adaptability is the ability of a system to continue functioning indefinitely despite the uncertainty of its environment (Conrad, 1983). The ability of an organization to change in response to unpredictable changes in its environment is therefore essential to its adaptability. To favor adaptability, the structure of an organization must therefore favor its ability to change in response to unpredictable changes in its environment.

We model organizations using the organizational control systems modeling formalism, or OCSM (Kampfner, 1987, 2002). This formalism, described in more detail in Section 2, allows us to model organizations as hierarchical, distributed control structures. This representation facilitates the analysis of the relationship between the structure of an organization and its dynamics, especially the dynamics of information processing. The representation of the structure of organizations provided by the OCSM formalism facilitates the analysis of the effect that certain structural features of organizations have on their adaptability. Among these features, subsystem independence is most relevant to our discussion because although it favors adaptability it makes the coordination of more independent subsystems more costly.

In this paper we focus on the compatibility of computer-based information processing with the control structure of the organization. The control structure of an

organization plays an essential role in the control and coordination of its functions and has a strong effect on its adaptability. Before going further into the discussion of the effect that the control structure of an organization has on its adaptability and the requirements it imposes on its supporting information systems, however, let us emphasize the fact that a new information system always affects the structure, dynamics, and adaptability of the organization it supports. An important consequence of this is that the structure, dynamics, and adaptability of the organization with which the information system must be compatible are also affected by its design.

An information system always affects the way in which information is processed in the organization it supports. The changes that an information system causes on the way in which information is processed in an organization may also affect its structure since it affects the way in which its functions relate to each other. Clearly, the changes that the information system causes in the organization may affect not only its structure but also its adaptability. Depending on the extent and nature of the changes it produces, the effect that an information system has in the structure and the adaptability of the organization can be quite considerable. The theory and techniques of business process reengineering (see, for example, Huff, 1992) and business process redesign (Venkatraman, 1990) refer to situations in which specific business processes in an organization undergo changes in connection with the development of information systems, especially when the introduction of new information technology is involved. We will consider these changes here but from a broader perspective that allows us to consider the impact that computer-based information processing has on the structure, dynamics, and adaptability of the organization as a whole.

The effect that the control structure of an organization has on its adaptability can be analyzed from the standpoint of the effect it has on subsystem independence, which favors adaptability. According to M. Conrad (1983), a necessary concomitant of efficient adaptability is that systems be broken up into levels of organization and compartments at different levels which are as independent as possible subject to the condition that the cost of constructing and maintaining a functional subsystem with the needed independence does not outweigh the benefits in terms of the modifiability needed for adaptability. Subsystem independence favors adaptability because it reduces the correlation between the modifiabilities of the subsystems of a system (Conrad, 1983). Constructing and maintaining subsystem independence, however, requires constructing and maintaining the mechanisms and capabilities needed for the control and coordination of the subsystems in question. The potential impact of computer-based information processing on the control structure of the organization they serve is clearly of great importance in this respect. The design principle mentioned earlier provides us with the necessary guidance for the development of information systems that favor adaptability while reducing the cost of subsystem independence.

This paper is organized as follows. In Section 2 we discuss the OCSM representation of the structure of organizations. This representation facilitates the analysis of the control structure of organizations from the standpoint of its relationship to subsystem independence. The OCSM representation of the structure of organizations can be associated with key aspects of the dynamics of their functions including the information processing aspect of this dynamics. This clearly

