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Some Notions of Complex Adaptive Systems and their Relationship to Our World

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Abstract

This paper assumes that the world we live in consists of many interwoven ***complex adaptive systems***. In the literature such systems are characterized as comprising many moving parts and processes that interact significantly in a mostly non-linear manner. It is argued that the forces that act on such complex systems are not additive, and that their impact occurs along non-linear interactions within the system. In particular, many of these systems are ***adaptive*** in that they change their behavior (through their interactions) over time, so that if they are subjected to a similar force or event a second time they may react in a substantially different manner. Over the past several decades a number of researchers have been intrigued by the abundance of complex adaptive systems in both the natural and human world (Holland 1995, Cowan et al. 1994, Kauffman 1992). In the natural world these include the human brain, immune systems, ecologies, cells, and many others. In the human world, where it is well known that the interaction of just two persons can reach a high level of complexity, they include cultural and social systems (Figs. 1 and 2).

The paper describes the behavioral characteristics of complex adaptive systems, as they have been identified in the literature, and briefly discusses how these characteristics appear to manifest themselves in the evolution of technology, biology, and the economy. The influence of complex adaptive system notions on the structure and operation of a business organization is addressed in respect to decentralization, diversification, communication, and organizational flexibility. Attention is drawn to the inadequacies of existing quantitative tools and the opportunities that exist for leveraging human behavioral characteristics and organizational capabilities in a complex adaptive systems environment.

Background and Introduction

For the past 13 years the CAD Research Center has been exploring the nature of complex problems and developing computer-based systems that can assist human decision makers in near real-time decision-support environments. Our systems ranging from research explorations to prototypes and in-use products have focused on a variety of application fields, such as engineering design (Pohl et al. 1988 and 1992), facilities management (Chapman et al. 1998), maritime transportation planning (CADRC 1994), and military command and control (Porczak et al. 1999, Nadendla and Davis 1995).

We have come to understand some of the characteristics of real world complex problem situations, and have recognized several effective strategies for designing decision-support systems that can address these characteristics. Recognizing that the complexity of such problems stems from their web-like relationships and not from the difficulties associated with any particular variable, we have moved away from the rationalistic ***decomposition*** approach to problem solving (Pohl 1994).

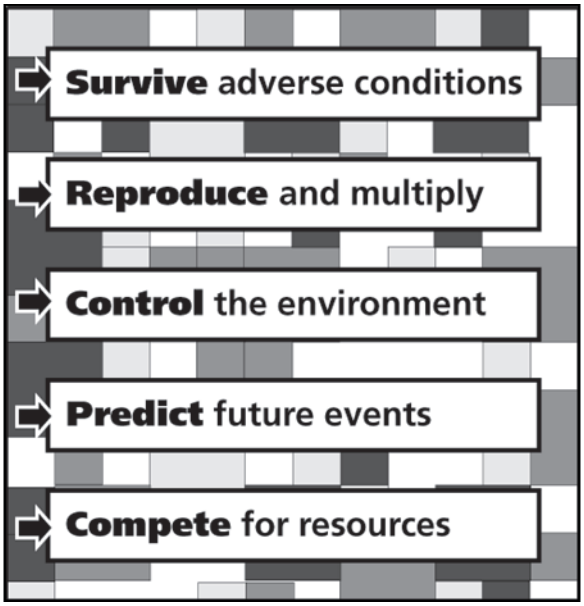

Fig. 1: Dominant human desires

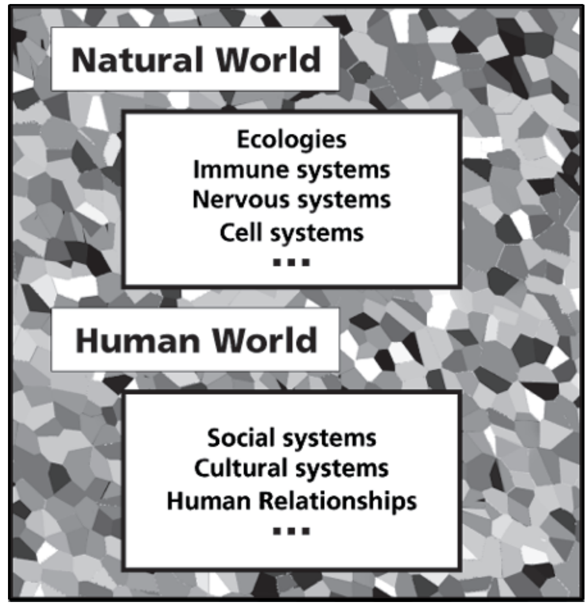

Fig. 2: Complex adaptive systems in our environment

After becoming increasingly interested in ***complexity*** and ***chaos*** in recent years, it is now apparent that the complex problems that we have been exploring and describing in our CAD Research Center over the past decade are part of the branch of knowledge that is commonly referred to as complex adaptive systems. Clearly, the various multi-agent decision-support systems that we have been building since the late 1980s have increasingly become ***adaptive tool sets*** for decision making in complex systems.

While it can be convincingly argued that the environment in which we and the organizations that we belong to operate in is non-linear and pervaded with uncertainty, the tools that we still largely rely on for our decision making processes are essentially linear and deterministic (Holland 1998). Even the prevailing dictionary definition of the term ***system*** implies that systems constitute a finite ***whole*** with definable boundaries and an intrinsic nature of predictability (Webster's New World Dictionary 1975).

> ***e.g.,*** ***"… 1. a group of things or parts working together or connected in some way so as to form a whole … 2. a set of principles, rules, etc. linked in an orderly way to show a logical plan …"***

This traditional notion of a system is, in fact, a necessary idealization of the world to provide a suitable basis for the application of mathematical tools. The rationalistic approach relies heavily on mathematics to predict the impact of internal and external events on the modeled behavior of a selected set of subsystem components. Due to the logical nature of mathematics, it has been necessary to clearly describe the boundary conditions of each subsystem and thereby convert uncertainty into a definable set of parameters (Fig. 3).

There are several weaknesses in this approach. First, it is hardly possible to describe a complex system involving human behavior unless the behavior analyst is separate from the system. In other words human beings have great difficulty describing a system in which they exist. Second, the selection of the subsystems is a form of decomposition that assumes that groups of interacting elements will display meaningful behavior when studied in isolation. Even when attempts are made to model the boundary conditions, these models rarely reflect the dynamic nature of all of the external forces that impact the internal elements. Third, the question of what constitutes a subsystem and which set of subsystems is representative of the behavior of the system, need to be answered? Unfortunately both of these questions are premature because the ability to answer them with any degree of confidence depends on an understanding of the behavior of the system as a whole.

Fourth, the context within which the elements of the system interact largely defines the behavior of the system. In this respect we are concerned not only with the impact of the external forces on the behavior of any particular group of interacting elements, but also on the influence that this group has on other parts of the system. In other words, the decomposition into subsystems creates artificial constraints that are in serious conflict with the dynamic and unpredictable nature of a complex adaptive systems environment (Fig. 4).

