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Adaptability, Cooperation and Reconfiguration in Very Complex Multiregional Network Organizations

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PREFACE

There seems to be a general trend that the development of technologies which interact with human beings also enhances the knowledge of human functions. For example, with the development of color television systems progress in the knowledge of human color vision was also recorded. In return this new knowledge then helped in the design of even more efficient color television system.

A similar situation seems to reign in computer systems and computer networks. Managing different resources in computer systems by operational systems resembles somewhat the management of resources in an organization. The inference block in 5th generation computers may resemble human inference and is pursued by an artificial intelligence discipline. The study of cooperative features in computer systems and networks may bring us closer to understanding these processes in organizations or even in human societies at large. This happens because many causal relations are present in computer systems in clearer and sometimes more primitive forms, stripped of many of the accompanying but irrelevant (emotional) ingredients.

This Collaborative Paper is the continuation of an activity that started when Dr. Cifersky joined the Management and Technology Area of IIASA in 1982 as a participant in the Young Scientists Summer Program, under the supervision of Dr. R. Lee. The paper scans those problems in organizations which are evoked by the environment. It attempts to describe some of those processes which are taking place in complex organizations as a reponse to external influences, and identifies some of the impacts this may have on the organization's performance objectives.

The paper has not been edited and supplemented by a vocabulary, therefore it does not make easy reading. It uses terms common in organization research, computer systems (for example, communication protocol), or principles used in fail-safe computer systems (reconfiguration). The topic is interesting and stimulating and can contribute to further research at the Institute in this field.

Tibor Vasko

Leader

Clearinghouse Activities

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ADAPTABILITY, COOPERATION AND RECONFIGURATION IN VERY COMPLEX MULTIRELATIONAL NETWORK ORGANIZATIONS

Jan Cifersky and Ronald M. Lee

1. INTRODUCTION

The purpose of this work is to summarize selected preliminary results concerning the analysis of matrix, dual-relational organizations and more complex multi-relational network organizations, results relevant to processes of changing internal structure and information flows during adaptation to various external and internal influences. We call these processes "adaptive reconfiguration". The results are selected according to their importance for successful reconfiguration. Therefore, the roles of integrating positions, their network and dynamics of changes of their intercommunication are discussed. Then the overlapping of their scopes of interest and knowledge and their changes are described. The overlapping is important for the mutual interchangeability of members of the integrating positions during the adaptive reconfiguration.

During the course of changes in organizational structures there are problems with the corresponding changes in information, task and coordination complexity. We have tried to pay particular attention to the coordination and autocoordination mechanisms, and their support by cooperation during the reconfiguration. Every change in system structure and information flows brings potential problems with various types of uncertainty. These changes are described in the context of bottom-up and top-down reconfiguration initiation. The last section contains a brief discussion of the problems of semantic change arising from organizational change, and the demands this makes on the modifiability of software. Sections 2, 3, and 4 were written by Jan Cifersky and Section 5 by Ronald M. Lee.

2. COMPLEX ORGANIZATIONS WITH HIGH ADAPTABILITY

2.1. Dual-Relational Networks

It is well known that *matrix structures* (see, for example, Mintzberg 1979) in human organizations emerge naturally in situations when it is necessary to face, to a certain degree, a complex and uncertain dynamic environment (Cifersky 1982). Examples of matrix organization structures are common, for example, in research institutes where it is necessary to solve complex problems with unpredictable results, and this may serve as a useful object of analysis for our purposes.

An organization (or a system of an organization) solving complex and higher interdependent tasks requires the utilization of specialized resources and, at the same time, an integration of the programs, i.e., the integration of specialized resources. In this case matrix structures based on dual authority relations are introduced, i.e., functional and integrating. Such structures can be relatively permanent, where the interdependencies become more or less stable or shifting, geared to project works, where the interdependencies and groups of people in them change frequently. Organizations designed to handle unique or custom tasks base specialists in functional groups for housekeeping purposes but deploy them into task force groups for operational purposes (Thompson 1967).

It seems at present that the matrix structures are the most effective structures for developing new activities and for coordinating complex multiple interdependencies, especially when it is supported by modern computer system facilities (Cifersky 1982). It has been confirmed elsewhere too (e.g., Toffler 1980) by arguments that an organization now has to pay attention not only to economical tasks but also to social, informational, environmental, political, and ethical tasks, so that its environment and tasks become implicitly highly interdependent and complex naturally.

In this paper we pay attention primarily to the control mechanisms of complex organizations. It will be convenient for describing processes of adaptive reconfiguration.

Let us first make a brief summary. In a matrix there are *integrating positions* (IPs). These positions serve to enhance flexibility of the formal structure by supporting informal relations and in situations where uncertainty increases, the roles of IPs will be stronger and dominating. Formal communication will often be overridden and informal communications support dynamic working groups creation. In the presence of high uncertainty we can observe decrease of formalism and change of communication protocols to more informal ones.

There appears to be a much more dense network of IPs and their communication lines towards the top of the matrix organization, and at the strategic levels. This is necessary for quick middle and long term adaptive scheduling of systems operations. Integrating positions in the middle and higher levels are generally interchangeable because their scope of general knowledge and interests are highly *overlapping*. The term *"scopes of interest"* will be used here to designate a spectrum of directions of activities concerning a member of an organization or a group they are interested in, due to some motivation for their individual or common goals. This term is to be distinguished from *"scopes of knowledge"* which designate a spectrum of knowledge that an individual or a group possesses. The scopes differ substantially in their dynamics of change. It enables effective and rapid assembly of members of integrating positions into merged positions for further increased performance during adaptations.