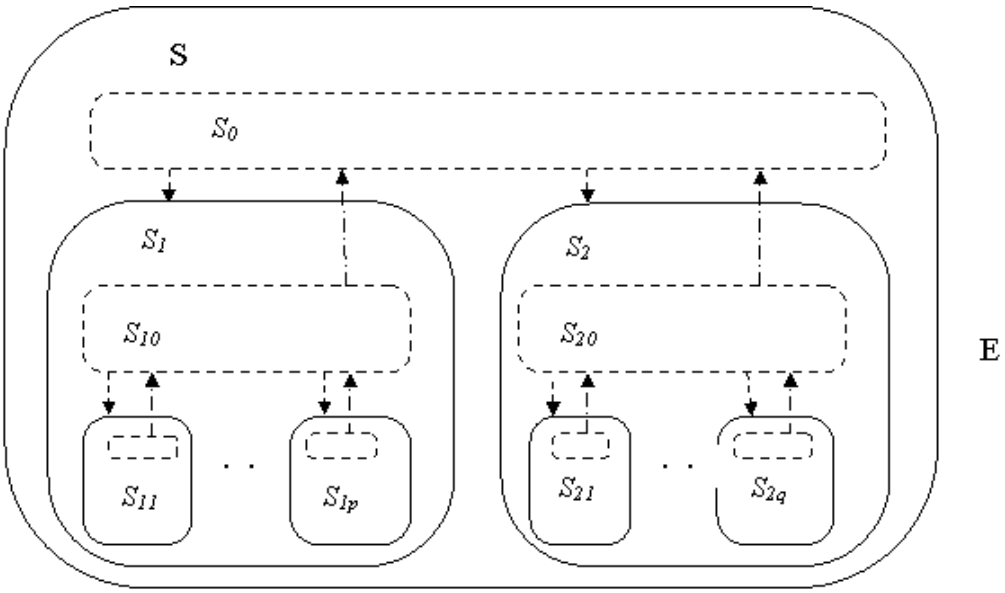
helps to analyze the impact of computer-based information processing on subsystem independence and, consequently, on the adaptability of the organization. In Section 3, we discuss the nature of the impact that computer-based information processing has on the structure and dynamics of organizations and on their adaptability. In particular, we discuss the impact that the programmability of digital computing has on the adaptability of organizations from the standpoint of M. Conrad's tradeoff principle of information processing (Conrad, 1985). According to this principle the programmability of information processing is achieved at the expense of adaptability and computational efficiency. The programmability of digital computing, in particular, is accompanied by a corresponding lack of adaptability. Because of this, computer-based information processing has a potentially negative effect on the adaptability of the organizations that, if overlooked, may result in an actual loss of adaptability. Also, an increase in the degree of integration of the processes that perform the functions of organizations, by what we mean a tighter coupling between these processes, is likely to result in a loss of subsystem independence for the organization, hence adaptability. The integration of processes often results in an increase of the efficiency with which the integrated processes are carried out. This efficiency-adaptability tradeoff needs of course to be carefully considered by the designers of information systems before any design alternative is selected for implementation. In Section 4 we discuss some of the basic factors involved in the application of the design principle to the development of computer-based support for the control functions of organizations. In Section 5 we summarize the results obtained and discuss their implications for the design of computer-based support to the functions of organizations.

Modeling the Structure of Organizations

The organizational control systems modeling (OCSM) formalism (Kampfner, 1987, 1997) helps us to model adaptive systems such as organizations as hierarchies of relatively self-controlling subsystems, each performing a particular organizational function. This representation allows us to describe the structure of control that exists in a particular organization in terms of the relationship that exists between the subsystems in which it is decomposed. As shown in Figure 1, the OCSM formalism provides three binary relations for this kind of structural description. Although the organizational structure shown in Figure 1 is highly simplified, is easy to see that the OCSM formalism allows for the description of arbitrarily complex structures. The structure shown in Figure 1 is sufficient for our purposes, however, since it allows us to consider the impact of subsystem independence on the complexity of the control function and on the adaptability of the organization.

The structure of any system, including organizations, influences its dynamics. As mentioned above, however, an important aspect of the dynamics of systems is information processing which, for this reason, is also influenced by the structure. The OCSM formalism allows us to model the basic pattern of information flow that the structure of a particular organization imposes on its functional subsystems. This pattern of information flow that must exist in order for the functions of the organization to be performed properly is captured in the informational interaction diagrams such as the one shown in Figure 2. According to the design principle, in order to provide effective function support, an information system must provide the

organization it serves with automated information processing processes that process information in a manner consistent with its structure, dynamics, and adaptability. In other words, it must support the pattern of information flow that the structure of the organization imposes on its functions. In the next section we discuss the impact that computer-based information processing has on the adaptability of organizations from the standpoint of its programmability and the effect it has on subsystem independence.