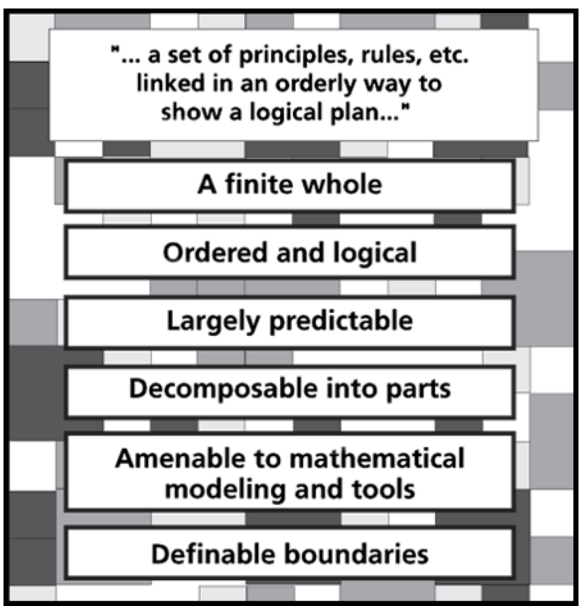

Fig. 3: Traditional simplified notions of a system

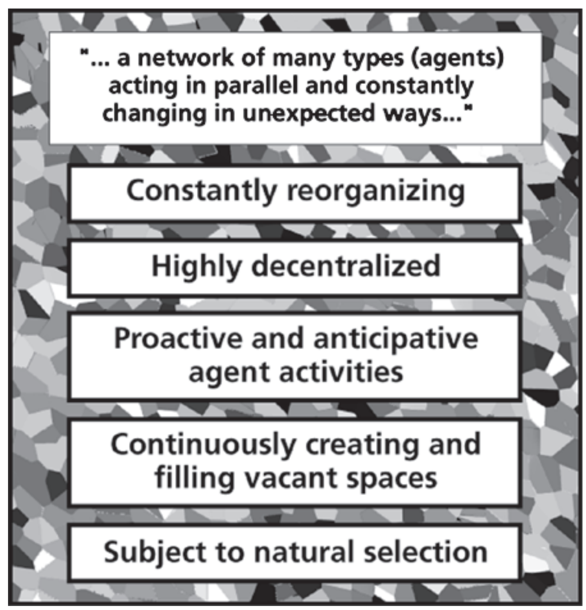

Fig. 4: More realistic notions of complex systems

If decomposition and mathematical modeling are inadequate and unsuitable tools then what tools are available for gaining an understanding and predicting the behavior of a group of interacting elements within a complex adaptive systems environment? Such a group can constitute, for example, a business organization that operates within the context of: many other larger, smaller and similarly sized companies; a local, regional, national and global economy; a political system; an educational system; and, a pervasive conglomerate of human relationships and interactions.

The necessary tools are likely to be very different in nature to the existing set of linear tools, in respect to both the objectives of their application and the manner in which they are applied. Specifically, they are likely to be ***relative*** rather than absolute and ***speculative*** rather than precise. For example, an estimate of the potential market response to a new product will be based on a relative assessment of past and present consumer patterns and a speculative projection of future consumer preferences and economic trends. This is a very different approach to the application of a related group of mathematical equations with predefined boundary conditions, the substitution of numerical values for variables, and the expectation of deriving a precisely defined and numerically rated set of alternative outcomes.

The Nature of Complex Adaptive Systems

For a system to be complex it is not necessary for there to be many parts. There are many systems that consist of a small number of parts each of which is relatively simple to describe in isolation, but which together interact in a complex and largely unpredictable manner. For example, the game of chess comprises only six types of pieces (i.e., king, queen, bishop, knight, rook, and pawn) that follow somewhat different rules in a severely constrained environment of only 64 distinct spatial locations. Yet, any individual game can reach a high level of complexity with an outcome that is often largely unpredictable until the final stages of the game.

Many, although not all, complex systems are also adaptive. This means that the system alters its response to particular events so that the next time that the same event occurs the response may be substantially different. Such systems adapt to events in a manner that allows the system to enhance its effectiveness and survival capabilities. The ability of a system to be adaptive requires the system to incorporate one or more methods of assigning credit for rewarding positive or successful behavior. In this respect, behavior that is worthy of reward is likely to be due to the interaction of two or more parts rather than the behavior of a solitary part (Fig. 5). It can be argued that the majority of complex systems are adaptive due to the simple fact that adaptive systems are likely to survive longer and will therefore be more prevalent than non-adaptive systems (Axelrod and Cohen 1997).

Holland (1988) characterizes complex adaptive systems as a ***network of many agents acting in parallel***. In the human brain the agents are neurons, in an ecology the agents are species, in an economy the agents include individual tax payers, households, firms, and so on. Each agent is always ready to interact with the system, proactively and reactively responding to the state of its environment (i.e., to whatever the other agents are doing).

Control within a complex adaptive system is ***highly decentralized*** (Fig. 4). In other words, any coherent behavioral patterns of the system are due to the collective competitive and cooperative activities of its parts (i.e., agents or elements). It follows that such a system has many levels of organization, with the agents at any level contributing in a building block manner to the agents at a higher level. For example, *"… a group of cells will form a tissue, a collection of tissues will form an organ, and an association of organs will form a whole organism, and a group of organisms will form an ecosystem …"* (Waldrop 1992). Similarly, a group of individuals will form a team or department, a number of departments will form a division, and so on through companies, economic sectors, national economies, and finally the world economy. Most importantly complex adaptive systems are ***constantly changing***, revising and rearranging their building blocks through their activities as they adapt to their experiences within the system and are subjected to the laws of natural selection.

According to Holland (1988) all complex adaptive systems ***anticipate the future***. For example, anticipating a period of inflation investors may decide to purchase real estate properties. During a military conflict both the friendly and enemy forces will normally make every attempt to conceal their presence from each other as a means of either avoiding enemy attack or in preparation for a future engagement. However, this anticipatory characteristic of complex adaptive systems applies equally well to those systems that do not involve human beings. Plants grow toward the sun in anticipation of facilitating the manufacture of chlorophyll. Even bacteria have an implicit set of predictions encoded into their genes, which allow an individual bacterium to do well under certain conditions. These predictive blueprints tend to become active at appropriate times, like the rules of an expert system that only fire when a certain combination of data appears in the fact-list.

Complex adaptive systems typically are ***continuously creating and filling*** vacant spaces where agents can be added. This allows the system to exploit opportunities for extending its web-like structure. As these niches are filled new spaces open up offering additional opportunities for extending the network (Fig. 5). Therefore, a complex adaptive system is never in equilibrium but continuously changes as it adapts to its current state in an opportunistic manner. It employs in this dynamic process one or more mechanisms of ***credit assignment*** to reward positive or successful behavior. However, in by far the majority of cases the behavior that the system judges to be worthy of reward is likely to be due to the interactions of two or more parts (i.e., agents) rather than the behavior of a solitary part.

Conversely, it would appear reasonable to hypothesize that complex adaptive systems also incorporate the notion of penalties that retard their growth and/or accelerate their demise. Whereas the elimination of some agents might be necessary to the survival of the system, as in the constant vigil of the agents of an immune system to prevent the proliferation of a virus infection, this does not necessarily mean that such systems also incorporate the notion of self-destruction. One could argue that any self-destructive system is really a part of a larger adaptive system that requires the retardation of this part to accelerate its overall growth and survival.

Taking these characteristics of complex adaptive systems together (i.e., many agents acting in parallel, highly decentralized control with multiple levels of organization, continuous change and rearrangement, anticipatory behavior, credit assignment, and growth through the opportunistic occupation of vacancies), it becomes clear that they cannot and do not conform to standard linear mathematical models.

Mechanisms that change the number of agent types:

Agents typically have mechanisms for creating, destroying or transferring types (Fig. 6). For example, in populations of organisms germination, birth and death are obvious change mechanisms.

> ***Mutation*** changes the relative frequencies of the existing types and creates new types (e.g., the annealing of a metal changes the atomic structure).

Selection creates copies of the better types and eliminates others.

Imitation transforms one type into a copy of another type.

Since the mutation mechanism is normally the result of external forces, it is often deleterious to the system. The selection and imitation mechanisms, on the other hand, are positive in that they are mostly generated by internal forces and tend to reduce the variety of types. However, neither of these two change mechanism generates new types unless an error occurs during the copying process.

Crossover recombines genetic contributions from each of the parents.

Constraint relaxation generates variants that violate one or more constraints.

The crossover and constraint relaxation change mechanisms, however, can create new types and change the relative frequencies of existing types. They operate internally within the complex adaptive system and therefore may be more attuned to the ambient conditions of the system.

Exploration and exploitation describe the tension in complex adaptive systems between the creation of untested types (i.e., exploration) and the creation of copies of tested types (i.e., exploitation).

The constant tension between excessive exploration and premature exploitation is a significant factor in complex adaptive systems (Fig. 9). ***External boiling*** is said to occur if activity in the system is so high that the system appears to remain in permanent disorder, because any potentially valuable formations are again broken apart before they can become useful. Conversely, ***premature convergence*** will occur if the first formations are immediately applied by the system without further exploration that might have led to the discovery of better formations and increased variability.

