Adapting to the Information Age

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Abstract

This paper draws attention to the profound changes that human civilization is experiencing as it moves from an industrial environment into an information environment, in which unprecedented emphasis is placed on the knowledge and capabilities of the individual. A clear distinction is drawn between data and information in relationship to computer-based facilities, and the transition of data-processing to the higher levels of information and knowledge representation in quasi intelligent decision-support systems. It is argued that the cultivation of its human capital becomes a foundational requirement for the success of a knowledge-based organization. In such an organization traditional practices of hierarchical, authoritarian control are replaced by a distributed framework of leadership that utilizes different methods for maximizing the contributions at each node of a web-like organizational structure. Throughout the paper the close relationship between the apparent behavior of the natural and human systems in the real world and the theories relating to chaos and complex adaptive systems is emphasized.

Keywords

Agent, business intelligence, complex adaptive system, computer, data, decision-support, knowledge, knowledge-based organization, knowledge management, Industrial Age, information, Information Age, ontology, organization, problem solving.

Introduction: A Time of Profound Changes

It is perhaps a paradox that we live in an environment in which everything is relative and yet we continuously seek absoluteness. Human beings appear to be most comfortable when they are absolutely sure of what is going to happen next and the anticipated event is not unlike one that they have coped with successfully on at least one previous occasion. Under these circumstances we are confident that we will continue to survive in an environment that we know to be highly competitive and largely unforgiving.

Our level of confidence is based on our past experience. While every change in our environment adds to this experience base, our immediate emotional reaction is a deep-seated fear that we will not be able to accommodate the change in a satisfactory manner. The fact that change is a necessary prerequisite for gaining experience is something that we typically recognize only after we have survived a short term reactionary anxiety. This paradoxical relationship between our emotional need for stability and predictability, and the reality of a changing environment in which everything is relative and nothing is entirely predictable, is an intrinsic source of stress in the human psyche. Further, the degree of stress appears to increase disproportionally with the rate of change. It should therefore not come as a surprise that the changing focus from a physical world to a virtual world that we are currently experiencing is presenting a significant challenge to our emotional comfort.

The transition from an Industrial Age to an Information Age is not only bringing many changes but the rate of change is also increasing. This is entirely consistent with prevailing concepts of chaos theory and, the emerging recognition that we live in a world of interacting complex adaptive systems (Axelrod and Cohen 1997, Kauffman 1988). In these systems time is perceived to be accelerating whenever the time interval between major events decreases, and conversely time will appear to slow down when the interval between events increases (Kurzweil 1999). Recognizing that it takes much less time to create a virtual product than to manufacture a physical artifact, the accelerating rate of change that we are beginning to experience at the threshold of the Information Age should not evoke surprise.

This paper examines five major changes that are beginning to challenge the very structure of human society as we transition into an Information Age. The first change is placing an unprecedented focus on the individual. At first sight, this change would appear to be anything but stressful to the individual. Surely the more value society places on the protection and promotion of human rights, the preservation of life, and the insistence on equal opportunities, the more freedom and personal comfort should result. In fact, it can be said that never in the history of society has the individual been presented with more opportunities and the means to take advantage of these opportunities, than today. There are however at least two aspects of these opportunities that are placing increasing pressure on the individual. First, in our highly competitive complex adaptive system like environment we cannot afford to let opportunities slip by. Therefore, we are under constant pressure to take advantage of every opportunity that presents itself lest it should be pursued by other individuals who will progressively become more capable and therefore more competitive than we are. In other words, in a rapidly changing environment inaction carries with it a penalty that can potentially greatly exceed the perceived loss of opportunity.

Second, focus on the individual increases the expectation that the individual is capable and motivated to take advantage of at least the most obvious opportunities. This creates an implicit pressure for the acquisition of skills. The increasing demand for computer skills by employers for virtually any position in any discipline is an obvious example. However the pressure is exacerbated in several ways. For example, persons who are not motivated to continuously upgrade their skills and increase their knowledge base find themselves at a decided disadvantage and on the path to obsolescence. Whereas in the past subservience and compliance were considered virtuous characteristics, today they are viewed negatively. Whereas in the past initiative and proactiveness were considered to be the exception rather than the rule, today these characteristics are the expected norm. Whereas in the past earned degrees and diplomas were accepted as evidence of knowledge and skills, today persons are judged on the basis of their performance whether or not they have been officially certified to have particular skills.

A second change is currently creating a great deal of confusion and frustration. In the world prior to the advent of computers the distinction between data and information was an academic issue that had little practical relevance. Human beings do not have to make a conscious effort to convert data to information. This is a largely subconscious cognitive process that we perform automatically. For example, when we speak to someone about a 'table' we can assume that the person will understand what kind of an object we are referring to. However, the word 'table' has no meaning. It is the associations that this person intuitively makes with his or her knowledge of and experience with tables that constitute meaning. In other words, the person has automatically converted data to information through the application of context. In recent years we have come to the realization that computers do not have this inherent capability. The ability to store and transmit virtually unlimited amounts of data (that is not automatically converted into information) in computers has led to a great deal of frustration and disappointment.

For example, a person may receive about 80 to 100 e-mail messages per day. Unable to access her e-mail system for a few days (e.g., while on a camping trip) the person will be faced with the daunting task of answering 400 or more e-mail messages while receiving another 100 new messages each day. Surely the computer should be able to sift through these messages and group them into various categories: those that need immediate attention; those that have been superceded by new messages; those that should be immediately sent on to someone else; and so on. However, the computer cannot undertake this very simple task (by human standards) because these e-mail messages are stored and transmitted in the computer as data (i.e., meaningless text strings). Under these conditions the value of current e-mail systems depends on the human recipient's ability to interpret the transmitted data message as information by the addition of context. The vast volumes of data that are currently being stored in millions of computers world-wide are of little value unless they can be converted into information. This is an enormous task that cannot and must not be performed by human users alone. There is an urgent need for the storage and transmission of information, rather than data, in computer-based systems.

The third change is closely related to the 'data' problem. Global connectivity brings with it increasing complexity, since the complexity of a decision making situation is a function of the number and nature of the relationships that connect the elements of the situation with each other and external systems. This coupled with generally higher expectations for both quality and responsiveness, are forcing us to leverage our human capabilities through computer-based assistance. Increasingly, the need for this assistance is at a higher level of expertise (i.e., at the decision-support level rather than the data-processing level). To be useful at that higher level the computer must have reasoning capabilities, however those can be exercised on the basis of information only. Therefore, any meaningful human-computer collaborative partnership is predicated on the representation of information in the computer.

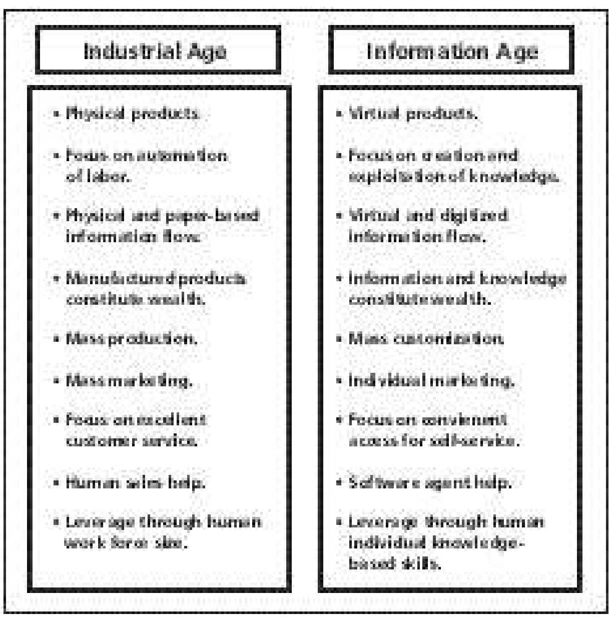
However, as we gain confidence in the ability of the computer to assist at this quasi 'intelligent' level we will also come to rely more and more on the availability of this assistance. The tensions generated by this increasingly dependent human-machine relationship will manifest themselves in several ways: trust in the reliability of computer generated advice; threat of privacy and security breaches; temptation for isolation in a virtual world; abandonment of self-determination for the convenience of a computer controlled environment; inability to differentiate between a virtual and a real world; and so on.