The OCSM considers three binary relations between subsystems:
The *CONTROLS* relation (symbolized by downward dashed arrows) relates a control subsystem to the operational subsystems it controls. e.g. *CONTROLS*(S_0, S_1).
The *REPORTS-TO* relation (symbolized by upward dotted arrows) relates two control subsystems at contiguous levels in the hierarchy of control. e. g. *REPORTS-TO*(S_{10}, S_0).
The *SUBSYSTEM* relation has the usual meaning of the term. e. g. *SUBSYSTEM*(S_{11}, S_1). It is symbolized graphically by placing the subsystem box within the box of its parent system.

Figure 1. Schematic view of the structure of an organizational system with three subsystems using the organizational control systems modeling formalism, or OCSM, (Kampfner, 1987, 2002). At the top level, the whole adaptive system (or organization), say S, is capable of adapting to the uncertainty of its environment E. It does so because S_0, its control subsystem, coordinates S_1 and S_2, its functional (operational) subsystems. However, since S_1 is adaptive, it consists of a control subsystem, say S_{10}, that monitors and coordinates S_{1j}, $j = 1, 2, \ldots, p$, its functional (operational) subsystems towards the achievement of its own goals. A similar decomposition scheme can be applied to each functional subsystem that has adaptive capabilities.

The Impact of Computer-Based Information Processing on the Adaptability of Organizations

M. Conrad's tradeoff principle of information processing states that the programmability of information processing is always exchanged by adaptability and computational efficiency (Conrad, 1985). Computational efficiency refers here to the use of the computing power available in a system. It can be measured for example in terms of the proportion of processors that can be concurrently active in a system at a given time (Conrad, 1985). According to this principle, computer-based information processing is not adaptable in the sense that it cannot evolve through a process of variation and selection. The lack of adaptability of digital computing can be easily corroborated at the machine language level, where the computations specified by computer programs cannot be effectively changed without rewriting the programs. Also, as the tradeoff principle asserts, computer-based information processing is not very efficient computationally in the sense that the degree of concurrency and parallelism that can be obtained in computer-based systems is much lower than the one obtained in biological systems. The inherent adaptability and computational efficiency of biological information processing, on the other hand, is always accompanied by a corresponding lack of programmability.

An important characteristic of modern organizations is that they combine biological and computer-based information processing. Biological information processing takes place in organizations mostly in the form of human intelligence. Human intelligence plays a unique role in organizations because of its unique computational capabilities. The creativity and intuition of humans, our ability to solve general problems and to make decisions in ill-structured situations, and many other capabilities of human intelligence are no doubt essential to the ability of organizations to function well on the face of complex and uncertain environments. However, it is obvious that the success of modern organizations wouldn't be possible without the help of computer-based information systems. The advances of information technology have made it possible to utilize the great speed, capacity, and computational capabilities of digital computers for the support of practically all kinds and levels of organizational function. No doubt, the computational power that digital computing brings to organizations is to a great extent possible because of its programmability. According to the tradeoff principle mentioned earlier, however, the programmability of computer-based information processing is accompanied by a lack of adaptability that, if left unchecked, may affect the adaptability of the organization as well. An important way in which the programmability of computer-based information processing affects the adaptability of organizations is that it makes software more difficult to modify. The cost and difficulty of building, modifying, and maintaining computer-based systems makes it more difficult for the organization to change in response to changes occurring in its environment.