Variability of the scopes of interest and knowledge overlapping is important for uncertainty reduction in communication among positions and for eventual quick rearranging of these positions.

Generally, the increase in scopes of interest overlapping, forces the creation of *cooperative groups* with more or less intentional cooperation and an increase in knowledge scopes overlapping reduces coordination problems during cooperation. The knowledge scopes and their overlapping express a passive aspect of the IPs whereas the scopes of interest and their overlapping express a goal directed active aspect. We abstract here from such situations where the scopes of interest may highly overlap but for the reasons of different intentions of members caused either by improper agreement with the other members or by own subjective, possibly egoistic, efforts.

2.2. Increase In Complexity and Uncertainty—Further Need for Adaptability

As complexity and uncertainty of environment increases (Cifersky 1982) matrix structures are subject to some serious changes. Galbraith (1973) identified the general changes in an information processing system of an organization: the introduction of slack resources (always), i.e., a reduction of performance; formation of compact working groups with complete facilities; investments in hierarchy of information on processing and widening informal communications--i.e., liaison devices.

Reduction of performance is in most cases temporary and is observed during periods of reconfiguration at all levels of an organization. It stems from the bounded rationality principle. New systems are created according to the principle of near decomposability (Simon 1962) which requires that the number of transactions amongst units be less than within the units.

Complexity can be defined as excessive demands on rationality (Fox 1979). That is, problem requirements exceed current bounds of rationality of an organization. Three major types of complexity will be discussed here:

-- information

-- task

-- coordination.

Information becomes too complex when it requires more processing than available in order to be properly analyzed and implemented (understood). It can be reduced by abstraction or omission. Increase in complexity requires corresponding sophistication of abstraction and omission mechanisms.

Task complexity is concerned with the volume of actions (disjointed or coupled) necessary to accomplish a task. The solution is division of labor. It requires partitioning of resources into units. Each unit is assigned a specific task related to the organizational goal. If a unit is to work in concert with other units certain interunit constraints must be met: the products of the unit must be well defined, the interaction between units must be minimal, the effect of the unit upon other units must be understood, clear lines of authority must be recognized and finally, clear lines of information flow must be recognized.

Coordination complexity must be considered once a task has been decomposed to a point it is comprehensible. The actions of each unit must be coordinated so that each produces the proper resource at the proper time. There is an important problem of proper task decomposition. To reduce the complexity of coordination there may be several approaches:

-- Slack resources. One aspect of coordination complexity is the coordination of coupled tasks. Tasks are coupled when the input of one depends on the output of another. Tasks are tightly coupled when state changes in one task immediately affect the state of another task. To reduce tightness of the coupling (and thus task synchronization reliability) slack resources are introduced.

-- Functional vs. product division creation.

-- Cost analysis and then contracting.

We know that there are organizations called *bureaucracies* (e.g., see Mintzberg 1979) with a very high degree of complexity in all the dimensions mentioned above and that they are working well. We will not describe them in detail here but we formulate several observations related to our topics:

-- Bureaucracies face effectively clear and stable problem functional decomposition. Decomposition of such (possibly algorithmizable) problems gives a relatively fixed hierarchy.

-- Intercommunication between subsystems in bureaucracies relies on relatively high degrees of formalism with highly formalized communication protocols which is higher when the environment is more stable, less uncertain, though very complex.

-- In bureaucracies the operation is mostly driven according to pre-established, pre-planned, fixed sequence (algorithm). Therefore, the operation is also relatively fixed and that means that there are fewer integrating positions. They are situated only in those subsystems facing relatively more unstable conditions (e.g., at strategic level).

Because *bureaucracies* rely on hierarchy with elaborated functional subordination *they have potential problems with rapid decrease of intercommunication formalism, change in directions of information flows and with information processing at higher levels of hierarchy* due to information overflow, etc. All these factors are in close relation to adaptive reconfiguration and must be solved successfully and quickly during this process. Thus it follows from the above that we must interpret the term complexity in a different way for a stable environment than in a uncertain environment. In the first case we interpret it in light of a sophisticated hierarchy, in the second, in the light of the connectedness of intercommunication networks.

Uncertainty is defined as the difference between the information available and the information necessary to make the best decision. There are generally *four types of uncertainty* (Fox 1979):

-- information

-- algorithm

-- environmental

-- behavioral

We will consider *three types of information uncertainty* here:

-- intention: the reason for the creation and transfer of the information.

- veracity: the degree of truth and belief in the information being handled.
- semantic: the semantic interpretation of the information.

Linguists distinguish other types of information attributes such as emotive vs. cognitive; performative vs. descriptive.

Uncertainty of intention may be further distinguished as consumer uncertainty (who will receive this information), producer uncertainty (who is the source of the information), functional uncertainty (what mechanism will use this information), and result uncertainty (what is the result of using this information).

As for the consumer uncertainty, it is different when the producer knows who will receive the information. The information may be consumed by one or more consumers. The consumers may know what pieces of information to consume or taste all before deciding. Consumer identification requires the produced information to be available (information availability) to prospective consuming modules and they have the ability to identify the information they need (information identification). There are three traditional ***methods of communicating*** such information:

- broadcasting: every module is immediately notified of the existence of the information.
- message boards: information is placed on a message board for use by other modules.
- word of mouth (murmuring): a module informs the modules it knows about and they pass it on to the modules they know about, etc.

Why is there interest in the producer of information? Lesser and Erman (1977) state that it is necessary to know what processing produced an hypothesis in order to schedule further processing. We believe that it is the uncertainty in the algorithm that requires decisions to be producer-history-sensitive. If the algorithm is strong, there is no need for deciding what processing should be done next. The effect of producer uncertainty increases as algorithm strength (uncertainty) decreases.

