Dissipative Structure Theory, Synergetics, and Their Implications for the Management of Information Systems

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Dissipative structure theory and synergetics have far-reaching implications for self-organizing phenomena in many diverse fields. This article attempts to apply them in the management of information systems. It begins with a brief review of dissipative structure theory and synergetics, and then demonstrates why they could be applied in information systems. Orderliness is pervasive and of central importance in the operation of information systems. Information science can be regarded as a science about knowledge ordering with the goal of making information more accessible to potential users. Five types of entropy in information systems are analyzed. The relationship between dissipative structure theory and traditional management theories are also discussed. Implications for the management of information systems include: maintaining the system in the state of non-equilibrium, openness towards change, stimulating dynamic cooperative behavior, and selectively amplifying fluctuation.

Introduction

In recent years, we have witnessed the frequent and productive use of theories and techniques from other fields in library and information science research. Imported views can help us to see problems afresh and to generate new ideas and solutions. Most previous studies drew on applications from a particular social science field such as sociology, economics, or psychology to library and information science research.

In this article, we consider a theory derived indirectly from the physical sciences. From modest beginnings involving a simple model of a hypothetical chemical reaction, the study of nonequilibrium instabilities, of dissipative structures, and of cooperative phenomena which emerge from them, has exploded into a dynamic area with far-reaching implications for self-organizing phenomena in many diverse fields including sociology (Adams, 1982; Welge, 1977), economics (Berry & Andresen, 1982), cultural studies (Carneiro, 1982), communications research (Braman, 1994), and management (Gemmill & Smith, 1985; Jantsch, 1980; Leifer, 1989; Nonaka, 1988).

Despite these widespread applications, little attention has been paid to these theories in relation to the management of information systems. This article will attempt to apply dissipative structure theory and synergetics to the study of the management of information systems, using Buckland's conceptual framework for information systems (Buckland, 1991). Since libraries will be familiar to all readers, most examples are drawn from library settings. My hope is that it may contribute in some small way, if it can encourage further research.

Dissipative Structure Theory and Synergetics: A Brief Summary

In the preface to the first edition of *Synergetics: An Introduction*, H. Haken (1978), the founder of synergetics, stated: "The spontaneous formation of well organized structures out of germs or even out of chaos is one of the most fascinating phenomena and most challenging problems scientists are confronted with . . . [A]s in living organisms, the functioning of these systems can be maintained only by a flux of energy (and matter) through them. In contrast to man-made machines, which are devised to exhibit special structures and functionings, these structures develop spontaneously—they are self-organizing. It came as a surprise to many scientists that numerous such systems show striking similarities in their behavior when they pass from the disorder to the order state. This strongly indicates that the functioning of such systems obeys the same basic principles."

Classic thermodynamics was limited to equilibrium or near equilibrium. After years of studies, Nicolis and Prigogine (1977) found that systems exist showing two completely different types of behavior, namely, a ten-

Received January 19, 1994; revised December 5, 1994; accepted January 31, 1995.

dency toward maximum disorder state under certain conditions and a coherent behavior under others. The destruction of order prevails in the neighborhood of thermodynamic equilibrium. Creation of order may occur far from equilibrium provided the system obeys nonlinear laws of a certain type. Dissipative structure theory suggests that the presence of instabilities at the bifurcation point (where the limits of coping mechanisms are just exceeded) does not necessarily lead to chaotic random behavior, but instead offers the opportunity for a new dynamic order, which is able to handle increasing amounts of uncertainty and complexity (Leifer, 1989). Nicolis and Prigogine (1977) stated: "the distance from equilibrium and the nonlinearity may both be sources of order capable of driving the system to an ordered configuration." Johnson (1988) also stated: "Dissipative structures have the capability for self-organization in the face of environmental fluctuations. Self-organization involves an increase in complexity, and an increase in complexity, demanding greater work to be done, demands an increase in the rate of energy expenditure. Self-organization is a reordering of the old elements and the addition of new and possibly accidental components to provide a smoother and more ordered energy flow." Dissipative structures are characterized by a high degree of energy exchange with the environment.