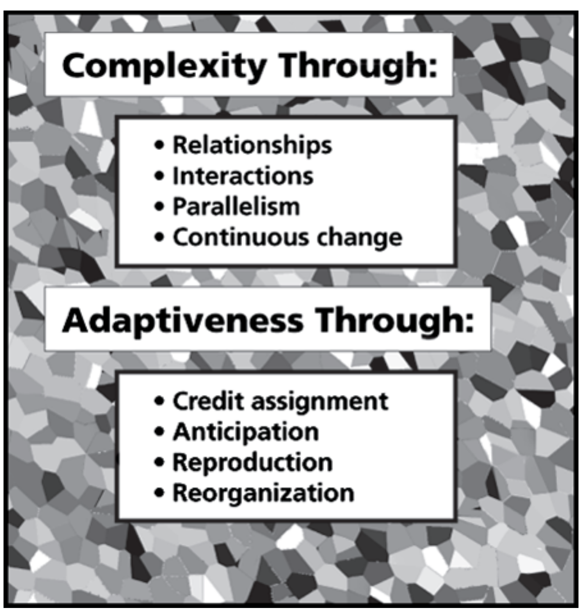

Fig. 5: Nature of Complex Adaptive Systems (CAS)

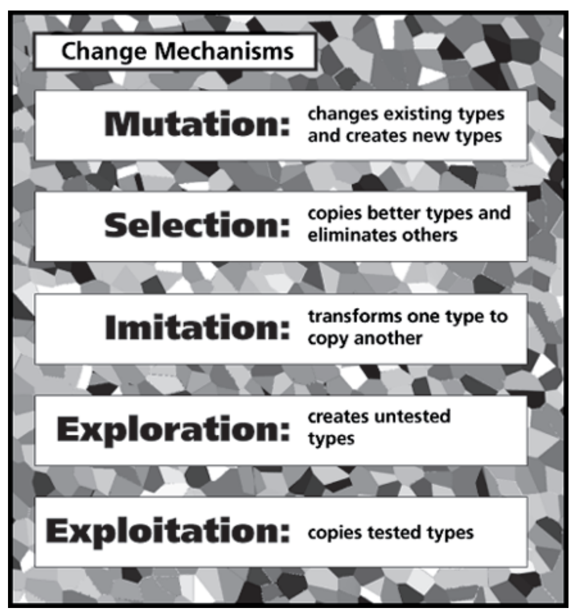

Fig. 6: CAS change mechanisms

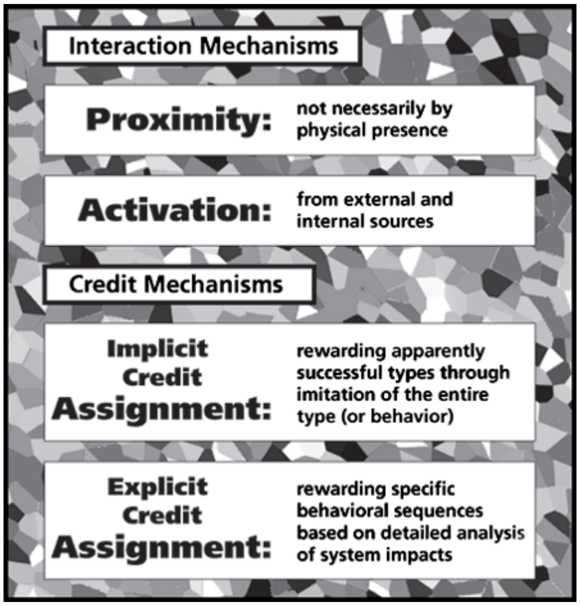

Fig. 7: CAS interaction and credit mechanism

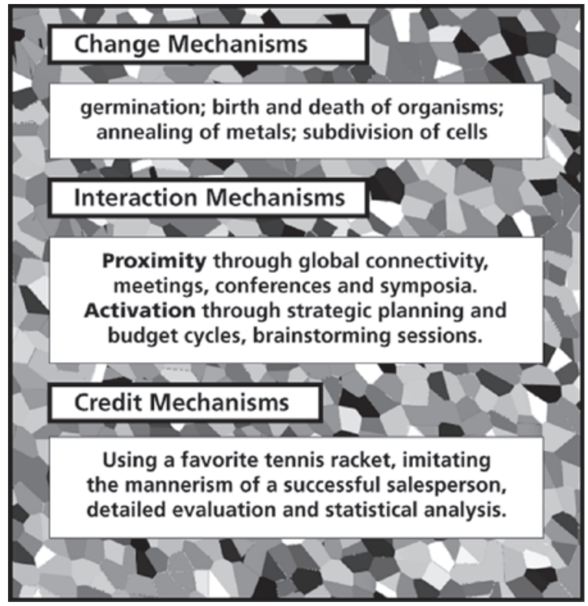

Fig. 8: Examples of CAS mechanisms

Mechanisms that depend on patterns of interaction:

In complex adaptive systems it is useful to distinguish between two mechanisms that largely determine which types or elements will interact with each other (Fig. 7).

> ***Proximity*** and the degree of commonality are significant factors that influence interaction within the system. However, proximity should not be interpreted literally as physical presence since, for example, in the Information Revolution the concept of presence is rapidly changing so as to exclude the need for physical proximity.
>
> ***Activation*** may be either periodically imposed on the system from the outside (i.e., exogenous activation) such as 'budget cycles' in business organizations, or it may occur internally (i.e., endogenous activation) where subsequent interactions are governed by the current event(s) within the system (Fig. 8 and 9).

Mechanisms that depend on credit assignment:

Change mechanisms that depend on credit assignment can be divided into two types; namely, ***implicit*** and ***explicit*** credit assignment (Fig. 7). Axelrod and Cohen (1997) argue that both of these have serious and complementary limitations and that therefore there exists a trade-off tension between these two types of credit assignments in most complex adaptive systems.

> ***Implicit credit assignment*** can be described as the practice of rewarding (and therefore promoting imitation) the practices of apparently successful elements (members) of the organization. Under these circumstances credit is assigned to the entire practice which is copied with as much accuracy as possible, although it is by no means certain that all (if any) of the individual actions that are executed by the practice are actually responsible for the favorable results. The fundamental premise of implicit credit assignment is to copy

successful types (i.e., behavior). Examples abound in everyday life: the use of a favorite bat in baseball; imitation of certain preparatory behavior prior to an important presentation; imitation of the peculiar mannerism of a successful salesperson by other less successful salespersons; and so on (Fig. 8).

Explicit credit assignment is more specifically related to the identification of quantitative signs that appear to signal success. It usually requires detailed analysis of the impact of actions on the system (or organization) in order to identify causal sequences. Examples include: detailed methods of program evaluation; experimental design; statistical analysis and inferencing; and so on (Fig. 8). None of these work perfectly, although the more detailed and refined (and most likely more expensive) explicit credit assignment mechanisms may avoid errors.

Unfortunately, credit assignment schemes are almost always imperfect. Both the implicit and explicit credit assignment mechanisms have somewhat complementary weaknesses. Limitations of implicit mechanisms relate to ignoring context or fine granularity, while the limitations of explicit mechanisms stem from focusing on the wrong, insufficient or poorly measured aspects of fine granularity or context (Fig. 9).