The fourth change is related to the first change, namely the increasing focus on the individual and the assumption that we live in a complex adaptive systems environment. In such an environment the initiatives and activities at the local nodes largely determine the capabilities and success of the organization. Central control, on the other hand, is typically ineffective since it tends to be insensitive to local changes. The very notion of a single control is misplaced in such an environment where the plurality of activities at the nodes constitutes a collective contribution that often greatly exceeds and usually differs in its nature to the individual contributions of the parts. The best that can be achieved centrally is the communication of intent (accompanied by explanation) based on the continuous monitoring of feedback.

All of these changes are contributing to a fifth change, the emergence of the knowledge-based organization. Such an organization views its members as its true capital and exploits every opportunity to increase and improve its collective capabilities through the autonomously cultivated efforts of each individual member. The objectives of a knowledge-based organization are to nurture and orchestrate the self-motivated initiatives and efforts of its constituents.

Focus on the Individual

The Industrial Age placed great value on physical products and devised ingenious ways to maximize the manual contributions of its human work force in a subservient role to a highly automated mass production process. This focus on the automation of labor viewed individual initiative and self-determination largely as a troublesome obstacle to a central hierarchy of authoritative control. Consequently manufactured products constituted wealth and the manufacturing organization leveraged its capabilities through the size of its workforce (Fig.1).



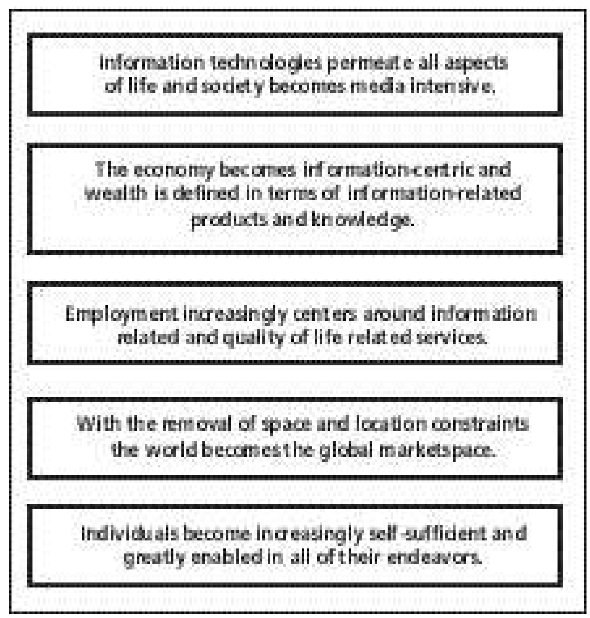


Fig.1: Changing Focus in the Information Age

Fig.2: Indicators of change

In the Information Age the focus has moved from the physical capabilities of the human work force to the intellectual capabilities and potential of its individual members. The attendant symptoms of this profound shift are the replacement of mass production with computer controlled mass customization, virtual products as opposed to physical products, and the creation and exploitation of knowledge. The high value placed on intellectual skills has generated an unprecedented desire and need for information that cannot be sustained by a manual paper-based information flow. The first step in facilitating the necessary information flow has been the creation of a global communication infrastructure for the high-speed transmission of digitized data. The second step will see the development of local ontological frameworks that will allow data to be mapped to object models as a form of information that can support at least a primitive form of analysis by computer-based agents. Over the next decade both the information representation and the automatic agent analysis capabilities will evolve to leverage by a significant degree the capacity of human intellectual activities within a collaborative human-computer partnership.

In this environment society will become information-centric and information technologies will permeate all aspects of everyday life (Fig.2). Increasingly wealth will be measured in terms of information-related products and knowledge, and individuals will become greatly enabled in all of their endeavors. Early drivers of this trend are the digitization of all forms of data, the declining cost of data-processing devices, and the convenient availability of communication facilities.

As individuals become more valuable they will also demand a higher quality of life, and continuous access to the virtual products of the Information Age, such as on demand multi-media support of all business and recreational activities, convenient and reliable wireless communication, and customized human services that are continuously available everywhere at any time.

Transition from Data to Information

It is often lamented that we human beings are suffering from an ***information overload***. This is a myth, as shown in Fig.3 there is no information overload. Instead we are suffering from a data overload. The confusion between data and information is again very apparent. Unorganized data is voluminous but of very little value. Over the past 15 years industry and commerce has made significant efforts to rearrange this unorganized data into purposeful data, utilizing various kinds of database management systems. However, even in this organized form we are still dealing with data and not information.

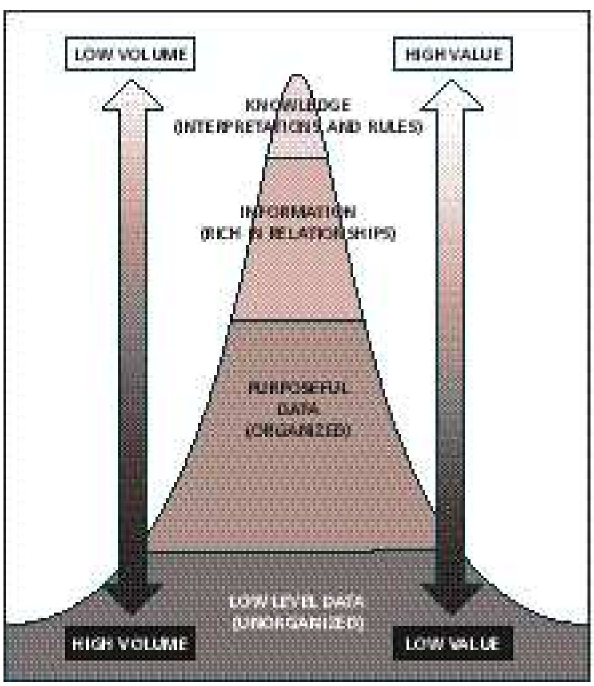


Fig.3: The ***information overload*** myth

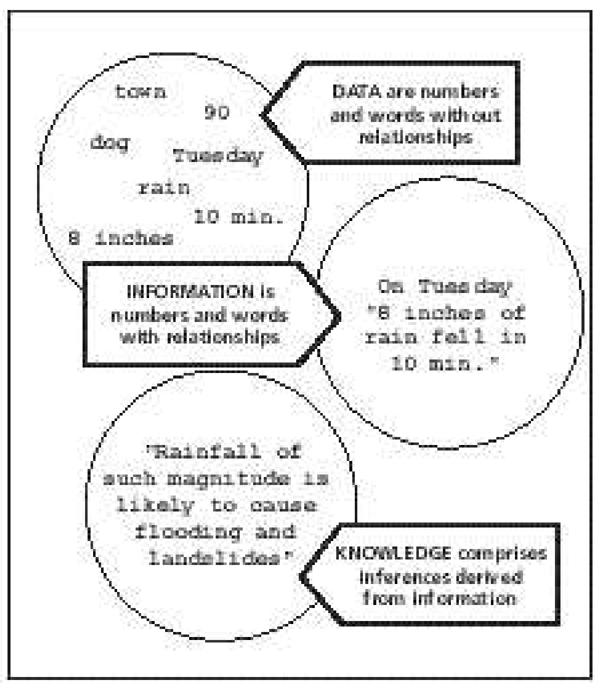


Fig.4: Data, information and knowledge

Data are defined as numbers and words without relationships. In reference to Fig.4, the words “town”, “dog”, “Tuesday”, “rain”, “inches”, and “min”, have little if any meaning without relationships. However, linked together in the sentence "On Tuesday, 8 inches of rain fell in 10 min." they become information. If we then add the context of a particular geographical region and historical climatic records we could perhaps infer that "Rainfall of such magnitude is likely to cause flooding and landslides." This becomes knowledge.