In Prigogine and his co-workers' studies (Nicolis & Prigogine, 1977; Prigogine & Allen, 1982), the concept of excess entropy production which leads to instabilities has played a central role. But their approach does not explain what happens at the instability point and how to determine or classify the new evolving structures (Haken, 1978). Synergetics particularly investigates what happens at the instability point and the determination of the new structure beyond it. Haken's studies (1978) found that there are profound analogies between completely different systems when they pass through an instability. This instability is caused by a change of external parameters. In many cases, the detailed mechanism can be described as follows: "Close to the instability point we may distinguish between stable and unstable collective motions (mode). The stable modes are slaved by the unstable modes and can be eliminated. In general, this leads to an enormous reduction of the degree of freedom. The remaining unstable modes serve as order parameters determining the macroscopic behavior of the system. The resulting equations for the order parameters can be grouped into a few universality classes which describe the dynamics of the order parameters. . . . The interplay between stochastic and deterministic 'forces' ('chances and necessity') drives the systems from their old states into new configurations and determines which new configuration is realized" (Haken, 1978). This mechanism appears to apply to and to explain the evolution of libraries.

There are several criteria for identifying dissipative structure: (1) Exhibiting finite information and cohesion; (2) maintaining the systems through irreversible dissipation of matter and energy; and (3) existing in an open energy system (Brooks & Wiley, 1986). "Information systems used by human beings are open systems, in other words, the provision and use of information systems are not isolated from the rest of the world" (Buckland, 1991). Information systems can be viewed as dissipative structures, because the maintenance of systems' performance requires a continuous exchange of energy and matter with the surrounding environment—collecting, arranging, and storing materials for a variety of purposes.

Understanding Information Systems Using a Concept of Order

The concept of order is much more pervasive and important in information systems than we have previously thought. Information systems can be viewed as orderly systems. For example, a library is more than a pile of books. "A library without a filing system is certainly in a highly disordered state to which a large entropy can be assigned, while a properly organized library has a relatively low entropy" (Angrist & Hepler, 1967).

Whether human knowledge can be utilized or not largely depends on the degree of orderliness of information. Therefore, information science could be regarded as a science about knowledge ordering with the goal of making information more accessible to potential users. For example, the purpose of library and information retrieval systems is to bring sustained order to information-as-thing. Documents are arranged according to titles, authors, or subjects. Partitioning, ranking, and sorting are employed as techniques for changing and increasing ordering. Indexes, abstracts, classifications, subject headings, and catalogs are used as tools for orderliness of information. Garvey (1979) stated: "indexed abstracts serve as a great net to catch articles" and "Separate items of information from separate journal articles are interrelated, and these clusters in turn become compounded into a self-consistent, meaningful body of knowledge." Landry and Rush (1970) argued that documents arrive at the indexing system in a highly disordered state and indexing could be viewed as an order-increasing operation, which leads to the reduction of entropy in a document/document-searcher system. Davis noted that vocabulary control can decrease the entropy and thus promote order of stored information by providing greater specificity and minimizing ambiguity (Davis 1975; Shaw & Davis, 1983). Thus a central feature of bibliographic information systems is that they add order to the informational materials with which they deal.

Avramescu (1980) applied dissipative structure theory to study the diffusion model of information transfer, noting that the model represents an irreversible process.

Goonatilake (1991) used dissipative structure theory to explain the evolution of information. She also discussed the role of artificial intelligence in the self-organization of information.

Order is only relevant to some criterion, goal, or purpose. Some existing forms of order become counterproductive as circumstances change and should be replacing by other forms of order. For example, online catalogs and bibliographies that only order results into two categories, retrieved/not retrieved, and then order the retrieved categories into (unhelpful) alphabetical order by main entry are less useful than they could be (Buckland, Norgard, & Plaunt, 1993). Obviously, there is scope for an extended theoretical analysis of information systems and services in terms of "order"—and unhelpful ordering—and how changed circumstances may need different ordering. We will further analyze and discuss the types of ordering problems.