One method of discovering the degree of control a module has over another is to compare the processing results of a module M2 with the information communicated to it by module M1. The resulting uncertainty depends on authority relationships and on uncertainty as to who is the consumer. To take alternate action when the communicated results are not met, the producer must have sufficient control (authority) to redirect the system's attention (or part of it). It must then have vast possibilities of communication channels control access.

Veracity uncertainty may be reduced by verification, synthesis (the key idea is that uncertain data are combined to lend mutual support thus increasing collective certainty, and extrapolation.

Semantic uncertainty has principally two sources: lack of agreed upon language for representing information shared among modules and differences among world models (belief systems) employed by modules during information interpretation.

Upon reviewing important aspects of uncertainty we may again return to the analysis of the impacts of these aspects on general structure of organizations.

Organizations facing uncertain and dynamic environment are driven to organic structure. Descriptions of such structures are in most cases too superficial to use them as a background in describing adaptive reconfiguration processes. Let us try to point out some observations from our point of view:

-- In the environment with high degrees of uncertainty (when it is not immediately evident what is important) the structure of *an organization must conform to situation assessment*, that is, it must be suited for operations of composing "certainties" from uncertainties.

-- Such assessments call for effective possibilities of spontaneous activation and assembling all situation (knowledge and interest) relevant contributors. It stresses the *roles of powerful information communicating features as broadcasting, message boards, etc.*, and their combinations, which is important when immediate altering of attention of individuals or groups is required.

-- Further means for rapid cooperative groups creation and dissolving must be provided which, in turn, stresses the *roles of the IPs and their integrating mechanisms, high degrees of their knowledge overlapping and scopes of interest variability coordination*. The IPs must have capabilities of spontaneous integrating activities reflecting reality, environmental scenario impressions, by integrating all relevant knowledge about this and similar situations. Further, they must know who has the knowledge and where it is dispersed to solve the problem, rather than the solution. It generally requires a non-algorithmic operation.

-- Effective dynamics of cooperation changes requires *possibilities of dynamic semantics and communication protocols changes* and first of all not order (as in bureaucracies) but type-of-information driven cooperation activities.

-- The organic structure, to cope with a wide spectrum of missions must have a *high degree of redundancy*, that means not only redundant identical subsystems, IPs and communication lines as is common bureaucracies, but primarily functional redundancy, when various functional subsystems can take over the roles of another subsystem (substitute them partially) during adaptations and new missions. This is the general principle valid for all biological structures because using identical back-up spares is economically and architectonically unfeasible in quickly reconfigurable complex organizations.

2.3. From Dual-Relational to Multiple-Relational Networks

From the analysis of complex organizations in highly dynamic environment it follows that, from a certain point, the matrix dual-relational based structure will not be sufficiently flexible, adaptable and reconfigurable. The problem emerges first in the control subsystem (middle level and strategic apex). There is a need to ensure mutual interchangeability and dynamic cooperation groups creation for problem solving. It appears first as extensive emergence of communication channels between IPs and density of this subnetwork rapidly increases. It can easily be understood that this will result in a change of the middle and strategic level hierarchy itself. Some of the previously informal (liaison) channels become more formalized and dual-relational structures will be more bureaucratized. The matrix structure becomes a part of the former formal hierarchy and is extended again by the informal channels in a bottom-up direction: thus, the *multirelational networking* emerges. Development of such a complicated but extremely adaptable organization requires inevitably extensive and *integral application of the whole scale of computer facilities (in human systems).* Recall that we are primarily interested in the problem solving (control) subsystem of an organization. Multirelational control network structures thus have sophisticated capabilities of knowledge transportation, flexible cooperative groups creation, quick selective information spreading, system alerting in anticipation of dangerous situations, capabilities of quick centralization and selective decentralization and situation assessment.

3. COOPERATION IN MULTIRELATIONAL NETWORKS

Cooperation is a key activity in all types of organizations. Here we define it as a somehow (centrally or decentrally) controlled activity of individuals directed towards a common solution of tasks (e.g., decisions) more or less important for the overall organization mission. Tight cooperation is necessary, particularly in solving problems such as coordination and information complexity changes.

Some cooperative activities are *predetermined*, prescribed and prescheduled. The other cooperative activities are initiated at *random* according to momentary needs of problem solving. The prescheduled cooperation has a predetermined number of individuals with predetermined knowledge and scopes of interest. They are selected carefully from relevant problem determined areas. Their problem solving coadaptation is therefore very quick. In the second case, so-called *contractation cooperation* is often used. Here the participants are selected according to their own interest and potential contribution power to the task. The control of selection may be centralized or decentralized (self-selection). Requirements for task solution are transmitted (by means of broadcasting, message boards, murmuring) among members of organization and they report themselves for possible selection. They are therefore dynamically assembled from various places in the organization's hierarchy. The process may even be self-organizing when members create cooperative groups spontaneously without central control, which may arise later. However, coadaptation of various scopes of knowledge and interest is relatively long.

In *centrally controlled* cooperation there is control of resource sharing and individual activities sequence and priorities, with centrally controlled contention arbitration. In *decentrally controlled* cooperation more conflicts may arise because the degree of cooperation may be loose and the individuals act with a high degree of autonomy. Their resolution may be spontaneous with dynamic emergence and disappearing of conflict resolution individuals or their groups. However, the procedure in the problem solving, though less systematical, is not so much affected by the nature of changes in data and environment and is more reliable relying on functional redundancy (mutual functional substitution). There may be a lower degree of variable protocols of their task solving activities. For effective decentrally controlled cooperation a high degree of overlapping knowledge scopes is generaly necessary. It will require a high degree of mutual coadaptation (semantic, algorithmic).