Context is normally associated solely with human cognitive capabilities. Prior to the advent of computers it was entirely up to the human agent to convert data into information and to infer knowledge through the addition of context. As shown in Fig.5, the intersection of the data, human agent and context realms provides a segment of immediately relevant knowledge.

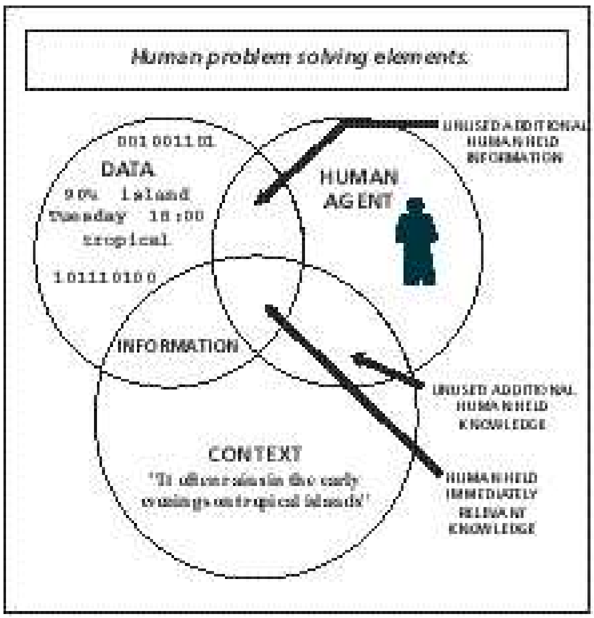


Fig.5: Unassisted problem solving

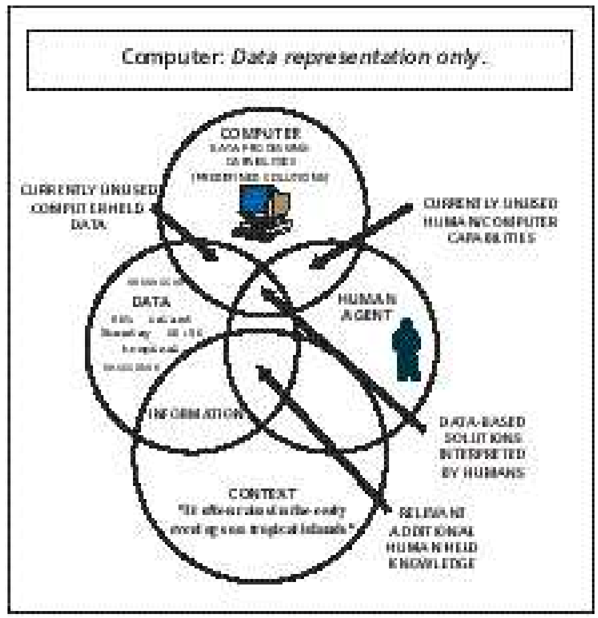


Fig.6: Limited data-processing assistance

When computers entered on the scene they were first used exclusively for processing data. In fact, even in the 1980s computer centers were commonly referred to as data-processing centers. It can be seen in Fig.6 that the context realm remained outside the computer realm. Therefore, the availability of computers did not change the need for the human agent to interpret data into information and infer knowledge through the application of context. The relegation of computers to data-processing tasks is the underlying reason why even today, as we enter the 21st Century, computers are still utilized in only a very limited decision-support role. As shown in Fig.7, in this limited computer-assistance environment human decision makers typically collaborate with each other utilizing all available communication modes (e.g., telephone, FAX, e-mail, letters, face-to-face meetings). Virtually every human agent utilizes a personal computer to assist in various computational tasks. While these computers have some data sharing capabilities in a networked environment, they cannot directly collaborate with each other to assist the human decision makers in the performance of decision making tasks. Each computer is typically limited to providing relatively low level data-processing assistance to its owner. The interpretation of data, the inferencing of knowledge, and the collaborative teamwork that is required in complex decision making situations remains the exclusive province of the human agents. In other words, without access to information and at least some limited context the computer cannot participate in a distributed collaborative problem solving arena.

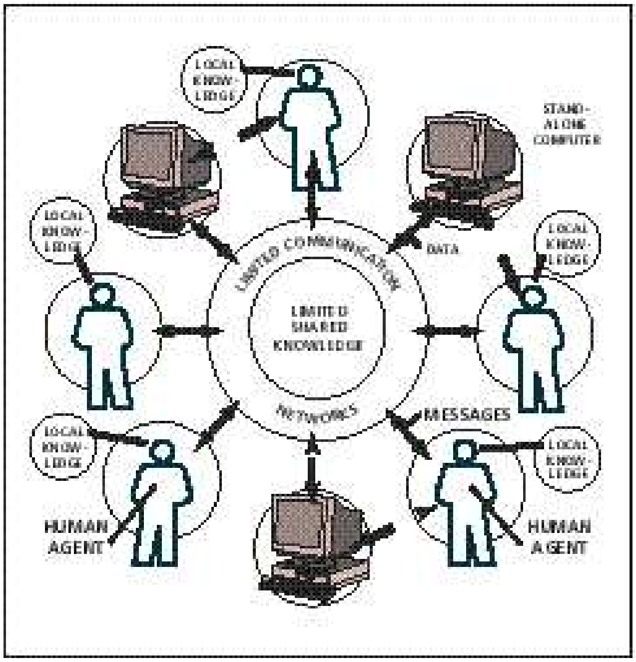


Fig.7: Limited computer assistance

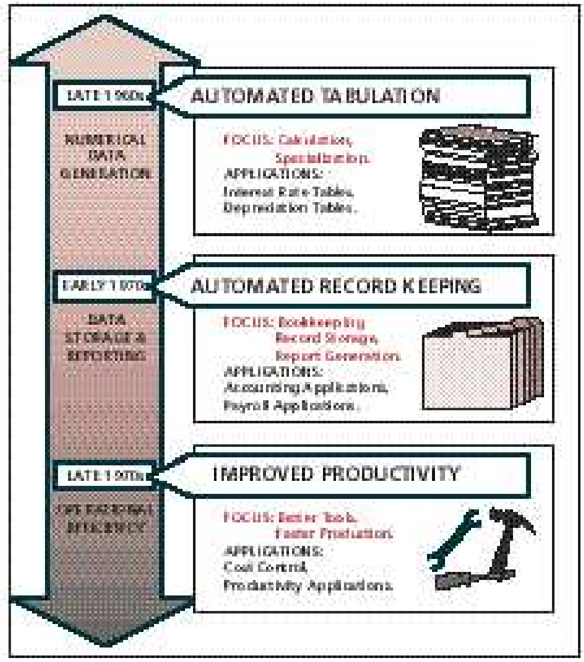


Fig.8: Evolution of business intelligence (A)

In this context it is of interest to briefly trace the historical influence of evolving computer capabilities on business processes and organizational structures. When the computer first became more widely available as an affordable computational device in the late 1960s it was applied immediately to specialized numerical calculation tasks such as interest rate tables and depreciation tables (Fig.8). During the early 1970s these computational tasks broadened to encompass bookkeeping, record storage and report generation. Tedious business management functions were taken over by computer-based accounting and payroll applications. By the late 1970s the focus turned to improving productivity using the computer as an improved automation tool to increase and monitor operational efficiency.