In the procedures of information systems—selection, collection, arrangement, utilization, there exist inevitably a variety of problems. If the problems cannot be solved properly, a disordered situation will occur. Entropy is a measure of the degree of disorder. The system as a whole may not be equal to the sum of the parts due to the interaction between these parts. Under certain conditions, the whole may become more than or less than the sum of the parts. The latter situation happens when the value added by the infrastructure interferes and the production of internal entropy increases. Cooperative phenomena cause order, while incompatibility leads to disorder. Georgescu-Roegen (1971) stated that "disorder is a highly relative, if not wholly improper, concept: something is in disorder only in respect to some objective, nay, purpose." Classification systems vary in different countries. For example, books on law are in Z according to Colon Classification (India), while they are classified in K in the LC, in D in the Chinese standard classification, and in X in the Soviet classification (Liu, 1993). Two different classification schemes, for instance, may each work well in classifying books when used separately, but if they are simultaneously used to classify or arrange books on shelf, disorder will occur. This example illustrates why incompatibility may result in disorder. Cooperation and coordination are the means of linking various components within a system. The lack of coordination between parts in a system is one of the chief reasons for internal entropy production. Therefore, internal entropy reflects not only the system's effectiveness but also whether the infrastructure of the system is optimal or not. According to the causes, entropy in information systems can be grouped into five types:

(1) Component Entropy

The quality of components (librarians, collection, equipment, users, etc.) is fundamental to the production of component entropy. For example, an unsuitable book may have been selected or a suitable book may be unusable because of incorrect cataloging and shelving. Effective library use may be hindered because of lack of user training for unskilled users.

(2) Structural Entropy

"Any organizational structure needs to be compatible with and acceptable to the parent organization or broader social context" (Buckland, 1991). Structural entropy is the result of inappropriate structure and lack of coordination among the components of a system. For example, an unsuitable organizational structure causes overlaps, inefficiencies, and conflicts of responsibility.

(3) Functional Entropy

Every system exists in a specific environment. Like other social systems, an information system must exchange energy, matter, and information with its surrounding world so as to keep the system dynamic. It must maintain mutually acceptable and desirable relations with its environment. If exchange cannot be carried out smoothly, the system's function will become abnormal and the internal entropy increases. The functional entropy is caused by failure of coordination between the system and its environment. For example, a library may provide efficient but irrelevant services and so cannot support healthy cross-boundary relations because its services fail to respond to the information needs of the populations to be served. It is obvious that information needs and information services should be matched across the boundaries. In a recent article, Braman (1994) stated: "evolutionary developments within one system serve as stimuli for developments within other systems in its environment. When evolutionary cycles become coordinated among systems, the process is known as coevolution."

(4) Timeliness Entropy

New books waiting for a long time to be cataloged and shelved, personnel with obsolete knowledge, out-of-date collection and equipment, indexes and abstracts which cannot reflect the latest articles, and a long period of binding, are all factors which will result in the poor operation of an information system. Timeliness is a valuable resource. Every document may lose its utility if it is not used in a timely fashion.

(5) Situational Entropy

Relevance is viewed "as a measure of the effectiveness of a contact between a source and a destination in a communication process" (Saracevic, 1975). As previously noted, entropy is a highly relative concept. If a library user is provided with a book in a foreign language which he (she) cannot read, entropy will occur. According to a library use study, several undergraduates were confused when the database retrieved too many records. For example, on April 15, 1991, MELVYL retrieved 10,346 records on the American history, 3,725 results on biochemistry, and 613 on coastal ecology. One freshman complained that she did not know how to choose a suitable book (an excess of entropy), but several doctoral students suggested they prefer too large a retrieval set rather than one that was too small (Liu, 1993).