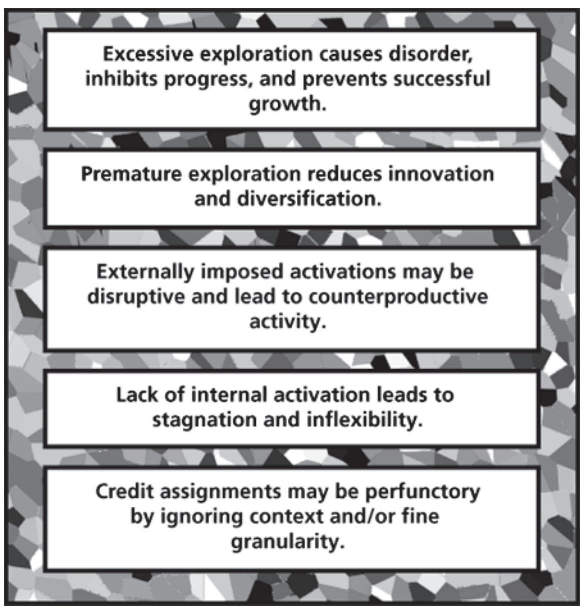

Fig. 9: Potential tensions within CAS mechanisms

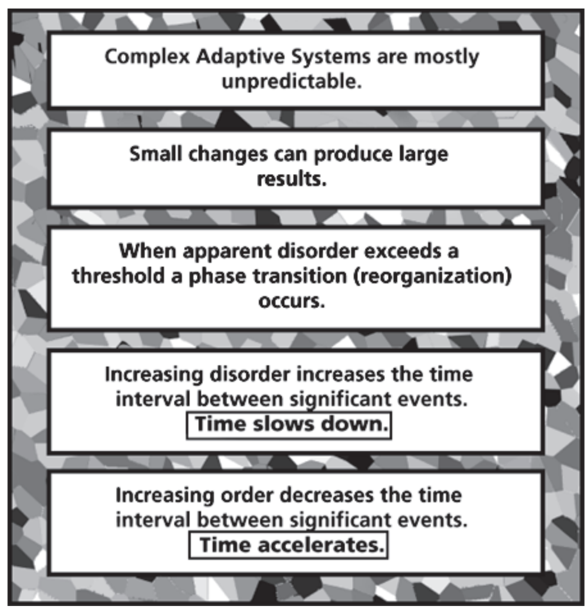

Fig. 10: CAS non-linear behavior

Technologies as Complex Adaptive Systems

According to Kauffman (1988) technologies form interconnected webs like a network, akin to an evolving ecosystem. They tend to grow in an organic fashion, with innovations made possible and stimulated by other innovations already in place (i.e., technologies A, B, C make possible technology D). For example, computer networks, faster computers, and computer languages make possible distributed decision-support systems.

These technological networks can be subject to bursts of activities and growth, and major extinction events (Fig. 6). For example, the automobile technology replaced the horse – blacksmith - pony express - watering troughs – stables - etc. At the same time the automobile technology provided stimuli for road construction machinery, traffic control systems, fuel refineries, service stations, and so on. As a technological web becomes denser with many dependent technologies it becomes more and more difficult to change that technology in anything but a marginal manner, until some major forces (i.e., events) impact the technology. Typical examples include the replacement of the horse by the automobile and the aircraft, and the replacement of all physical transportation modes by global connectivity (e.g., the Internet).

The Origin of Life within a Complex Adaptive Systems Environment

According to the standard theory of the origin of life deoxyribonucleic acid (DNA), ribonucleic acid (RNA), proteins, polysaccharides and all of the other molecules of life arose billions of years ago in a ***primordial atmosphere***, from the accumulation (in ponds) of simple molecular building blocks such as amino acids. In 1953, the Nobel laureate Harold Urey and his graduate student Stanley Miller showed experimentally that an atmosphere of methane, ammonia and the like could have produced these molecular building blocks quite spontaneously with the occasional lightening bolt to provide energy for chemical reactions. These simple molecular building blocks would have collected in ponds and lakes and undergone further chemical reactions to become more and more complex. Eventually a collection of molecules would have arisen that included the double helix DNA and/or the single strand RNA molecules, both of which have the ability to reproduce themselves. It is then argued that with the advent of ***reproduction*** life developed through ***natural selection***.

Opponents of this long standing theory would argue that most biological molecules are very large (e.g., several hundred amino acids) arranged in a precise order. Such molecules are difficult to produce even in a laboratory with very sophisticated biotechnology tools. So how could such a biological molecule form all by itself in a primordial pond? In evidence it is pointed out that statistical analysis of this happening in a truly random manner suggests that it would likely take longer than the life of the universe to produce even one useful protein molecule, let alone the relatively large number of proteins, sugars, lipids and nucleic acids that make up a fully functioning cell. In any case, why should the origin of life be tied to the appearance of DNA, and why should the origin of life be the result of random events? DNA's ability to reproduce itself depends on a complex process of: uncoiling; unzipping its two strands; and, making copies of itself. This process, which depends on many specialized protein molecules in 'helper' roles, would seem to be too complicated a process to occur randomly in a pond.

Treating the primordial atmosphere as a complex adaptive systems environment (Fig. 11), it can be argued that many small amino acids and sugars in close proximity are likely to be subject to at least some random reactions (i.e., interactions) with each other (Kauffman 1992). Statistically it is not difficult to show that these random interactions would have produced a significant number of small molecules with short chains and branches (Fig. 11a). Further, it is quite likely that at least some of these small molecules would have started to act as ***catalysts*** (Fig 11a). This is quite common in chemistry where one molecule attracts two other molecules nearby and brings them together so that they can interact and fuse quickly. Then the catalyst molecule releases the two fused molecules and looks for another pair to repeat the process. Conversely, in chemistry we see also the reverse process, one molecule slicing up another molecule into two similar parts. Catalysts are the backbone of modern chemistry (e.g., gasoline, plastics, dyes, pharmaceutical products, etc.).

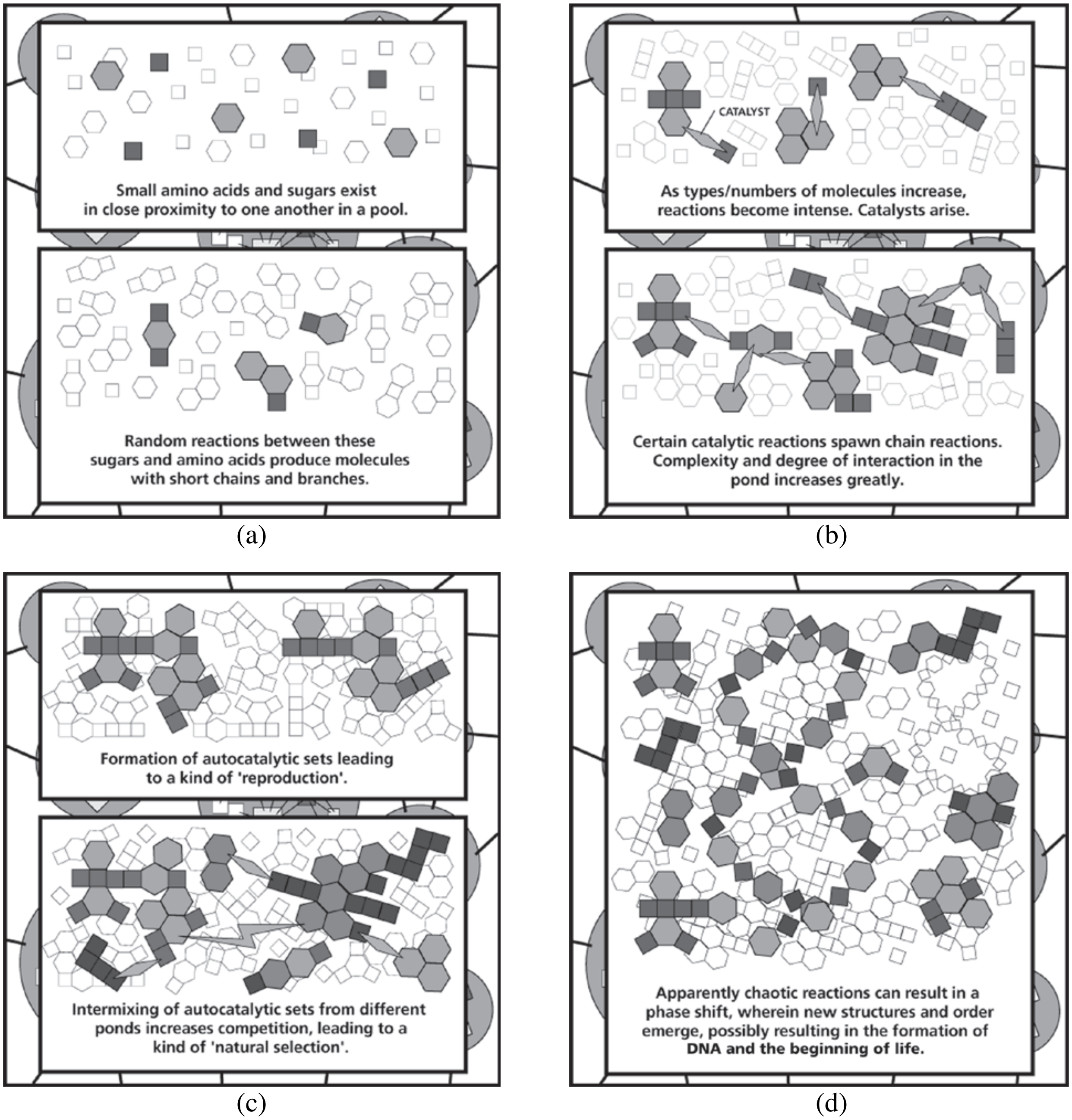

Fig. 11: Possible explanation of the beginning of life

Based on this ***catalyst*** notion it would seem reasonable to expect that at least a moderate ***chain reaction*** might occur. In other words, molecule A catalyzes the formation of molecule B, molecule B also has a catalytic capability (perhaps quite weak) and boosts the production of molecule C, and molecule C boosts the production of molecule D, and so on. If the pond is large enough and there are many different kinds of molecules then eventually a molecule Z might be found or created that closes the loop and catalyzes the creation of molecule A. This would increase the number of A molecules, accelerate the production of B, C and D molecules, and significantly increase the complexity and the degree of interaction in the pond (Fig. 11b).