In the early 1980s (Fig. 9), the business world had gained sufficient confidence in the reliability, persistence and continued development of computer technology to consider computers to be a permanent and powerful data-processing tool. Accordingly, businesses were willing to reorganize their work flow as a consequence of the functional integration of the computer. More comprehensive office management applications led to the restructuring of the work flow.

By the late 1980s this had led to a wholesale re-engineering of the organizational structure of many businesses with the objective of simplifying, streamlining and downsizing. It became clear that many functional positions and some entire departments could be eliminated and replaced by integrated office automation systems. During the early 1990s the problems associated with massive unorganized data storage became apparent, and with the availability of much improved database management systems data was organized into mostly relational databases. This marked the beginning of ordered data archiving and held out the promise of access to any past or current data and reporting capabilities in whatever form management desired.

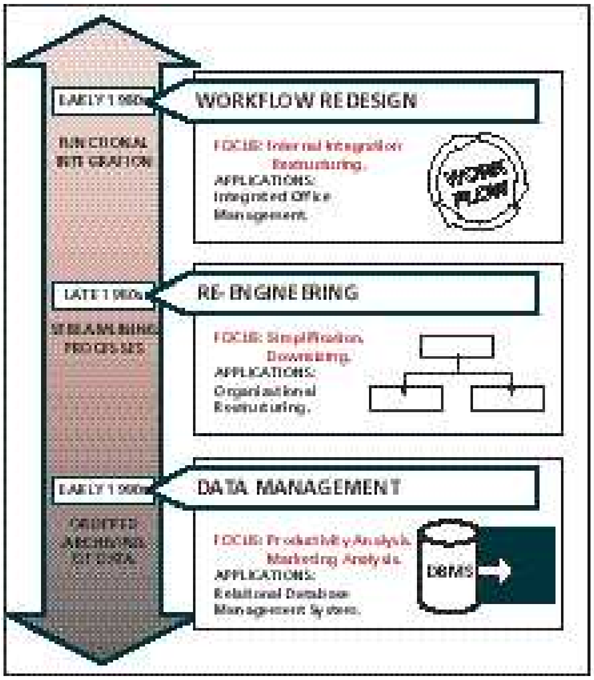


Fig.9: Evolution of business intelligence (B)

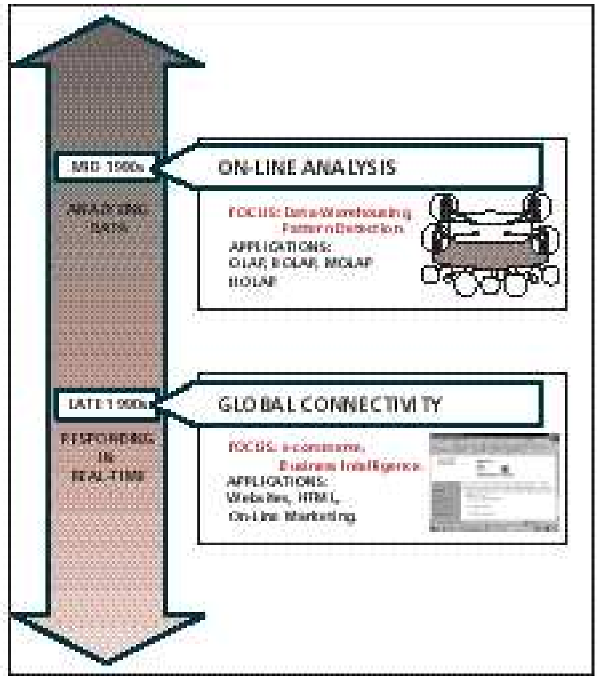


Fig.10: Evolution of business intelligence (C)

However, by the mid 1990s (Fig.10) the quickening pace of business in the light of greater competition increased the need for a higher level of data analysis, faster response, and more accurate pattern detection capabilities. During this period the concepts of data-warehouses, data-marts, and On-Line Analytical Processing (OLAP) were conceived and rapidly implemented (Humphries et al. 1999). Since then the term 'business intelligence' has been freely used to describe a need for the continuous monitoring of business trends, market share and customer preferences.

In the late 1990s the survival pressure on business increased with the need for real-time responsiveness in an Internet-based global e-commerce environment. By the end of the 20th Century business began to seriously suffer from the limitations of a data-processing environment. The e-commerce environment presented attractive opportunities for collecting customer profiles for the implementation of on-line marketing strategies with enormous revenue potential. However, the expectations for automatically extracting useful information from low level data could not be satisfied by the methods available. These methods ranged from relatively simple keyword and thematic indexing procedures to more complex language-processing tools utilizing statistical and heuristic approaches (Denis 2000, Verity 1997). The major obstacle confronted by all of these information extraction approaches is the unavailability of adequate context (Pedersen and Bruce 1998). As shown previously in Fig.6, a computer-based data-processing environment does not allow for the representation of context. Therefore, in such an environment it is left largely to the human user to interpret the data elements that are processed by the computer.

Methods for representing information and knowledge in a computer have been a subject of research for the past 40 years, particularly in the field of 'artificial intelligence' (Ginsberg 1993). However, these studies were mostly focussed on narrow application domains and did not generate wide-spread interest even in computer science circles. For example even today, in the year 2000, it is difficult to find an undergraduate computer science degree program in the USA that offers a core curriculum class dealing predominantly with the representation of information in a computer.

Evolution of a Human-Computer Partnership

Conceptually, to represent information in a computer it is necessary to move the context circle in Fig.6 upward into the realm of the computer (Fig.11). This allows data to enter the computer in a contextual framework, as information. The intersection of the data, context and human agent circles provide areas in which information and knowledge are held in the computer. The prevailing approach for the practical implementation of the conceptual diagram shown in Fig.11 is briefly outlined below.