Implications for the Management of Information Systems

Management theories have evolved today around how to seek and maintain stability, and therefore they can be considered as equilibrium-oriented approaches (Nonaka, 1988). Stemming from the machine paradigm which assumes the world is simple and basically ordered, management theory emerged with the emphasis on designing organizations to match the ordered environment (Leifer, 1989). The theory of bureaucracy developed by Max Weber best exemplifies management's response to the ordered environment. To quote Weber (1946), "The fully developed bureaucratic mechanism compares with other organizations exactly as does a machine with nonmechanical modes of production." The scientific management school (also called "machine-theory" school) views the environment as constant and assumes that organizations have a set of explicit and constant goals and can be ordered in terms of their importance (Hasenfeld, 1983). Realizing the simplistic and mechanical view of human nature in scientific school, the human relations perspective tries to seek the equilibrium between formal and informal organizations. Grounded in the theoretical perspective of systems theory originally developed by Ludwig van Bertalanffy, the systems school views the role of management as being to maintain a continuous state of equilibrium between an organization and its environment and asserts that organizations must be designed to operate "under norms of rationality." Both Simon's *Administrative Behavior* (1976) and Katz and Kahn's *The Social Psychology of Organizations* (1978) exemplify this view. This perspective provides us a newer and more comprehensive paradigm developing in natural science, but it views systems as equilibrium-seeking. It is applicable only to systems operating within certain parameters and does not describe profound transformations beyond these parameters, as, for example, in response to a changing environment (Gemmill & Smith, 1985; Jantsch, 1980). Dissipative structure theory, constituting an extension to the general theory of the dynamics of systems, provides a theoretical basis for introducing instability to human systems.

As previously mentioned, an information system is a large and complex system, usually deeply embedded in and heavily influenced by its social and technical contexts. External change may have internal repercussions. External turbulence, technological developments, increasing demands and competition, rising costs of services, and scarcity of resources, offer a critical condition, in terms of dissipative structure, called a bifurcation point. This is the point at which some restructuring, successful or otherwise, becomes necessary. Losee (1990) suggested that the thermodynamic model for order and complexity could provide the formal basis for models of systems surviving, growing, and adapting. Today, information systems are facing great uncertainty. How to cope with changing environments becomes a central issue in the management of information systems. It is hoped that dissipative structure theory and synergetics could offer insights into managing the transformative process of information systems.

Maintaining the System in the State of Non-Equilibrium

According to Kuhn's theory of scientific revolutions, non-equilibrium plays an important role in the accumulation of knowledge. Kuhn (1970) stated that "discoveries commence with the awareness of anomaly, i.e., with the recognition that the nature has somehow violated the paradigm-induced expectations." Jantsch (1980) also argued that "openness and inner non-equilibrium of scientific structures is mirrored in the working style of creative scientists." Prigogine and Stengers (1984) found that non-equilibrium may be a source of order, a viewpoint which has been neglected by previous management theories. Jantsch (1980) further stated that "a management geared to equilibrium may ruin ecosystems." How to generate appropriate chaos for the evolution of organizations is an attractive challenge for management. Introduction of new skills and techniques, questioning performance gap, job rotation, and stimulating demand, all these can break some kinds of social, technological, or economic equilibrium and promote change. It is important to note that generating chaos does not mean that all kinds of chaos can be introduced indiscriminately. This requires us to consider what kind of chaos should be created, and how and when to recreate chaos. For example, different management styles should be encouraged when organizations are in the stable periods. As Goldstein (1988) stated, systems beyond equilibrium are not purely "chaotic," instead they are systems in which equilibrium-seeking processes are incomplete or not yet dominating. For example, imagine an academic library that operates in an unresponsive spirit to a sudden influx of foreign students. A librarian questioning what the library should do under the situation of increasing foreign students may eventually lead to providing responsive service for them. It is not difficult to see that the sudden influx of foreign students breaks the equilibrium of the library's routine service and the librarian's questioning is a way of generating change, a re-ordering of service. For an organization to be effective, it must be a change-seeking organization. Peter Drucker (1954) said that a major obstacle to organizational growth is managers' failure to change their attitudes and behavior as their organizations require. Peters (1987) stated: "success will come to those who love chaos—constant change—not those who attempt to eliminate it."

Far-from-equilibrium conditions can be induced only through constant metabolism with the environment. An appropriate illustration would be an information system that receives its budget, personnel, materials, and equipment from the external environment and provides services and rejects obsolete materials. Accordingly, information systems must have autonomy for the self-determination of their own evolution. Nonaka (1988) argued that for an organization to renew itself, it must maintain itself in a state of non-equilibrium at all times.