Of course, this is not yet life, but simply a web of molecules or an ***autocatalytic set***. It has no DNA, no genetic code, and no cell membrane. However, soon the compounds in the web or pool could easily form a self-reinforcing set of reactions. Under such conditions the molecules in the web would become more and more abundant, because each molecule would have catalyzed the formation of other molecules. In other words, the web would have catalyzed its own formation as an autocatalytic set. Now an autocatalytic set could certainly exhibit a primitive kind of ***reproduction*** (Fig 11c). For example, during a flood if one autocatalytic set spilled over into another pool that also contained an autocatalytic set, then a competition for resources would start as each autocatalytic set tried to grow. It can be argued that this sets the stage for ***natural selection***.

Also, mathematically it can be shown that under such conditions the number of reactions will increase faster than the number of polymers (i.e., chains of molecules). Therefore, at some level of complexity this web could become ***mutually autocatalytic*** and undergo a ***phase transition***, a behavior that has been demonstrated with genetic networks (Dennett 1995). Kauffman (in Waldrop 1992, 122-5) argues that in a sufficiently rich primordial atmosphere ***life*** could spontaneously crystallize out of such a soup (Fig. 11d).

Economies as Webs with Autocatalytic Behavior

If we recognize an economy as a web of goods and services, then an ***autocatalytic set*** can be characterized as a submicroscopic economy that extracts raw materials (i.e., like primordial food molecules) and converts them into products (i.e., produces more molecules). Further, if innovations result from new combinations of old technologies then the number of innovations can grow rapidly as more technologies become available (Waldrop 1992, Holland 1988 and 1998). Under these conditions once the economy passes a certain ***threshold of complexity*** a type of ***phase transition*** can take place (i.e., like a ***mutually autocatalytic*** condition). For example, a small developing country that is dependent on just a few technologies (e.g., wool, wheat and sugar cane) is likely to experience little if any economic growth. Pouring more money into this country is unlikely to lead to significant economic growth. What this country needs above all is a broader technological base that can support an increased level of innovation.

Historically, trade has proven to be an effective catalyst for increasing the number of technologies and corresponding innovations. If two countries with more or less stagnant economies start trading with each other then the complexity level of their partnership will increase with an attendant increase in the level of activity and innovation. Of course the rate of development will depend on many factors, such as the complementary nature of the economies offered by each country, the political framework within which each country operates, the potential market size, and so on. It may not take long for this trading coalition to attract other partners, thereby further increasing the level of complexity toward a threshold and what some economists refer to as an "…economic take-off…".

The question of how much and what kind of technological diversification is productive, and what constitutes too much or inappropriate diversification, is a delicate one and requires careful consideration. Branching into technologies that can be leveraged from a foundation of skills that already exist in the economy under consideration would appear to be more promising than embarking on an entirely new path. The interactions of the new technology with the existing technologies and the potential for spawning secondary, supportive technologies, will largely determine the risks involved and the opportunities for growth. One would expect natural selection to play a helping, but also dangerous, role. As discussed earlier, complex adaptive systems are also subject to ***rapidly diminishing returns*** sometimes leading to mass extinction. Therefore, there exists a danger that an unsuccessful attempt to diversify will seriously deplete the existing technological base. Careful monitoring is necessary to avoid a destructive chain reaction.

Business Organizations in a Complex Adaptive Systems Environment

On the assumption that the primary goal of a business is to make a profit, the dual abilities of the business to predict future market trends and adapt or organize itself to maintain a competitive edge, are critical to the survival of that business (Fig. 12). In a complex adaptive systems environment the principal obstacle to predicting the future is the multiplicity of interacting forces. For example, technologies are adopted not only as a function of cost and utility, but also as a function of the number of users (i.e., early acceptance, market lead, etc.) and the deployment of related technologies. Examples are the delayed adoption and exploitation of facsimile (i.e., FAX) transmission (i.e., the facsimile technology was invented several decades prior to its wide spread commercialization), the market dominance of the VHS video format over the qualitatively superior BETA format, and the dependence of Internet services on the installed telephones base.

Since complexity is largely due to associations we can expect that changes will be accompanied by increased interaction among the parts of the system. However, the ***Information Revolution*** is focussed on reducing the barriers among the isolated parts and increasing the interactions. Therefore, the Information Revolution is likely to be accompanied by a ***complexity revolution***. Axelrod and Cohen (1997) argue that the Information Revolution by its very nature of enabling and accelerating information exchange (i.e., through connectivity, decreased communication costs, and increased storage capacity) will maximize interaction, change and adaptation in society as a complex adaptive system (Fig. 13).

For a business organization to operate successfully in such a dynamically changing environment, ***adaptation*** is likely to play a major role. Adaptive mechanisms such as increased communication and system status detection are embedded in many of the conditioning factors of the Information Revolution, potentially providing many new capabilities for establishing and measuring the status of an organization that operates within its realm. It stands to reason that in such a volatile complex adaptive system environment individual persons and organizations should be able to manipulate significant aspects of the system to their advantage (e.g., business). At the same time such manipulations could easily move beyond the original objectives, out of control (e.g., politics)

Viewed as a complex adaptive systems environment the ***Information Revolution*** is likely to precipitate a rate of change that will exceed the adaptive desires and capabilities of a significant section of the human population. As a result this environment will become increasingly uneven with some parts of the system adapting and changing at a much faster rate than other parts. This would suggest that the environment might separate into multiple systems some of which will become increasingly isolated from the others.

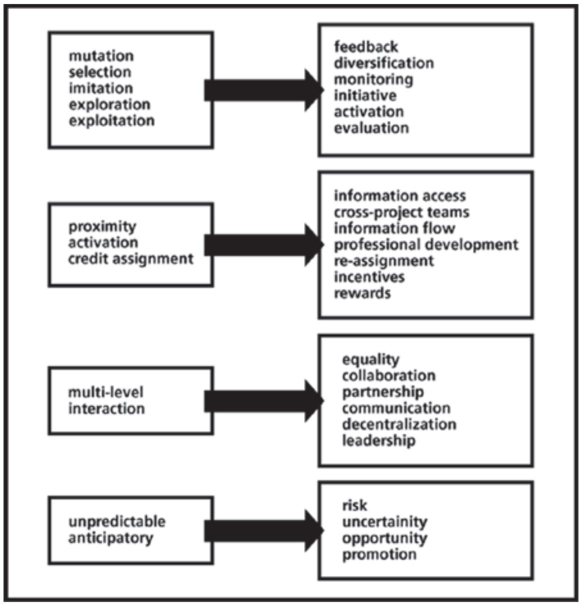

Fig. 12: CAS characteristics and organizational equivalents

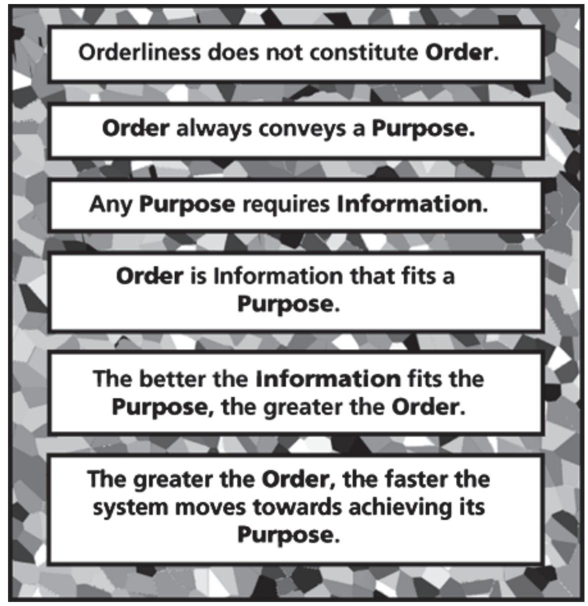

Fig. 13: Nature of CAS order

Is the Information Revolution therefore moving us into an era where society is going to disintegrate into many subcultures and groupings based on education (i.e., skills), earning capacity, motivation and imagination, social skills (e.g., leadership), and so on? If yes, then these groupings are likely to cross traditional boundaries of race, family, geographical location, and employment. (i.e., profession, career, etc.). In particular, the status of individual persons may change rapidly in this environment. The influences of background, family, and similar traditional determinants will still be felt but in a different way. In the past these factors have directly contributed and often determined the physical environment and the social position of an individual. In the Information Revolution these influences are likely to be felt more indirectly through the emotional make-up and intrinsic behavioral characteristics of the individual person.