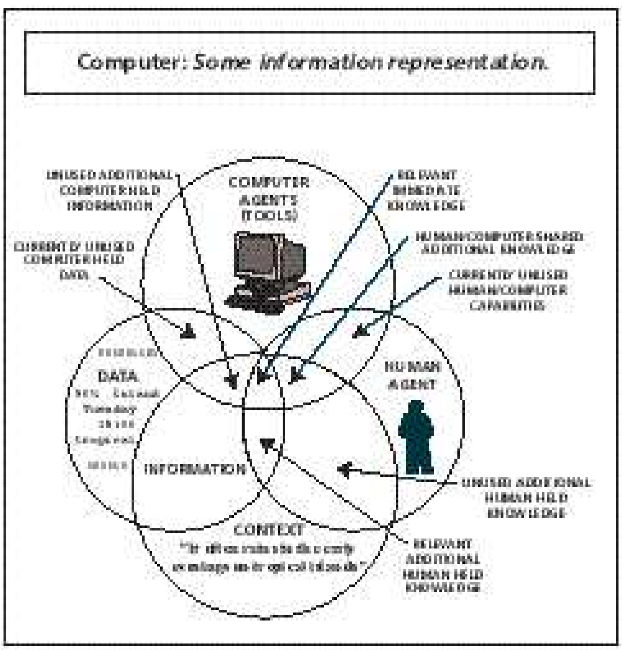


Fig.11: Early human-computer partnership

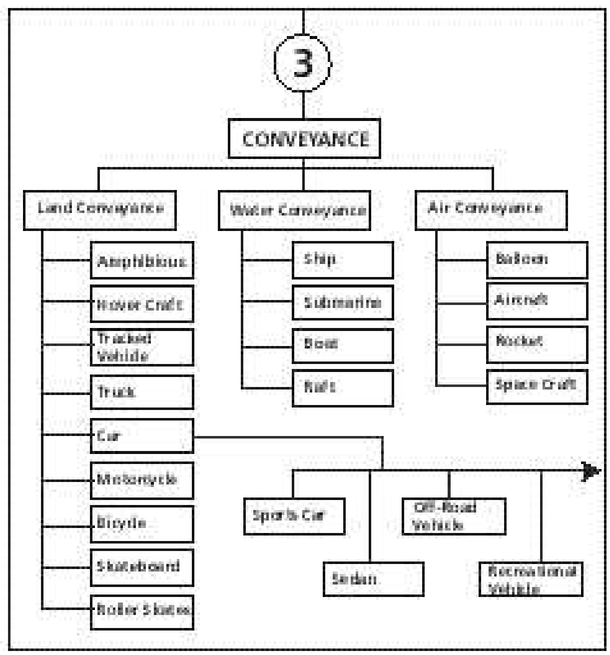
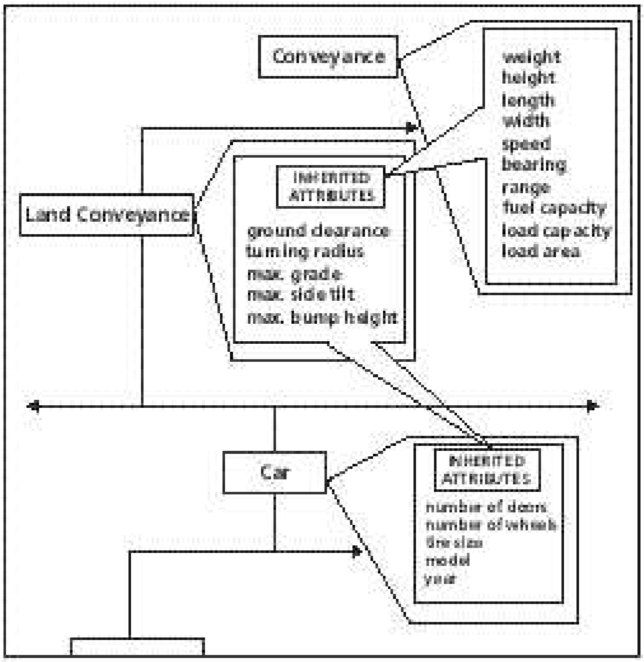


Fig.12: Branch of a typical object model

As discussed earlier (Fig.4) the principal elements of information are data and relationships. We know how data can be represented in the computer but how can the relationships be represented? The most useful approach available today is to define an ontology of the particular application domain in the form of an object model. This requires the identification of the objects (i.e., elements) that play a role in the domain and the relationships among these objects (Fig.12). Each object, whether physical (e.g., car, person, building, etc.) or conceptual (e.g., event, privacy, security, etc.) is first described in terms of its behavioral characteristics. For example, a ***car*** is a kind of ***land conveyance***. As a child object of the ***land conveyance*** object it automatically inherits all of the characteristics of the former and adds some more specialized characteristics of its own (Fig.13). Similarly, a ***land conveyance*** is a kind of ***conveyance*** and therefore inherits all of the characteristics of the latter. This powerful notion of inheritance is well supported by object-oriented computer languages such as C++ (Stroustrup 1987) and Java (Horstmann and Cornell 1999) .



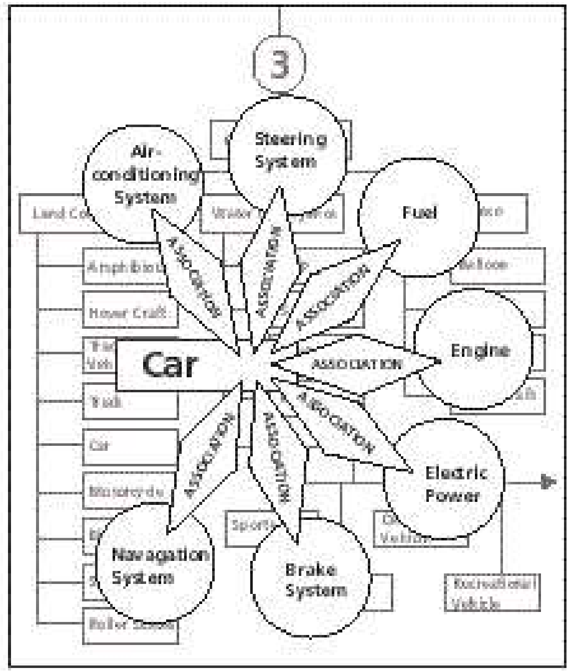


Fig.13: Object model - ***inheritance***

Fig.14: Object model - ***associations***

However, even more important than the characteristics of objects and the notion of inheritance are the relationships that exist between objects. As shown in Fig.14, a car incorporates many components that are in themselves objects. For example, cars typically have engines, steering systems, electric power units, and brake systems. They utilize fuel, often have an air-conditioning system, and may even be outfitted with an on-board navigation system. For several reasons it is advantageous to treat these components as objects in their own right rather than as attributes of the car object. First, they may warrant further subdivision into parent and child objects. For example, there are several kinds of air-conditioning systems, just as there are several kinds of cars. Second, an air-conditioning system may have associations of its own to other component systems such as a temperature control unit, a refrigeration unit, an air distribution system, and so on. Third, by treating these components as separate objects we are able to describe them in much greater detail than if they were simply attributes of another object. Finally, any changes in these objects are automatically reflected in any other objects that are associated to them. For example, during its lifetime a car may have its air-conditioning system replaced with another kind of air handling unit. Instead of having to change the attributes of the car we simply delete the association to the old unit and add an association to the new unit. This procedure is particularly convenient when we are dealing with the association of one object to many objects, such as the wholesale replacement of a cassette tape player with a new compact disk player model in many cars, and so on.