Computer-based systems may affect the adaptability of organizations through changes that they instill in their structure and dynamics. Particularly relevant in this respect is the effect that these changes may have in subsystem independence, a feature of the structure of systems that, as mentioned above, is strongly related to their adaptability. Subsystem independence may be affected by the degree of integration of the information system into the organizational functions it supports, meaning by that the degree of tightening of the coupling between the information processing processes provided by the information system and the processes that

perform the functions. Clearly, the tighter the coupling between these two kinds of processes the more difficult that it is to change any of these kinds of processes in a manner independent of the other.

Computer-based information processing may also affect subsystem independence in organizations by instilling structural changes that affect the integration of organizational processes. An increase in the integration of these processes decreases subsystem independence which, as noted above, has a negative effect on adaptability. Conversely, a decrease in the integration of these processes increases subsystem independence which favors adaptability. It must be noticed, however, that the structures and mechanisms needed for subsystem independence have to be created and maintained. This means that there is a cost associated with the increase of subsystem independence. A component of this cost that is particularly relevant to our discussion is the added cost of coordinating the more independent subsystems. Obviously, the cost of building and maintaining subsystem independence needs to be carefully considered. Otherwise, as mentioned earlier, it may outweigh the benefits that it brings in terms of adaptability (Conrad, 1983).

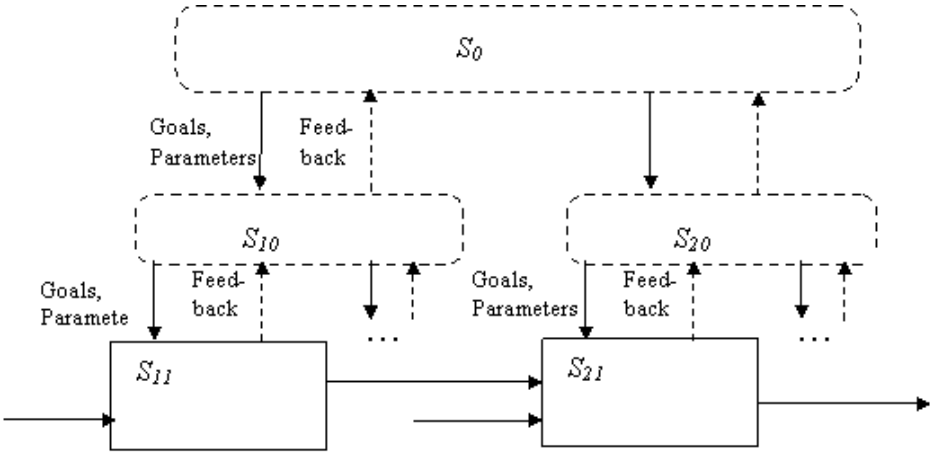


Figure 2. The informational interaction diagram shows the information flows that must exist between the organizational functions (or functional subsystems) into which an organization is decomposed. Two kinds of information flows are shown. Vertical (or control) information flows, like those shown in the figure between S_0, the main control subsystem and S_{10} and S_{20}, between S_{10} and S_{11}, and between S_{20} and S_{21}, and horizontal (operational) information flows like those shown between S_{11} and S_{21}, and between them and the external environment. Notice that the functional subsystems shown in this figure are the ones shown earlier in Figure 1. This helps us illustrate the fact that the informational interactions shown in this figure are in fact induced by the structure shown in Figure 1.

Adaptability-Enhancing Computer-Based Support of Organizational Functions

The hierarchical, distributed control structure of organizations is essential to their adaptability. It allows for some degree of self-control at practically all levels of organizational function. The adaptive, relatively self-controlling character of the dynamics underlying the functions of organizations is possible principally because of the human element participating in them. The complexity of modern organizations, however, makes computer-based information systems an indispensable means of extending the computational capabilities of human intelligence. We have referred to the source of these computational capabilities as the biological information processing infrastructure of organizations (Kampfner, 2002). Effectively extending this infrastructure requires a combination of digital computing and human information processing that is appropriate for the effective support of each of the organizational functions involved. This can be achieved with the guidance of the design principle (Kampfner, 1997) by seeking the necessary compatibility of the information system with the structure and dynamics of the organizational functions it supports and with the adaptability of the organization.