Regardless, it can be argued that in an Information Society there is a critical need for business organizations to institute methods for monitoring changes within the market place and society at large, as an early indicator of those events and patterns that are likely to lead to significant adaptations (i.e., reorganizations) of the complex adaptive systems environment in which they operate. In other words, the time scale of history will be increasingly reduced with discernable changes occurring annually and monthly instead of within decades and centuries.

Decentralized organizational structure and leadership:

The behavior of a complex adaptive system emerges from the interactions of its parts, rather than from a dominant centralized control mechanism (Fig. 14). Accordingly, the Information Revolution will lead to increasing decentralization because of its propensity for increased change. Centralized control structures (e.g., dictatorships, monopolies, military chain-of-command, etc.) will be increasingly challenged and will become less effective. This places a greater emphasis on leadership capabilities at all levels of an organization, as centralized leadership is increasingly replaced by distributed leadership. However, as centralized leadership gives way to distributed leadership there will be an increasing need for a ***collective intent*** to prevent fragmentation and disintegration.

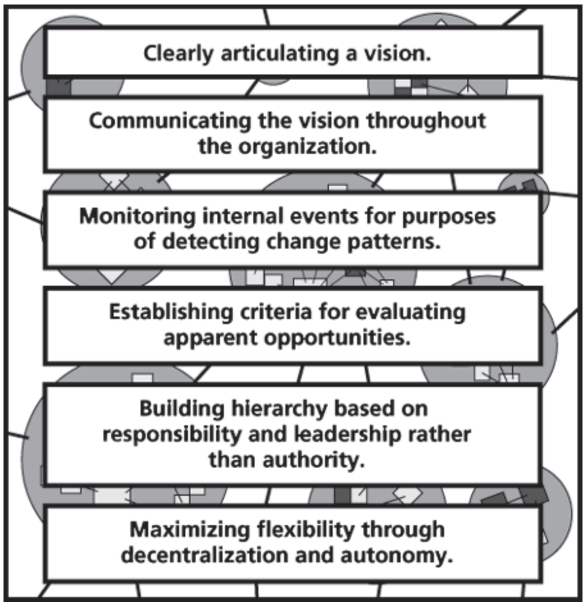

Fig. 14: Facilitating 'order' in an organization

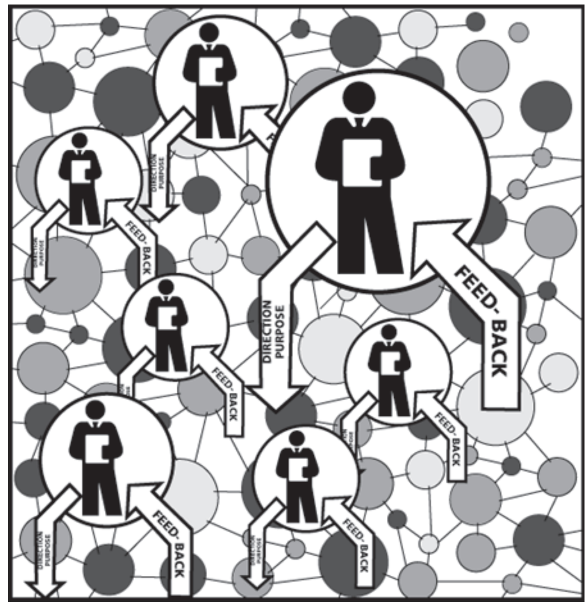

Fig. 15: Facilitating 'leadership' in an organization

Also, it should be noted that distributed leadership does not displace the need for an hierarchical organizational structure. Hierarchy is intrinsically related to degree of responsibility. Typically, higher levels in an hierarchical structure have increasingly broader responsibilities, while lower levels have increasingly narrower and more focused responsibilities. The broader the responsibilities, the greater the need for leadership.

Although leadership implies authority, the most successful leaders seldomly (if ever) explicitly exercise authority. The connotations associated with ***supervision***, a term favored by current management practices, suggest control, authority and subservience. All of these tend to stifle initiative, collaboration, and a genuine willingness to promote organizational interests in favor of self-interests. The concept of supervision is not compatible with the successful operation of a business organization within a complex adaptive systems environment, in which the ability of the organization to leverage flexibility, adaptiveness and proactiveness at every node is critical.

Direction and feedback:

For a business organization to survive and increase its competitiveness in a non-linear environment it cannot be controlled. Control assumes a degree of stability and certainty that cannot exist in an environment that is largely unpredictable, subject to continuous changes, and essentially out of control. However, such an organization can be, and should be guided and directed based on continuous ***feedback*** (Fig. 15). Any directions that are given must include an explanation of the purpose of the assignment (i.e., the intent) so that the recipients are encouraged to freely modify the directions subject to changing circumstances, without departing from the original intent.

The mechanistic approach to decision making is to attempt to control situations by recreating initial (i.e., previous) conditions, and by establishing certainty through the acquisition of more and more information. Since the situation is continuously impacted by external events and therefore subject to largely unpredictable changes, there will never be a sufficiently complete set of information to guarantee a correct course of action. As a result, decisions are delayed until inevitably they become entirely reactive and the organization is forced into a crisis management mode of operation.

Diversification of services and/or products:

To what extent does the need for technological diversification scale down to an organizational level? Certainly, it would be foolish to rely on natural selection to weed out those diversification attempts in a developing business organization that are failing. Small to medium sized businesses have little capacity for absorbing negative cash flows, even on a temporary basis. Typically, all of the human resources in such a business are already overextended. Under these circumstances it is particularly important that new services and products build almost directly on existing skills, capabilities and experience (Fig. 16).

At least three strategies appear to be useful in this respect. First, even moderate growth normally requires increased human resources, bringing with it the opportunity for adding new skills to the existing base of core capabilities. Second, ***partnering*** with another organization that provides different but complementary services or products can provide access to new skills and technologies. Third, the provision of targeted professional growth opportunities to employees can facilitate an influx of new ideas and capabilities particularly if the initial impetus came from the employee. However, regardless of the original source of the stimulus the benefits derived from the professional growth investment will depend largely on the effective dissemination of the gained knowledge within the organization. In other words, the organization must maintain ***open communication channels*** and nurture through formal and informal mechanisms the application of the gained knowledge in new technologies.

Underlying all three of these strategies is the need for the organization to maintain a high degree of flexibility facilitated by decentralized project teams, frequent cross-project communication and consultation, short decision channels, and an organizational vision that is freely shared at all levels within the organization.

Monitoring and evaluation:

Since relatively small stimuli occurring in mostly unpredictable ways within a complex adaptive systems environment can have disproportional large impacts, and since these impacts provide a means for accelerating the success of or demise of components of the environment, it is important for a business organization to be able to (Fig. 17):

- Identify opportunities when they occur.
- Evaluate opportunities based on clearly defined criteria.

- Pursue the most promising opportunities rapidly and aggressively with an effective internal development and implementation process.