Cooperation is carried out not only during a task solution but also *during communication*. Important examples are:

-- During semantics evaluation of communicated information from various scopes of various members of a cooperative group.

-- In processes as quick reconfiguration where it is necessary to spread information as quickly as possible.

-- During correctness evaluation of information communicated (e.g., in diagnostic modes when a subsystem generates ambiguous reports), error correcting capabilities of the communication subsystem are higher.

-- During isolation (wall isolation) around the place of an error in a malfunctioning subsystem with the goal to prevent contamination of the information in the rest of the system (cooperative immunity reaction).

Another interesting example of cooperation is *opponent cooperation*. During this activity the task solution is being continuously refined by two groups of cooperating members--one working directly on the solution and the other verifying this solution by taking opposition where necessary. The two groups cooperate but can have contradictory opinions coordinated in accordance with a common goal (scope of interest) towards a common solution. This procedure may help in finding alternative and, in some cases, better solutions.

This approach in cooperation is very effective in periodical or otherwise prescheduled problem *walk- throughs* directed towards an optimal solution. The walk-through cooperative groups are temporarily determined, assembled, and then dissolved flexibly in accordance with immediate necessities in course of the problem solution process. They are often variable, fluctuating and immediate needs-driven or, in more stable and low-uncertainty environments, they may be even predetermined and prescheduled. The subtasks to be discussed may, in this latter case, also be predetermined. The method of cooperation is a powerful tool for unifying the scopes of knowledge and interest of members.

Especially in the process of task solution verification, so-called *wave- verification* cooperative processes can be observed. During the wave process, the verification or diagnosis of errors is being done. This means that all members of a system are alerted and their attention and scopes of interest are directed towards verification. Their scopes of knowledge may differ. This is usually done at a global level where the degree of intercommunication of members working on the verification is very high, and cooperative groups are larger and loosely coupled. The degree of loose coupling depends on the nature of the problem and its severity for the whole system. The wave cooperative processes can be applied in predetermined (often periodical time intervals for the whole system or subsystem (preventive wave diagnostics), or at random, when serious errors have been introduced. The wave cooperative processes are also used at the beginning of an operation or before and after reconfiguration of an organization.

Cooperative activities are important during feed-back realization and its tuning, and during *feed- forward correction*, which is a very quick method of correction of activities carried on by a network of subsystems by another network (or a subsystem), i.e., by knowledge and information acquired elsewhere. It is very effective during quick adaptations of a large number of subsystems to a new situation. Feed-forward correction is also very important for coordinating the activities found in almost every integrating position. It is also one of the key mechanisms of auto-coordination in very complex systems.

Finally, the cooperation is often carried on in relaxation (information abstraction and omission) activities during communication of information.

4. RECONFIGURATION AND RECONSTRUCTION IN COMPLEX MULTI-RELATIONAL NETWORKS

Let us now try to describe the processes that can be identified in complex organizations during changes in their missions, their environments, and which are necessary for the organization to survive. We call these processes *adaptive reconfiguration. Under this notion we particularly understand:*

-- change of the organization's control structures, data, knowledge and interest scopes and their overlapping, strategic and operative planning, IP structures and intercommunication.

– change of functional subsystems configuration (subordinate structures changes).

-- changes of communication channels direction of communication, protocols, kinds of communicated data and their semantics.

-- modifications of databases, their locations, structures and semantics.

-- similar modifications of knowledge bases.

4.1. Phases of Adaptive Reconfiguration

The process of adaptive reconfiguration is not an entire process. It may be subdivided into several phases. During the phases performance degradation is always observed and they may also be accompanied by a decrease in functional capabilities. Figure 1 shows a diagram of the reconfiguration process and its possible outcomes.

An organization enters an adaptive reconfiguration state depending upon certain external and internal influences (these are not the subject of our investigation here). After assessment of a situation in the environment and in the internal sphere of the organization, it is necessary to work out new or modified strategies not only for the reconfiguration but also for the future operation under new conditions. When reconfiguration changes influence the whole system it is first necessary to effect the most important (emergency) changes and test this degraded structure. Then the system will enter a degraded mode of operation that may be temporary or permanent. A temporary degradation mode of operation is entered when the internal and external influences enable introduction of further sophistications in the phase I (such as new data processing facili-