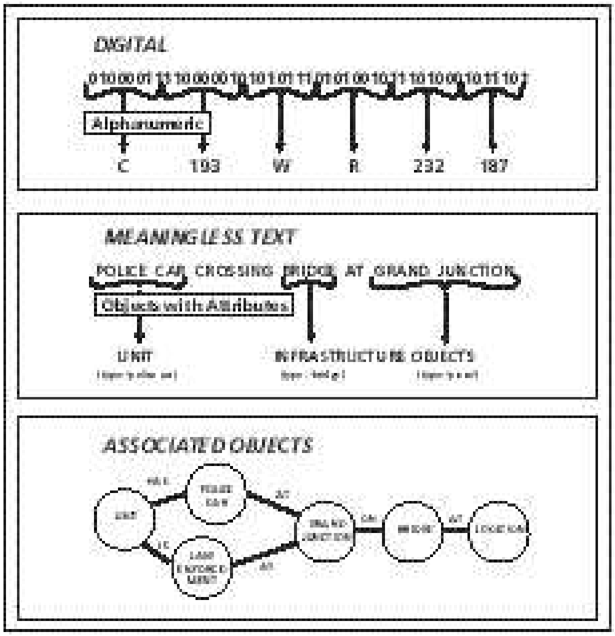


Fig.15: From ***digital*** to ***information***

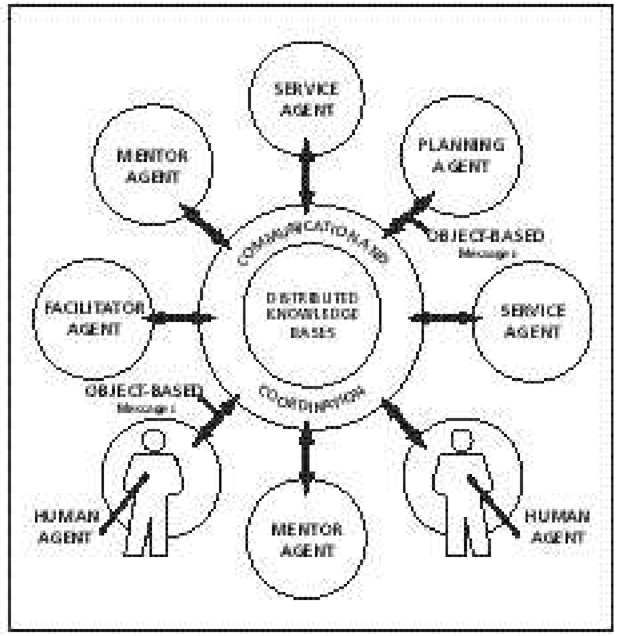


Fig.16: Types of agents

The way in which the construction of such an ontology leads to the representation of information (rather than data) in a digital computer is described in Fig.15, as follows. By international agreement the American Standard Code for Information Interchange (ASCII) provides a simple binary (i.e., digital) code for representing numbers, alphabetic characters and many other symbols (e.g., +, -, =, ( ), etc.) as a set of ***0*** and ***1*** digits. This allows us to represent sets of characters such as the sentence ***"Police car crossing bridge at Grand Junction."*** in the computer. However, in the absence of an ontology the computer stores this set of characters as a meaningless text string (i.e., data). In other words, the computer has no understanding at all of the meaning of this sentence. As discussed previously, this is unfortunately the state of e-mail today. While e-mail has become a very convenient, inexpensive and valuable form of global communication, it depends entirely on the human interpretation of each e-mail message by both the sender and the receiver.

Now, if the ***"Police car crossing bridge at Grand Junction."*** message had been sent to us as a set of related objects, as shown at the bottom of Fig.15, then it would be a relatively simple matter to program computer-based agents to reason about the content of this message and perform actions on the basis of even this limited level of understanding. How was this understanding achieved? In reference to Fig.15, the police car is interpreted by the computer as an instance of a ***car*** object which is associated with a ***civilian organization*** object of kind police. The ***car*** object automatically inherits all of the attributes of its parent object ***land conveyance***, which in turn inherits all of the attributes of its own parent object, ***conveyance***. The *car* object is also associated with an instance of the infrastructure object ***bridge***, which in turn is associated with a ***place*** object, ***Grand Junction***, giving it a geographical location. Even though this interpretational structure may appear primitive to us human beings, it is adequate to serve as the basis of useful reasoning and task performance by computer-based agents.

Such agents may be programmed in many ways to serve different purposes (Fig.16). Mentor agents may be designed to serve as guardian angels to look after the welfare and represent the interests of particular objects in the underlying ontology. For example, a mentor agent may simply monitor the fuel consumption of a car or perform more complex tasks such as helping a tourist driver to find a particular hotel in an unfamiliar city, or alerting a platoon of soldiers to a hostile intrusion within a specified radius of their current position in the battlefield (Pohl et al. 1999). Service agents may perform expert advisory tasks on the request of human users or other agents. For example, a computer-based daylighting consultant can assist an architect during the design of a building (Pohl et al. 1989) or a Trim and Stability agent may continuously monitor the trim of a cargo ship while the human cargo specialist develops the load plan of the ship (Pohl et al. 1997). At the same time Planning agents can utilize the results of tasks performed by Service and Mentor agents to devise alternative courses of action or project the likely outcome of particular strategies. Facilitator agents can monitor the information exchanged among agents and detect apparent conflicts (Pohl 1996). Once such a Facilitator agent has detected a potential non-convergence condition involving two or more agents, it can apply one of several relatively straight forward procedures for promoting consensus, or it may simply notify the user of the conflict situation and explain the nature of the disagreement.

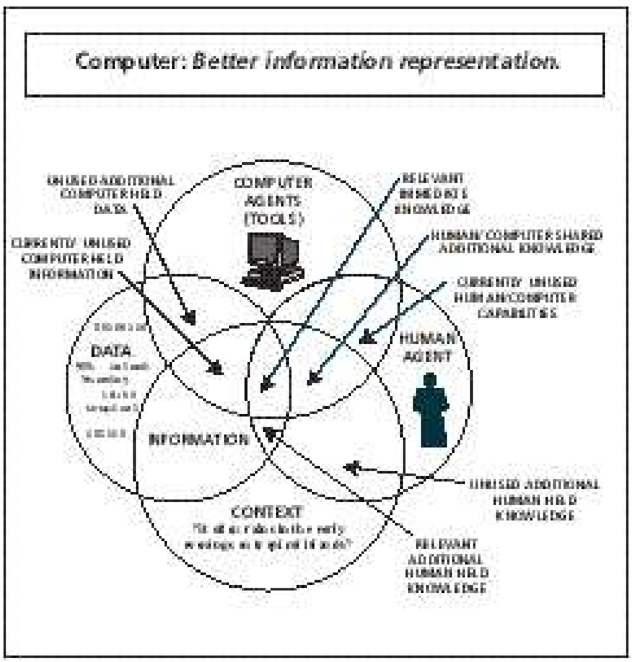


Fig.17: Evolving human-computer partnership

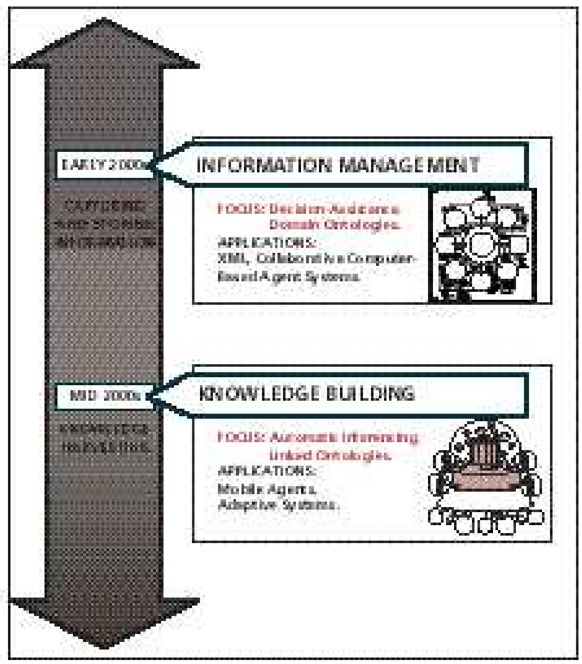


Fig.18: Evolution of business intelligence (D)

While the capabilities of present day computer-based agent systems are certainly a major advancement over data-processing systems, we are only at the threshold of a paradigm shift of major proportions. Over the next several decades the context circle shown in Fig.17 will progressively move upward into the computer domain, increasing the sector of "relevant immediate knowledge" shared at the intersection of the human, computer, data, and context domains. Returning to the historical evolution of business intelligence described previously in reference to Figs. 8, 9 and 10, the focus in the early 2000s will be on information management as opposed to data-processing (Fig. 18). Increasingly businesses will insist on capturing data as information through the development of business enterprise ontologies, and leverage scarce human resources with multi-agent software capable of performing useful analysis and pattern detection tasks. Toward the mid 2000s we can expect some success in the linking of these ontologies to provide a virtually boundless knowledge harvesting environment for mobile agents with many kinds of capabilities. Eventually it may be possible to achieve virtual equality between the information representation capabilities of the computer and the human user. This virtual equality is likely to be achieved not by the emulation of human cognitive capabilities but rather through the skillful combination of the greatly inferior artificial cognitive capabilities of the computer with its vastly superior computational, pattern matching and storage facilities.