Fig. 16: Facilitating 'diversification' in an organization

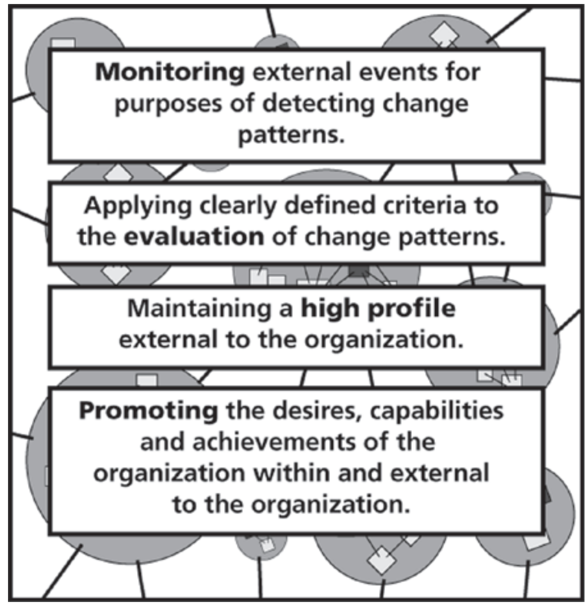

Fig. 17: Facilitating 'opportunities' in an organization

Does this mean that our value system which has evolved only very gradually in the past, will be subject to much more rapid change in the future, and that the monitoring of these changing values will become an important preoccupation? For example, in the United States we are increasingly blaming our existing education system (i.e., kindergarten to twelfth grade) for failing to adequately prepare the younger generation. However, we are measuring the capabilities of the younger generation mostly in terms of historical standards that may not be entirely relevant to current and near future states of society. It would appear that for measures of change (which in many respects constitute our value system) to be effective they must change with the changes that they are designed to measure. In this respect the term ***standard*** loses its traditional connotation of being ***static*** and ***absolute***, and assumes a new connotation of being ***dynamic***, and ***relative*** to the changing conditions. This means that in a complex adaptive systems environment even the measures of change need to change (i.e., adapt) relative to the changes that are being monitored (i.e., measured).

If the higher level purpose of measuring and monitoring the dynamic changes in a complex adaptive systems environment is to dynamically maintain a ***collective intent*** to guide the evolution of a business organization within its market environment, then the lower level purpose of measuring and monitoring the dynamic changes in the environment is to reward positive adaptive behavior and to anticipate change patterns for the gain (i.e., exploitation) of the organization.

Rewarding through credit assignment:

As discussed previously, credit assignment mechanisms in a complex adaptive system are prone to error and yet they constitute an important method for rewarding success and accelerating the growth of the system. The implications for a business organization that values individual initiative and desires growth would appear to include the following (Fig. 18):

- Provide employee incentives.
- Retain focus on the capabilities, aspirations, interests, and needs of the individual.
- Insist on leadership as opposed to authority.
- Promote initiative as opposed to control.
- Promote self-determination and equality as opposed to subservience.

How should the performance of individual employees be rated? Implicit evaluation may fail to give credit to individual team members whose contributions are not clearly visible. On the other hand, explicit evaluation is likely to be heavily influenced by the theories of the evaluator that do not match the tacit knowledge that individual skilled team members may have of the actual tasks.

Clearly the mechanisms of credit assignment are closely related to the ability of an organization to identify and judge the relative significance of events. Such events may occur within the organization itself, or they may occur in the external environment with the potential for impacting the organization. In other words, in a broader sense the mechanisms of credit assignment depend on the ability of an organization to recognize opportunities (i.e., ***activation***), accurately judge the relative merits of each opportunity (i.e., ***exploration***), decide on a course of action for pursuing the opportunity (i.e., ***exploitation***) within the resource constraints of the organization, and implement a mechanism for measuring performance and rewarding success (i.e., ***credit assignment***).

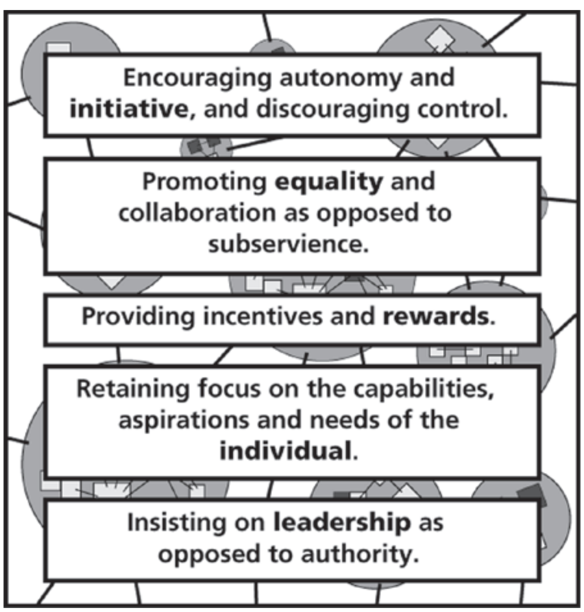

Fig. 18 Facilitating 'performance' in an organization

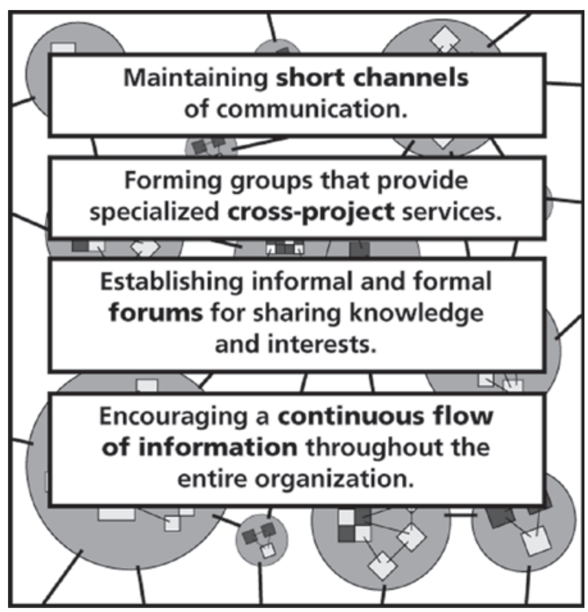

Fig. 19: Facilitating 'communication' in an organization

Internal and external communication:

In a complex adaptive systems environment, the tension between ***exploration*** and ***exploitation*** creates a continuous trade-off situation. It is therefore imperative for a business organization to (Fig. 9):

- Establish a clearly defined and easily applied set of criteria for evaluating opportunities and alternative courses of action.
- Implement an effective project management process that encompasses all project related activities (e.g., knowledge acquisition, design, development, testing, documentation, installation, training, and coordination functions).
- Maintain good internal communications so that all groups or teams have at least a conceptual understanding of the responsibilities, objectives, and endeavors of the other groups.

Since patterns of interaction (i.e., interaction through ***proximity*** and ***activation***) largely determine the vitality of a complex adaptive system, it behooves a business organization to vigilantly sustain a continuous flow of information within the organization, to ensure that all employees have a clear understanding of the goals and objectives of the organization and have the ability to contribute to the continuous adjustment and refinement of these goals and objectives. This would suggest the need to maintain short and open channels of communication to and from all nodes of the organizational matrix structure (Fig. 19).

Specialized support teams that provide services across project boundaries tend to have several useful influences. First, such teams lead to greater efficiency because they reduce duplication of effort and typically achieve a higher level of competency within the particular service area. Second, the necessary interaction among project and service team members facilitates horizontal and vertical communication within the organization. For example, in a business organization that provides highly technical services such as the design and development of computer software products, cross-project teams promote an understanding of the nature and the commonalties that exist among multiple projects. The results of these understandings tend to stimulate innovation, professional development, and a desire to share development tools and software components. Third, the availability of specialist support teams will allow the organization to react more quickly and effectively to new business opportunities. This increased responsiveness will manifest itself in both a shorter reaction time and greater accuracy in the assessment of the business opportunity.

Finally, specialized support teams bring potentially order and flexibility to an organization. The process of forming and establishing the boundaries of each support team, as well as defining the relationships of the services provided by all support teams to the project teams, forces the organization to identify not only personnel strengths and weaknesses but also the principal components of each existing project, and the ability of the organization to undertake new ventures.