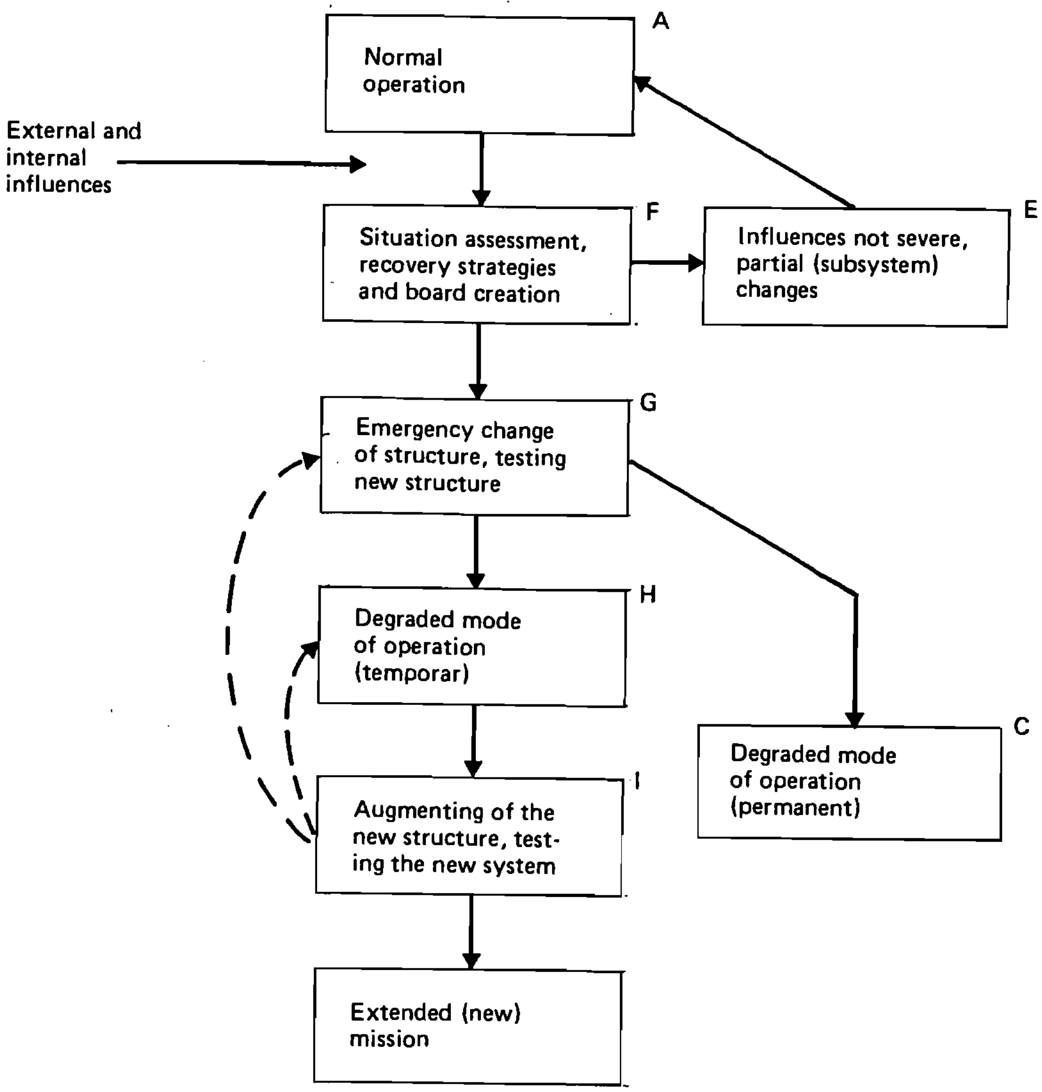

Figure 1. Phases of adaptive reconfiguration.

ties, technology). Augmentation may be carried on in several iterations and state H reflects the process of learning to work in new conditions even though processing partially continues. In the state G the organization will generally not be "in operation" with respect to its normal tasks. It is also apparent that the influences may be catastrophic and will cause total failure of the organization. However, this is not the subject of our examination here and it is therefore not shown in Figure 1. States G, H, and I are shown separately although in practice they are overlapping.

An organization may enter into a state of extended or new mission after successfully reconfiguring and testing itself, or enter the state of permanent degradation when it is not possible to reconfigure itself to cope fully with the new conditions. Then the influences require partial changes only (at a subsystem level) and the procedure is similar to the above. In this case we assume a return to the original state of normal operation.

An organization will always convert itself from being decentralized to temporarily centralized during reconfiguration and then, after reconfiguration, revert into the decentralized state. During centralization the knowledge scopes, and especially the scopes of interest, become more overlapping than during the "normal" decentralized operation.

4.2 Notes on Dynamics of Selected Factors During Adaptive Reconfiguration

It is necessary to distinguish between *two directions* of reconfiguration initiation: from ***bottom to upper*** levels of an organization and vice versa, i.e., from ***upper*** (control) levels to ***bottom*** (subordinate) levels. Let us now analyze the *first case*.

Influences in this situation cause event reporting to spread from bottom to upper levels. Figure 2 shows basic ways of such reporting.