The OCSM formalism provides us with the means to model organizations as hierarchical, distributed control structures. In the OCSM description of an organization, each control function (or control subsystem) represents the explicit self-controlling capabilities of the operational function to which it belongs. The self-controlling capabilities of the operational subsystems that a control function controls are not visible at the level of the controlling function and, for this reason, at this level they are considered as implicit control. In Figure 1, for example, S_0 represents the explicit self-controlling capabilities of system S, its parent system. S_{10}, on the other hand, is a control subsystem located at a level lower than that of S_0. Seen from the level of S_0, as Figure 1 shows, S_{10} is considered part of the implicit control of S_1. Notice, however, that at its own or a lower level, S_{10} represents the explicit control of S_1. In what follows we will discuss the main factors involved in the support of specific control subsystems (or functions) with reference to the OCSM representation of the subsystems involved. However, the hierarchical, distributed nature of the organization's control system must be kept in mind.

The designer of the computer-based support of a control subsystem of an organization must seek the compatibility of this support with the structure, dynamics and the adaptability of the organization. Let us briefly review each of these aspects of the compatibility of the information system with the control functions of organizations. The compatibility with the structure of the organization requires that the support provided by the information system be appropriate to the type of the function being supported and to its level in the organization's hierarchy. Because of the central role that humans play in the control of organizations, the role of the computer-based information systems in the control functions is primarily the support of the decision-making and problem-solving capabilities of the people involved in the performance of these functions. The degree of structure of the decision-making and problem-solving processes supported by the computer-based information systems varies with the level of the organizational functions involved, with the more structured situations occurring at lower levels of the organization's hierarchy. The fact that because of its algorithmic nature digital computing can only be used in the

automation of sufficiently structured tasks confirms the primarily supportive role that computer-based information systems play in the support of control functions. The higher the level of the function supported, however, the less directly that the results provided by the information system determine the decisions made or the actions taken in the organization.

The compatibility of the information system with the dynamics of the organization requires for the support it provides to be consistent with all the processes that perform the organizational functions being supported. In particular, the automated processes that the information system provides must interact with the other processes that perform the functions in a manner compatible with the levels of activity of these processes, the amounts of information transferred between them, the type and timing of the interactions, etc. In other words, the processes that perform the functions must receive the information they need in the form that they need it and at time they need it. Especially important from the standpoint of the support of the control functions, however, the supportive character of the role played by the information system is particularly important. In this respect, the information system must also be consistent with the psychological and cognitive characteristics of its users and with their problem-solving and decision-making styles. The compatibility with the dynamics requires also that the modes of computation used by the information system be consistent with the role it plays in the support of the control functions. It must tackle the more structured parts of the processes and do so with the necessary flexibility.

The compatibility of the information system with the adaptability of the organization is affected by all the aspects of its structure and dynamics. The programmability of computer-based information processing and the integration of organizational processes have a particularly strong effect on the adaptability of the organization. The programmability of computer-based information processing affects the adaptability of the organization not only because it makes computer-based systems more difficult to modify, but also because of the changes it introduces in the structure and dynamics of the organization. In this respect, the design principle calls for the automation of computational processes that are sufficiently structured. This should be done in as modular a manner as possible. Conventional computing approaches should be applied to the automation of the more stable, less frequently changing processes. More adaptive computing approaches, like those using machine learning and evolutionary programming techniques, can be applied in connection with less stable, more frequently changing processes.