Abandonment of Centralized Control Notions

In recent years we have witnessed profound changes in the management and structure of organizations. The emphasis has decidedly shifted from a largely sequential, hierarchical model to web-like networks which recognize the potential initiative and contributions of individuals.

A predominant feature of most mechanical systems is sequential activities, while the favored model for the management of organizations has been control (Fig.19). Centralized control has been deemed necessary to maintain organizational order. While such organizations or systems can react quickly and effectively to expected events they tend to be insensitive to unexpected occurrences. In fact, persons charged with maintaining central control typically view events that do not fit well into existing plans as disturbing and troublesome situations that should be ignored. Accordingly, hierarchical organizations are vulnerable due to a lack of redundancy, flexibility and responsiveness to local conditions.

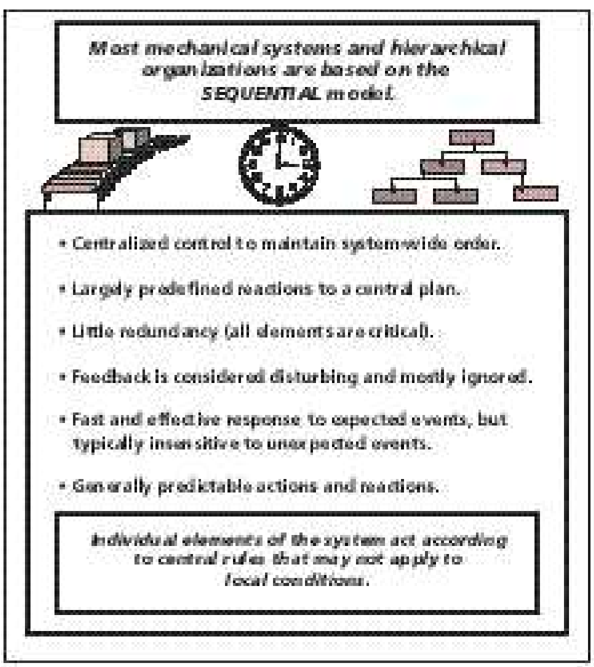


Fig.19: Systems based on ***singularity***

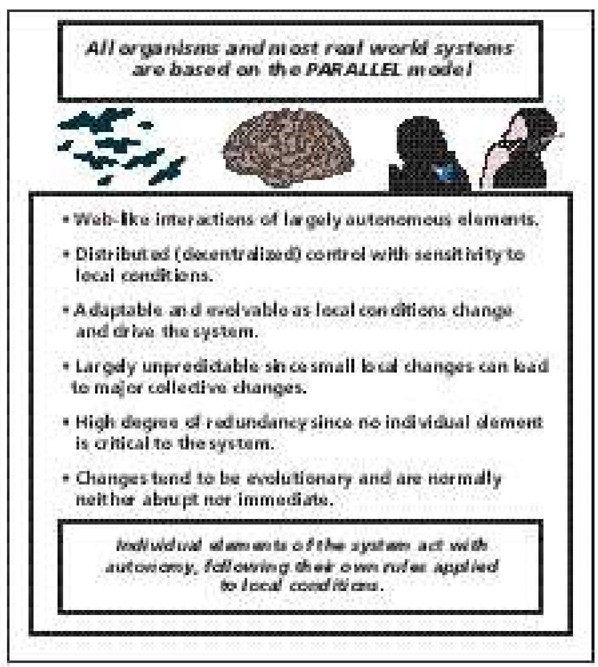


Fig.20: Systems based on ***plurality***

All organisms and most real world systems are based on a parallel model (Fig.20). This model is based on decentralization principles and fosters an environment of distributed control in which the individual elements of the system act with autonomy, following their own rules applied to local conditions. Treated extensively in the recent literature under the topics of chaos theory and complex adaptive systems (Pohl 1999), these web-like systems and organizations offer a high degree of redundancy. Typically no member of such an organization is considered to be critical to the survival of the organization. Yet, collectively the contributions of all members tend to result in an organizational capability that generally exceeds the individual capabilities of its members.

However, the nature of such an organization differs in other respects from the traditional centralized management model. First, it incorporates an intrinsic quality of unpredictability because even relatively small local changes can lead to major collective changes through the spontaneous triggering of catalytic reactions. Second, changes in such organizations tend to be evolutionary rather than abrupt or immediate. In other words a web-like organization responds to predicted events neither as quickly nor as decisively as an hierarchical organization.

Another interesting and perhaps disconcerting characteristic of a complex adaptive system environment is that it is anything but a calm environment. In the past, thriving conditions and prosperity have generally been associated with order and predictability. However, the ability of a complex adaptive system to adapt and grow under changing conditions is based to a large extent on the diversity and intensity of interactions among its elements or agents. Why an intense level of interaction would stimulate and promote the performance of a complex adaptive system is intuitively obvious. The role played by a diverse set of agents is more subtle. Variety provides a wider range of skills, experiences and expectations. When these are applied with some degree of autonomous behavior by agents at the local nodes of a system then they promote initiative, ingenuity, adaptability, and interaction with other nodes. Of course this interaction may not all be constructive. In fact, much of the interaction might be confrontational and destructive. An analogy that immediately comes to mind is the history of civilization which is pervaded by conflict and wars with catastrophic local consequences leading collectively to a stronger and more resilient global human society.

Emergence of the Knowledge-Based Organization

Clearly the increasing focus on the individual and the flattening of the traditionally favored hierarchical organizational structure into a web-like structure with a high degree of local autonomy, is placing unprecedented value on knowledge. Whereas in the past knowledge has been presumed to be the sole province of human beings, today there is a growing and realistic expectation that knowledge can also be held in computers. Certainly the belated discovery that data and information are not synonymous in the realm of computer-based systems and that the ability of the computer to hold information (rather than data) is a prerequisite for a human-computer collaborative partnership with intelligent decision-support facilities, are visible signs that this expectation is appropriate.

The foundations of a knowledge-based organization may be characterized in terms of three kinds of capital (Fig.21), namely: human capital; organizational capital; and, relationship capital. Within the continuous interactions among these spheres the human capital constitutes the source of knowledge that is largely responsible for generating the capabilities of the organization. The organizational capital generalizes these capabilities through a distributed framework of leadership that communicates the organization's collective intent to all nodes, and the relational capital leverages the capabilities of the organization to generate products.