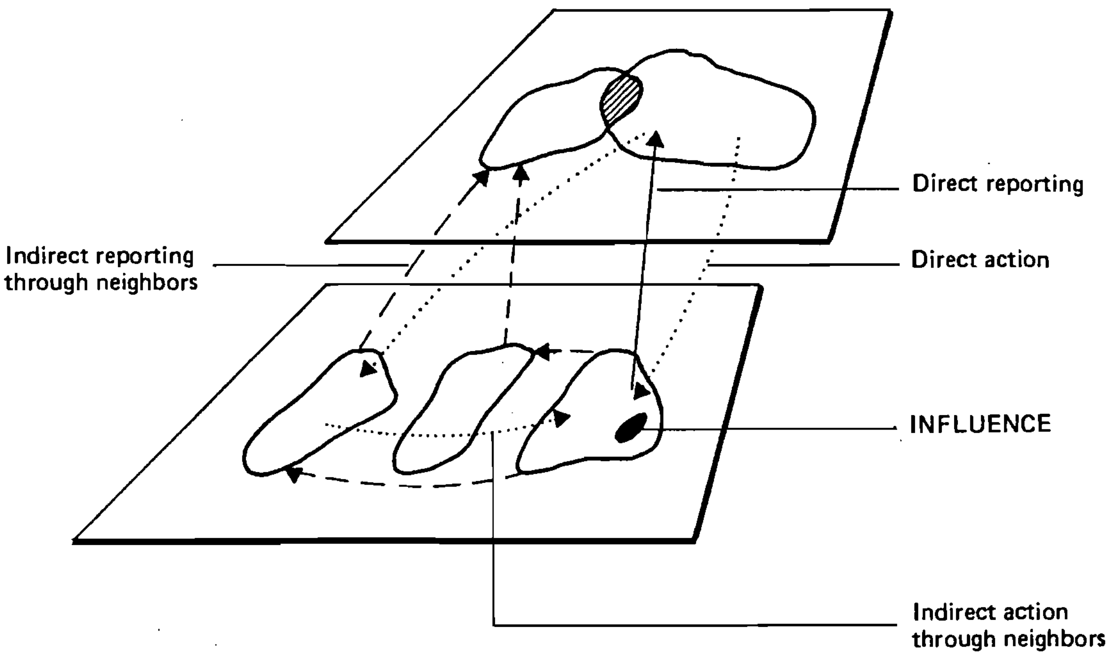

Figure 2. Bottom-up reporting.

Upon a report, according to the severity of the influence, all or selected parts of the subordinate level and corresponding level members are alerted. That means they interpret semantics of subsequent reports in more details and in a different context. Moreover, they begin to seek all the change relevant information. Their knowledge scopes begin to be more overlapping and their scopes of interest (which have substantially higher dynamics) are shifted from normal work to different constellations of overlapping reflecting specifics of the process of reconfiguration.

When the influence and subsequent changes are relatively severe it is necessary to use broadcasting or a message board to communicate information (broadcasting in the most severe cases) instead of murmuring because it would be rather slow and it would affect veracity of information. Murmuring may become to be error-additive when we can suppose that information contamination will spread irregularly affecting randomly dispersed members. On the contrary, it can be error-eliminating when the contaminated area is well confined, and isolated from the rest of the system. This is because it is possible to create readily cooperative error correction actions around the area.

Scopes of overlapping of knowledge may be increased by ***transportation of knowledge*** (e.g., in computing systems), by learning and mutual coadaptation which otherwise lowers the degree of producer information uncertainty.

When influences affect the lower levels of an organization, bottom-up reconfiguration initiation is effected. It will be carried on generally without any problems concerning the acquisition of reconstruction information because the control core generally rests intact and its capability to play the integrating roles is preserved. The speed of the reconfiguration process is also maintained because the control core maintains the effort to *alert* members according to their particular locations in a proper way and within the proper time limits, i.e., the scopes of interest of important members (for the purpose of successful reconfiguration) are, upon receiving the alert, quickly drawn from their normal work and directed towards the reconfiguration activities. Figure 3 shows scopes of interest overlapping during normal work and upon alerting.