If we examine the role of selection, it is not difficult to see that selection and order are fundamentally related. It seems that collection development is also essentially the creation of order in the universe of documents. As previously mentioned, the flow of entropy from the environment does not have a definite sign. For example, collecting books not relevant to the collection policy can only occupy space and waste the budget. This, again, implies that order is only relevant to some goal or purpose. In the term of thermodynamics, this cannot reduce but will increase the internal entropy. It is obvious that self-organizing ability, controlling the influx of energy and matter, is needed. Lack of self-organization may result in unsuitable resources being available to the system. Maintaining the information systems far from equilibrium also requires systems to have their own autonomy so that they could introduce the most suitable personnel and materials in the light of their concrete situation.

Openness towards Change

Far-from-equilibrium systems can generate more information and are more sensitive to environmental changes than equilibrium systems (Goldstein, 1988; Jantsch, 1980). Generating information about itself (self-reflexive) is an important way to drive the system into a non-equilibrium state, which is of crucial importance for the evolution of a system. It is essential that managers should pay more attention to users' needs and desires. Information systems are dynamic systems and heavily influenced by their social and technical contexts. To maintain their performance, we must establish feedback mechanism so as to revise plans, especially long-range plans. There is no doubt that good planning cannot be achieved without effective feedback of information. Jantsch (1980) suggested that: "strategic planning creates a mental non-equilibrium structure with fluctuations fed into it deliberately to trigger further evolution in one or other direction."

In his *Information and Information Systems,* Buckland (1991) raised an interesting and important question: Some information services, especially noncommercial, publicly funded services, such as libraries and museums, present a paradox. Feedback from their users is generally weak, services may be criticized for being unresponsive, and managers may have little influence over their environment. Yet in systems theory, feedback is essential for an organization to adapt and to survive. How do they not merely survive but are widely regarded as crisis-free places (in the short term)? In the term of dissipative theory, one explanation may be that libraries are noncommercial and publicly funded organizations. Their resources do not come directly from users. They can obtain an influx of resources with their budget. The influx of resources may compensate the internal entropy. Therefore, these organizations are relatively stable (crisis-free). In his *What Is Life?,* Schrödinger (1967) explained a similar situation: A living organism "feeds upon negative entropy" from its environment "to compensate the entropy it produces by living and thus to maintain itself on a stationary and fairly low entropy level." If the libraries are commercial organizations or the allocation of resources links directly with the services, it will present a completely different landscape—a decreased budget will prevent them from introducing resources from the surrounding world, and the system will reach maximum disorder. The greater the misalignment with the environments, the less the libraries can depend on their environments for resources necessary to renew themselves, leading eventually to a deterioration in coping mechanisms and eventually to substantial decline (Leifer, 1989). An information service that is heavily used is perceived as having greater value, which is likely to result in the allocation of more resources.

Stimulating Dynamic Cooperative Behavior

Integrity has been a management concept for ages. Today's accelerating changes give this concept a new importance. Peters (1987) proposed a paradox: more competition requires more cooperation. In today's network environment, dynamic cooperation and coordination are of particular importance.

Internal entropy within the information system is the result of many factors, including lack of integrity. For example, the mismatch of organizational technology and structure, and cross-functional barriers between collection development, cataloging, and reference all can lead to an increase of internal entropy. It is therefore that enhancing cohesion is an effective way to reduce internal entropy production. Synergy-oriented strategies always aim at the optimal combination of individual functions or an entity. Synergy may serve as an instrumental criterion to determine whether the organizational structure is appropriate or not.

Successful implementation of a synergy-oriented strategy requires creative work of management. Since the world is more complex than ever before, communication is very important for avoiding permanent chaos in organizations. Prigogine and Stengers (1984) stated that: "There is competition between stabilization through communication and instability through fluctuation. The outcome of that competition determines the threshold of stability." We can use the following situation to explain this issue: In response to the emerging network environment and changing user needs, a director of an information organization developed a new vision which aims at restructuring the organization and offering new services.