It would appear that top-down (i.e., hierarchically imposed) ***activations*** in an organization will produce largely predictable and minimally stimulating results, while bottom-up activations are likely to produce more creative and constructive results (Fig. 20). For instance, periodically imposed strategic planning efforts and mandatory personnel review cycles are unlikely to result in significant changes within an organization. However, the current state and needs of the organization, as well as its size and external dependencies, are factors that will influence the response to the activation. For example, a small organization that operates in a dynamic and highly competitive environment is likely to have a better chance of survival and growth based on endogenous (i.e., internal) activation, because it needs to be able to respond quickly with innovative plans and ideas (Fig. 21). A larger organization, on the other hand, tends to be more concerned with control as a means of retaining its dominant and apparently safe position in the market place (i.e., success does not breed change while lack of success tends to foster innovation).

There is a tendency for smaller organizations to imitate larger organizations and impose ***structure*** to counteract lack of ***process***. Process provides a methodology for approaching the solution of a problem. Any organization, whether it has a clearly defined structure or not, can suffer from lack of process. Structure simply defines (and purposely restricts) the lines of communication and the decision making hierarchy within an organization. In this respect structure must be viewed more as restraining than enabling, while the entire aim of process is to enable the organization to be more efficient, cohesive and productive.

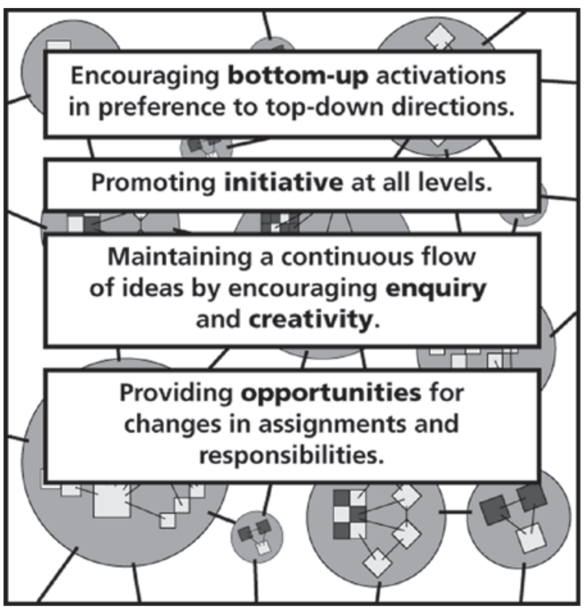

Fig. 20: Facilitating 'activity' in an organization

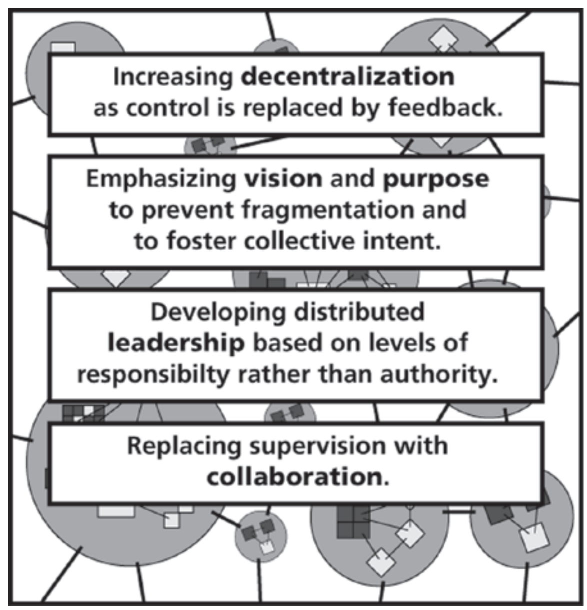

Fig. 21: Facilitating 'initiative' in an organization

Since stimuli can come from both internal and external sources in a complex adaptive systems environment, and since such stimuli largely determine the success and survival of the system (i.e., organization), it is necessary for a business organization to maximize its opportunities by:

- Maintaining a high profile externally.

- Building on its uniqueness to establish itself as a leader in its area of expertise.
- Presenting and demonstrating its concepts and services in multiple ways on a continuous basis.

Maintaining adaptiveness through flexibility:

It was pointed out earlier that the mechanisms that alter frequencies (i.e., create, destroy and transform types within a complex adaptive system) through mutation, selection, imitation, crossover, and relaxation, are fundamental to the survival potential of the system. Accordingly, the structure of a business organization needs to be well attuned to a dynamically changing environment in which rapid response to opportunities is critical to the survival of the organization. Important features of such an organizational structure include (Fig. 22):

- A flattened, web-like, matrix structure.
- A highly interactive environment.
- Information access at all nodes.
- Small teams.
- Distributed decision making.

These features should allow the organization to maintain a friendly, stimulating, and highly collaborative work environment that maximizes opportunities for professional growth and development as an important business investment.

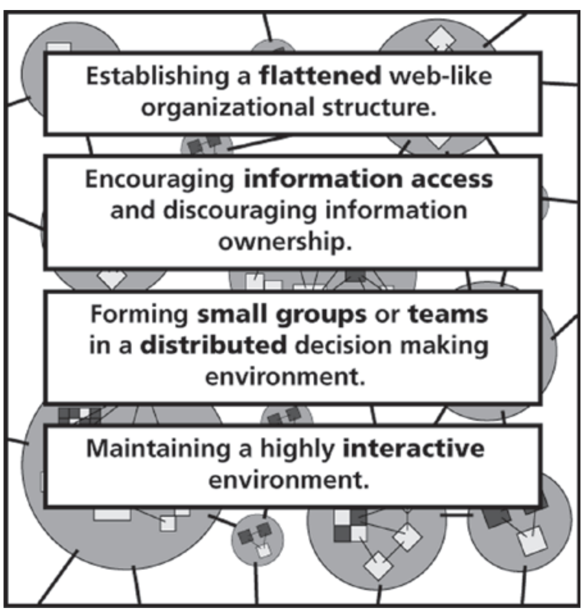

Fig. 22: Facilitating 'flexibility' in an organization

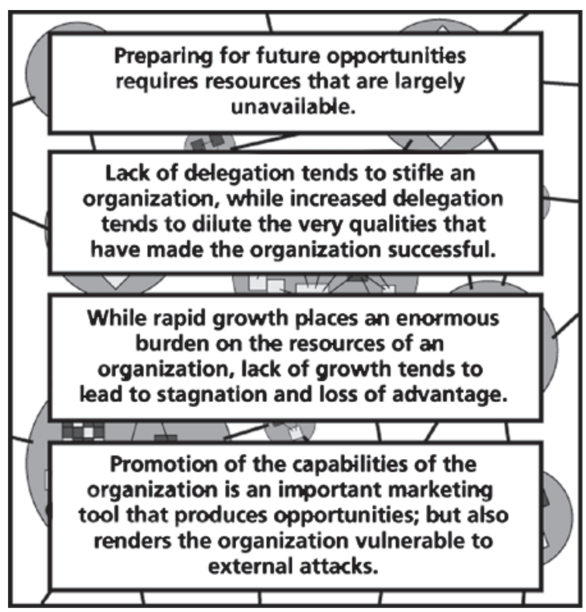

Fig. 23: Organizational dilemmas

Concluding Remarks

The thesis of this paper is that the world is much more complicated than we have generally allowed ourselves to believe in the past. Our rather simplistic view of the systems that engage our endeavors has suggested that we can largely control our destiny by predicting future events. Unfortunately, the assumptions that have to be made to apply essentially linear tools to non-linear systems are not compatible with the fundamental characteristics of these systems, as described in this paper.

The dominant human desire to control the environment is in direct conflict with the unpredictable nature of complex adaptive systems. Effectively, control is replaced by feedback. In other words, any attempts to identify change patterns, detect apparently major events, and determine possible future occurrences, depend almost entirely on continuous monitoring of the current condition of the complex adaptive systems environment. As discussed earlier, in this environment feedback represents the principal basis for planning and decision making.

The impact of these considerations on the organizational structure and operation of a business enterprise are potentially profound (Fig 23). In summary, the key strategies for maintaining a necessary degree of responsiveness, discussed in this paper include: decentralization with a focus on multi-level, distributed leadership, as opposed to centralized control and authority; emphasis on the acquisition of new skills through partnering and professional growth investments; identification and evaluation of opportunities arising from multiple sources; increased reliance on internal and external communication channels for achieving a desirable level of activation within the organization, and maintaining a competitive edge in the marketplace; and, sustainment of a high degree of adaptiveness through the flexibility afforded by smaller teams capable of providing services and interacting at any level in a semi-autonomous manner.

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