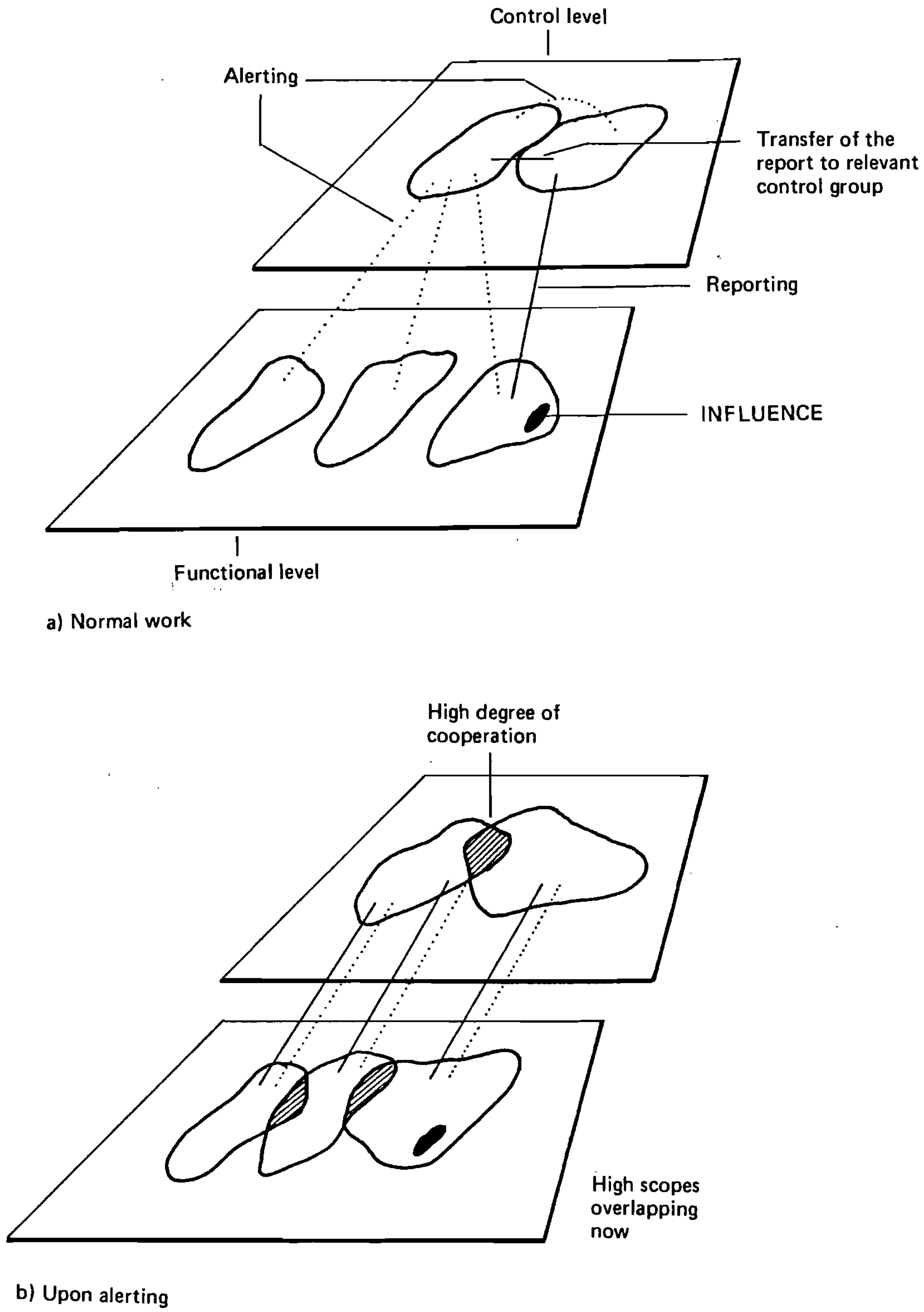

Figure 3. Dynamics of scopes of interest overlapping.

Under relatively known situations the alert may even be initiated by neighboring groups in a subordinate level. A high degree of cooperation in the control levels, supported by high overlapping of the scopes of interest (Figure 3b) helps to achieve reduction of mutual intercommunication among groups, to cope with higher information flows during the situation assessment, to have a common knowledge interpretation and to be able to reduce effectively producer history uncertainty. In subordinate levels, groups develop their knowledge interpretation and their interest during intensive cooperation as ordered by control levels to reduce result uncertainty by cooperation on partial decisions, to reduce consumer uncertainty because everybody can handle the information to the right place (especially members close to a place of change), to facilitate neighbors cooperation in status information spending (about the result of a change), and transferring it to the place of change, to interrogate neighbors which may help to see the change in different lights (different semantic interpretation).

In this scheme the cooperation generally has centralized control.

Now we shall analyze the *second case* i.e., top-down reconfiguration initiation.

When influences affect the control levels of an organization and they are recognized, the alerting of members of the control levels will be very quick because their scopes are highly overlapping and therefore their mutual semantics relations are well "compatible".

However, the influences may not be recognized in the control levels. They may be recognized first by subordinate levels and they may even interpret it as not relevant to control levels. This is because they will not generally understand the nature of such influences. Their scopes of interest, etc., are too narrow and in a lower level of abstraction. In such situations it will generally be necessary to seek for information for control level reconstruction as they have been unconsciously "infected". This is a task for all subordinate levels and "uninfected" members. They must stick together to obtain a picture about the new system status and to be able to work out recovery strategies. To be able to stick together they must adapt their scopes accordingly, which will not be easy in subordinate levels.

Integrating positions and their groups may be influenced and begin to integrate in an improper way. It is a very serious malfunction which may be moreover observed too late by surrounding unaffected members. To make corrections the members and remaining integrating positions in lower levels assemble spontaneously relying on decentralized control of cooperation, which in turn is based on quick scopes of interest coadaptation and approximation according to a common global goal of all members. Because assembling of members is spontaneous, driven by immediate system state assessment of individual members or their groups, extremely high information flows must be handled at all levels. Multirelational networks will probably be the only structures to withstand such requirement.

The main task is to reconstruct the control levels and return them to operation. The subordinate levels will need to think in more abstract terms. In this process, ***under the highest degree of uncertainty, the opponent cooperation and walk- throughs will possibly be the key*** *activities*. They are powerful mechanisms for uncertainty reduction. *Further reduction* will be obtained here by *murmuring* (incremental information spreading) which will be the main method of communication in the initial phases of reconstruction.

5. CHANGE IN HUMAN ORGANIZATIONS: USING INFORMATION SYSTEMS AND DATABASES TO SUPPORT MULTIRELATIONAL NETWORKS

5.1. Natural vs. Formal Language in Organizations

Of special concern is the role databases play as a communications channel between separated parties in the organization. How do these parties know to attach the same meaning to the data they find in the database?

The problem of semantics in communication is of course an old one and has been the object of considerable linguistic and philosophical study. While current theories appear to be making progress, many deep problems remain. These studies apply to all uses of language, however, and therefore have to deal with the immense variation of all aspects of human experience, from baby-talk to poetry. Our working hypothesis is that the language of administration, especially those communications likely to be routed through information systems, are more restricted, hence more tractable. Managers of course converse using natural language. The language is "natural" in the sense that it is a product of cultural evolution (Whorf 1956). Contrasting with natural languages are artificial or ***formal*** languages where the syntax and semantics are specified in fixed and exacting rules. The temptation is to distinguish natural from formal languages on the basis of syntactic complexity and/or semantic range. The distinction we emphasize is, rather, one of *authority* -- the syntax and semantics of natural languages is decided by the linguistic population as a whole (more often perhaps by evolving accident than consciously negotiated consensus). Formal languages, whose character is embodied in explicit rules, are the product of a single authority, whose pronouncements remain fixed.

While an information system might standardize the vocabulary and form of the communications routed through it, the system does not control the meanings users attach to the symbols that are communicated. That is to say, the system enforces syntax but not semantics. Thus, a basic issue is how do users of an information system, separated in space and time, know what the other is communicating about?

The linguistic/philosophical research on natural language semantics will obviously be of use here. However, that work is mainly directed towards explaining language phenomena that are otherwise regarded as beyond any particular authority's control to modify.

However, in information systems we do control the syntax and vocabulary and (partly, potentially) the way this language is taught to its users. Thus, the semantics of communication through an information system is more a matter of design and deliberated consensus.