We also mentioned earlier that computer-based information systems are bound to affect the structure, dynamics, and adaptability of organizations, sometimes in ways that involve the redesign or reengineering of organizational processes. Among the changes introduced by computer-based information systems in organizations, those that affect the integration of organizational processes are particularly important from the standpoint of adaptability. An increase in the integration of organizational processes results in a decrease in subsystem independence and, consequently, in a loss of adaptability. The degree of integration of the information system into the processes that perform the organizational functions it supports (in other words, the degree of tightening of the coupling between these two kinds of processes) is in this respect an important factor to consider. The tighter the coupling between these two kinds of processes the more difficult that it is to change the information system or

any of these organizational processes independently of the other, obviously a reduction of subsystem independence. Another related factor is the degree of integration (or the tightness of the coupling) between the organizational processes themselves that results from computer-based integration. Tightening the coupling between organizational processes is bound to decrease subsystem independence. If these organizational processes are also tightly coupled with the processes provided by their supporting information system the loss of subsystem independence, hence adaptability, might be extremely high.

This loss of adaptability can be avoided by preserving or increasing subsystem independence. The caveat is that subsystem independence brings with it the added cost of coordinating more independent subsystems. This cost is at least in part absorbed by the computer-based integration of organizational processes through the automation of the coordination of the integrated processes. In addition to that, the computer-based integration of organizational processes usually brings with it a considerable increase in the speed and efficiency of the processes that perform the functions supported by the information system, with obvious benefits to the organization. In this respect, the design principle calls for exploiting the synergies that an appropriate combination of human and digital information processing brings about through the compatibility of information processing with the structure and dynamics of the organizational functions involved. Seeking the compatibility with the adaptability of the organization would help to avoid designs that would reduce too much the ability of the organization to cope with the uncertainty of its environment.

Obviously, the cost of coordination due to an increase in subsystem independence and the cost of process integration in terms of adaptability are both difficult to evaluate and compare. However, knowing the role played by the computer-based information system in the performance of organizational functions and the kind of support it provides to these functions is a solid step in the right direction. Through the compatibility of the information system with the structure and dynamics of the organization and with its adaptability the design principle helps us to build effective support in a synergistic manner. As applied to the development of computer-based support to the control functions of organizations, the necessary compatibility must be sought taking into account the relationship between subsystem independence, adaptability, and the cost of subsystem coordination.

Summary and Conclusions

We associate the effectiveness of the support that biological information processing provides to the functions of biological systems with the high degree of compatibility that it has with these functions. In fact, we adopt the achievement of this kind of compatibility as a basic principle for the design of computer-based information systems that effectively support the functions of organizations. The compatibility of the information system with the control structure of the organization it serves is particularly important for the effective support of function and adaptability. The hierarchical, distributed nature of control in organizations and the central role played by human intelligence in the control functions of organizations call for a very flexible, supporting role of computer-based information systems in the support of

these functions.

Because of its programmability conventional digital computing must support the control functions of organizations with computational processes that are as stable, i.e. less changing, as possible. Evolutionary programming and machine learning techniques, on the other hand, can be used in connection with less stable, more adaptive processes. The computer-based integration of organizational processes must be achieved in a manner that capitalizes on the efficiencies of organizational processes that it produces but only to the extent to which the cost in terms of adaptability is not too high. Subsystem independence, on the other hand must be achieved in order to increase adaptability but only to a point in which the cost in terms of subsystem coordination that it causes is not excessive. In all cases, the most flexible, adaptable, information system architecture, and the one that favors more the adaptability of the organization as a whole should be preferred.

References

Conrad, M. *Adaptability*, New York: Plenum Press, 1983.

Conrad, M. "On design principles for a molecular computer," in *Communications of the ACM*, 28, 464-480, 1985.

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

Kampfner, R. "A hierarchical Model of Organizational Control for the Analysis of Information Systems Requirements," *Information Systems,* Vol. 12, pp. 143-154, 1987.

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

Kampfner, R. Dynamics and information processing in adaptive systems, *BioSystems*, 46, 153-162, 1998.

Kampfner, R. "Digital and biological computing in organizations," *BioSystems*, Vol. 64, pp.179-188, 2002.

Venkatraman, N. "IT-Induced Business Reconfiguration," in *The corporation of the 1990's*, M. Scott Morton (ed.), New York: Oxford University Press, 1991.