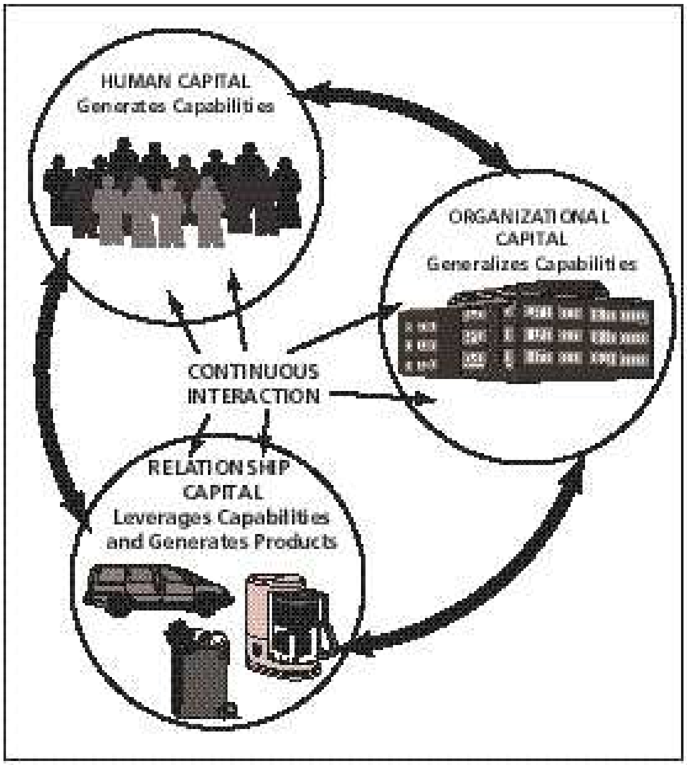


Fig.21: Foundations of the knowledge-based organization

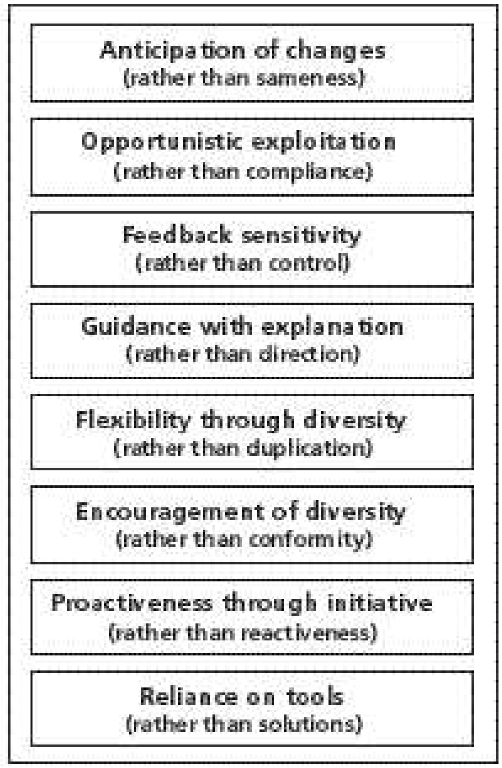


Fig.22: Surviving in a complex adaptive systems environment

With the crucial role played by human capital in a knowledge-based organization it is not surprising that the notion of knowledge management has started to receive considerable attention in both government and corporate organizations. Simply stated knowledge management involves the effective acquisition, development and utilization of the human capital in an organization. The emphasis of this definition is on maximizing the contributions of the individual to the collective benefit of the organization. In this respect knowledge management serves primarily as a facilitating vehicle, with the objective of ***enabling*** the human and organizational capabilities for the benefit of the individual and the organization.

Through the distributed framework of leadership and communication provided by the organizational capital, knowledge management is able to execute its enabling role in several ways. First, knowledge management must recognize that every member of the organization is a contributor and a potential decision maker. Therefore its methods should emphasize the encouragement, cultivation (e.g., professional development), and motivation of the individual. Second, by definition, knowledge management needs to emphasize local autonomy and concurrent activities. Leadership should be exercised through example, clarity and communication, and not through authority. Under these conditions the principal tools of leadership are the continuous analysis of feedback, the meticulous explanation and justification of intent and direction, and the maintenance of effective self-development opportunities throughout the organization. Third, knowledge management must foster the formation of internal and external relationships, because the relationship capital of the organization becomes one of the most important catalysts for increasing the productivity of the organization.

Conclusion

In the view of the author notions relating to complex adaptive systems are strongly reflected in current trends during the transition from a physical product centered industrial world to a knowledge centered information world. Of particular significance is the rapidly developing focus on the capabilities and potential contributions of each individual member of an organization. It can be argued that this focus has led to a reexamination of traditional hierarchical organizational models and in particular management practices. Knowledge management is emerging as the formal vehicle for responding to the apparent complex adaptive system like behavior of the increasingly preferred web like structure of a knowledge-based organization.

A real world in which everything is relative, nothing is predictable, and the intensity of parallel and autonomous activity at local nodes is the major driver that determines the capabilities of its natural and human systems, is not conducive to traditional notions of human comfort. To adapt to this environment it is necessary to re-evaluate some of the learned behavioral characteristics that human agents have acquired in a pre-information age society (Fig.22). We are conditioned to expect sameness, to either comply or control, to prefer conformity, and to apply predefined solutions to future problems. However, a more realistic complex adaptive systems view of our environment suggests that we would be better served by: anticipating the likelihood of changes; being prepared to exploit these changes opportunistically; carefully monitoring feedback rather than attempting to control a largely unpredictable environment; providing guidance with explanation rather than issuing authoritative directions; maintaining flexibility; encouraging diversity; taking a proactive rather than reactive stance; and, relying on capable tools rather than predetermined solutions that are unlikely to apply adequately to real world problem situations.

References

Axelrod R. and M. Cohen (1997); 'A Complex Adaptive Systems Approach to Information Policy'; Report sponsored by the Office of the Assistant Secretary of Defense for Command, Control, Communications and Intelligence; US Department of Defense, Washington DC.

Denis S. (2000); 'Numbers'; Intelligent Enterprise, April 10 (pp. 37-44).

Ginsberg M. (1993); 'Essentials of Artificial Intelligence'; Morgan Kaufmann, San Mateo, California.

Horstmann C. and G. Cornell (1999); 'Core Java'; Vol. 1 and 2, Sun Microsystems Press, Prentice Hall, Upper Saddle River, New Jersey.

Humphries M., M. Hawkins and M. Dy (1999); 'Data Warehousing: Architecture and Implementation'; Prentice Hall, Upper Saddle River, New Jersey.

Kauffman S. (1988); 'The Evolution of Economic Webs'; in Anderson P., K. Arrow and D. Pines, The Economy as an Evolving Complex System, Proc. Evolutionary Paths of the Global Economy Workshop, Santa Fe Institute, Santa Fe, New Mexico, September (pp.125-146).

Kurzweil R. (1999); 'The Age of Spiritual Machines'; Viking, Penguin Putnam, New York.

Pedersen T. and R. Bruce (1998); 'Knowledge Lean Word-Sense Disambiguitization'; Proceedings 5th National Conference on Artificial Intelligence, July, Madison WI.

Pohl J (1999); 'Some Notions of Complex Adaptive Systems and Their Relationship to Our World'; Proc. InterSymp-99 Conference, Baden-Baden, Germany, Aug.2-7.

Pohl J., M. Porczak, K.J. Pohl, R. Leighton, H. Assal, A. Davis, L. Vempati and A. Wood, and T. McVittie (1999); 'IMMACCS: A Multi-Agent Decision-Support System'; Technical Report, CADRU-12-99, CAD Research Center, College of Architecture and Environmental Design, Cal Poly, San Luis Obispo, California, August.

Pohl J., A. Chapman, K. Pohl, J. Primrose and A. Wozniak (1997); 'Decision-Support Systems: Notions, Prototypes, and In-Use Applications'; Technical Report, CADRU-11-97, CAD Research Center, Design Institute, College of Architecture and Environmental Design, Cal Poly, San Luis Obispo, California, January.

Pohl J., L. Myers, A. Chapman and J. Cotton (1989); 'ICADS: Working Model Version 1'; Technical Report, CADRU-03-89, CAD Research Center, Design Institute, College of Architecture and Environmental Design, Cal Poly, San Luis Obispo, California.

Pohl K.(1996); 'KOALA: An Object-Agent Design System'; in Pohl J. (ed.) Advances in Cooperative Environmental Design Systems, Focus Symposium: International Conference on Systems Research, Informatics and Cybernetics, Baden-Baden, Germany, Aug.14-18 (pp.81-92).

Stroustrup B. (1987); 'The C++ Programming Language'; Addison-Wesley, Reading, Massachusetts.

Verity J. (1997); 'Coaxing Meaning Out of Raw Data'; Business Week, June 15.