Databases are regarded as a convenient focal point for studying this issue. The semantics of a database is the correspondence between its symbolic data representations (a formal language) and phenomena in the organizational and/or societal environment. Our interest will be to explore the nature of this correspondence and how it arises, whether naturally or by design.

5.2 Database Semantics

A key motivation in the growth of database technology has been the *integration* of information. For example, production and sales may both need access to inventory records. If they each keep separate copies, the two sets of records may become unsynchronized, resulting perhaps in foregone orders or frustrated customers. Consolidating the record keeping in an integrated database avoids this problem. Note,however, that this presumes that both sales and production have a common conception of what is meant by inventory. Normally this is not a problem since the two departments have had to interact long before the appearance of the computer, and so arrived (informally, naturally) at a common understanding.

This phenomenon is so ubiquitous that we seldom notice it until we change organizations. Then we may find that in the new environment, familiar phenomena are now designated by different terms, or that once familiar terminology now designates other things. Further, the translation is in many cases not straightforward, particularly in the language pertaining to the technical details of the enterprise.

As noted earlier, not only do organizations tend to differentiate themselves linguistically, but that this linguistic differentiation is an important component of their successful functioning.

The database translation problem is the one typically cited to motivate semantic issues. This reflects the underlying operational orientation of database management, which concentrates largely on production and/or sales related transactions. However, a deeper and more important problem exists, namely semantic change within the organization itself.

It is commonplace to observe that the world is changing rapidly. Organizations, to survive, must keep pace, and to succeed, must innovate. This entails not just a re-combination of old concepts, but changes in the concepts themselves. Managers participate in these changes in their understanding of the markets, changing technology, social trends, politics, etc. Given that management behavior is almost entirely linguistic, conceptual change involves semantic change.

However, computational inference generally entails an assumption of stable semantics. For instance, a logical rule,

$$P(x) \dashrightarrow Q(x)$$

is valid or invalid depending on the semantic extension of P and Q. For example, if P is lemon and Q is fruit, the conclusion is correct, since anything that is a lemon is also a fruit. If P is interpreted as "elephant", however, the rule is invalid. The problem created by semantic change is that the inferences made by the system, once correct, become invalid as the extension of the symbol's change. For instance, fifty years ago, the term "computer" referred to a computationally skilled human being. Now of course one thinks more of mechanical computation. Hence the rule

$$COMPUTER(x) \dashrightarrow PERSON(x)$$

was once valid but is no longer. The effect of semantic change has deep consequences for the use of information systems in organizations in dynamic environments.

5.3. Transportability of Knowledge

Applications software is by and large custom made for each organization usually by an in-house data processing (DP) department. More importantly, these applications are typically written from scratch. That is, they do not make use of previously developed program code pertinent to the problem domain.

The exception to this is the use of "off the shelf" program packages and, occasionally pre-written subroutines which the new program can call at the appropriate point. For instance, numerous packages exist to do statistical analyzes and quantitative algorithms and are used quite frequently in scientific applications. Likewise, off-the-shelf packages exist to do such organizational tasks as payroll processing, inventory control, etc. The latter class of pre-written software has, however, been less successful.

The problem, once again, has to do with the "designed flexibility" of the package. In scientific applications, the contexts in which a particular analysis or algorithm is used is relatively well specified. For instance, in any application of a linear programming algorithm one must specify the objective function, constraints and technological co-efficients and one receives as a result, the values of the decision variables. For most organizational applications, however, the problems are less standardized. Probably the most regular of these is payroll processing, but even there considerable variations may exist from one firm to another as to the benefits to be added, automatic deductions, classifications of labor, etc.

In order to make use of an off-the-shelf package for such applications, the particular characteristics of the organization's problem must fall within the designed flexibility of the package. When this does not occur the DP department may sometimes try to modify the package. However, the general experience is that it is usually easier and more reliable to re-program the whole thing from scratch.

We call this aspect of application software development the problem of "transportability of knowledge" from one application to another. As observed, this is generally an all or nothing proposition. One may transport chunks of knowledge from one system or program to another only in the case that the chunk corresponds to a whole program or subroutine. There seems to be no middle ground; that is, where one could make use of an arbitrary part of one program function in developing another.

The consequence of this is that software for organizational information processing is not a smooth evolution; it does not build naturally from previous experience. Thus, for example, after a quarter century of automated payroll processing, firms still often have to write new payroll programs.

By contrast, knowledge in the form of human expertise is easily transportable. For instance, when company X hires a new bookkeeper, it is doubtful X's accounting system exactly fits the bookkeepers's training or previous experiences. However, provided the new person is reasonably competent, he/she can adapt to the new system after a brief orientation period. The situation with applications software is as if a complete re-education, starting with grammar school, would be necessary.

We summarize the arguments thus far. The basic claim is that a fundamental problem exists in the basic architecture of applications systems, namely that they are too "brittle" and resistant to change. This has two important consequences. One, as discussed in the last section, is that as an organization becomes increasingly reliant on its information system, it too becomes brittle and unable to adapt easily to new situations. The other consequence, the point of this section, applies not just to individual organizations, but to information system technology at large: current software architecture does not provide the proper framework for a smooth evolution of problem solving capability. We are forced to repeatedly re-invent wheels. Progress (what little can be seen) has always been in the form of someone's coming up with a bigger wheel. That this is wasteful of money and effort is the smaller part of the problem. The deeper difficulty is that when someone finds an improved method for some organizational task, these advances cannot easily be promulgated to other software for related tasks. The industry of applications software development thus cannot build on its accomplishments, and must continually re-start from the ground.

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