The proposed changes immediately ran into massive resistance from the people involved, because some people were in the fear of losing their jobs or a reduction in their power, while others were afraid that the new services would require new skills. After careful diagnosis of the resistance, the director employed various methods such as education, communication, and negotiation to mobilize employees to accept and work towards achieving the new vision, and institutionalized the needed changes. This example also implies that today's realities demand total integrity: integration between organizational technology and structure, new services and changing user needs, administrators and employees, and formulating and implementing changes. The greater degree the total compatibility, the less internal entropy. Widespread information sharing, participatory management, user education, and continuous education all can reduce entropy and foster integrity. Developing a new vision for the organization can also lead to cooperative behavior.

Since simplicity and integrity tend to be positively related, goals and plans should be designed to be easy to understand (Peters, 1987). It is hard to image that a lengthy and complicated library user guide can be well understood and guide users towards the desired directions. For example, it has been suggested that handouts on the library's basic rules and procedures be written in foreign students' native languages, as well as in English, with the end of minimizing communication barriers (Liu, 1993).

Selectively Amplifying Fluctuation

As the Chinese say, "poverty gives rise to a desire for change." A crisis may encourage creative activities or even rejuvenate the organization itself (Nonaka, 1988). Crises have been regarded as a necessary precondition for the emergence of novel theories. There are ample examples in the history of science. Kuhn (1970) stated that: "By concentrating scientific attention upon a narrow area of trouble and by preparing the scientific mind to recognize experimental anomalies for what they are, crisis often proliferates new discoveries."

One of the most important functions of management is not only to generate change, but also to amplify fluctuation selectively. Fluctuations play an important role in the self-organization processes. They have different functions when the system is in different states. When the system is in the stable state, fluctuation is merely perturbation. In such a case, fluctuations are dampened and disappear. When the system is in the non-equilibrium state, fluctuation may lead to large scale fluctuation and may carry the system off to some new configurations. Using the dissipative structure theory, we call this "order through fluctuation." In fact, the viewpoint of "nonequilibrium may be a source of order" and the principle of "order through fluctuation" could be empirically discovered in our daily life. For instance, we imagine a library which operates in the less innovative situation, in which the amount of entropy is very high. Into this library breaks a new technology (e.g., microphotography). If the library is in the equilibrium-seeking environment with everybody resistant to change, the new technology will be regarded as an intruder to routine practice. If, however, the situation is of sufficiently non-equilibrium in which tension of demand for duplicating copies is severe and storage space is limited, the introduction of new technology (e.g., microphotography) may easily trigger a jump to a new configuration. The challenge for a practitioner here is to decide how and when to implement proposed innovations with least resistance. For instance, in the above case, a practitioner can amplify change by focusing on some specific contradictions (demand for copies, limited storage space, etc.), which will stimulate a demand for a new perspective—the adoption of microphotography.

In the courses of exchanging the energy and matter with the outside world, the open system will be influenced by external changes. These changes are the fluctuation faced by the information systems. Buckland (1991) stated: "It is the process of response to stimuli that constitutes the means of change and adaptation by internal alteration, by changing relationships, or by influencing the external environment. Response to opportunities and to threats are of importance for achieving goals." The external changes of information systems include changes of national information policy, modern information technology, structural changes of users, and the allocation and the reallocation of resources may lead to change in information systems.

Prigogine and Stengers (1984) said that reasons for the amplification are "a legitimate matter for rational inquiry." Crisis may encourage creative activities, but the period of crisis may not be a good time for innovation and change because the environment may be inhospitable and resources may be strained (Hasenfeld, 1983). Therefore, the challenge to the managers is to amplify fluctuation in a selective and timely manner before the organization encounters crisis. In this sense, the role of manager resembles that of a catalyst.

Conclusion

Information services are entering an era of high uncertainty in which pressures for change are greater than ever before. Dissipative structure theory takes on increased importance as it provides us with a new perspective of change.

It has been noted that when researchers in library and information science have "borrowed" theories from other fields, it has often been short-term and superficial, because one cannot dabble in another field and immediately understand its nuances and complexities (Van House, 1991). In spite of these difficulties, dissipative structure theory and synergetics could and should play an important role in managing information systems in the changing world.

Acknowledgment

The author is grateful to Prof. Michael Buckland, Alan Inouye, and anonymous referees for their invaluable comments on the earlier draft of this article.

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